Capital Maintenance and the User Cost of Capital

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Tax-deductible capital maintenance attenuates the effect of capital tax policy on capital accumulation. I show that the strength of this channel is mediated by the elasticity of demand for maintenance intensity, which is a function of the maintenance elasticity of depreciation. If the maintenance elasticity is sufficiently large, tax policy has no effect on the capital stock even if it causes large variation in investment because depreciation endogenously responds in the opposite direction through the maintenance channel. Consequently, the (f)utility of cutting taxes depends critically on the maintenance elasticity. Using new evidence at the industry level from corporate tax returns and at the firm level from freight rail, I show that the elasticity of demand for maintenance is plausibly around one. This has large implications for both positive and normative tax policy analysis. Positively, the tax elasticity of output is about half as large as in a standard neoclassical model and the coefficient in standard investment regressions is underestimated by a similar magnitude. Normatively, the implied magnitude of the estimated maintenance elasticity places the welfare cost of the distortion at around 5% in a Ramsey model of optimal taxation, which eats up nearly half of the gains from cutting capital taxes to zero.

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1 Introduction

The last two decades witnessed a revolution in business tax policy. The period following 9/11 saw the introduction of bonus depreciation as an effective tool for economic stimulus. Later, the 2017 Tax Cuts and Jobs Act aimed to foster a new era of economic growth by implementing the largest tax reform since World War II. Both types of reforms share a common presumption that tax cuts promise more capital via new investment. This presumption follows from models of varying complexity, which, while they may object to the reforms on revenue or distributional grounds, do not directly question the causal chain from tax cuts to increased capital to economic growth. In this paper, I slacken that causal chain by providing a direct theoretical, empirical, and quantitative accounting for the extent to which tax cuts raise the depreciation rate through a decreased maintenance intensity.

On the margin, firms maintain capital to make it last longer at the cost of an additional unit of investment. Under tax and accounting rules, maintenance is treated as an operating expenditure and hence tax-deductible while new investment is typically taxed. This policy wedge throws a wrench in the government's own plans for stimulus and growth because cuts in the tax rate induce firms to maintain capital less intensively, which increases the depreciation rate. Depending on the elasticity of demand for maintenance, this distortion may substantially attenuate the effect of capital tax policy on capital accumulation. In the limit, the maintenance channel can make the capital stock completely tax-inelastic. Hence, determining its importance is first order for positive and normative tax analysis. That constitutes the goal for this paper.

It is not a new insight that tax policy matters for the maintenance-investment trade-off. Indeed, McGrattan and Schmitz Jr. (1999) first pointed this out using a homogeneous capital neoclassical growth model. I expand on their important theoretical work to provide a simple and flexible theory of capital maintenance that provides a guide to measurement and, in turn, a guide to clearly evaluating the positive and normative consequences of tax policy. The key theoretical extensions are a plausible assumption on the depreciation technology, adjustment costs, and inclusion of heterogeneous capital. The first assumption is most important because it yields a sufficient statistic framework that makes empirical and quantitative analysis significantly easier in both the short run and the long run. When combined with adjustment costs, we can characterize short-run dynamics between maintenance, investment, and depreciation as well as derive an empirically relevant and testable relationship between maintenance and relative prices. Including heterogeneous capital is particularly important because uniform capital taxation is not neutral when depreciation technologies vary by capital types and that can substantially change long-run allocations of capital.

The theoretical analysis raises the question of what depreciation technologies look like in practice. This is a difficult task because there are few reliable sources of maintenance data. As a first step, I use data from two novel sources. First, I use the line item for capital repairs from corporate tax filings by industry with the Statistics of Income from 1998-2022. Following a methodology in the tradition of Cummins, Hassett, and Hubbard (1994) and best exemplified by Zwick and Mahon (2017), I use cross-sectional variation in exposure to exogenous tax policy changes to identify the maintenance elasticity. Because those data have some important shortcomings, I examine a second source: the financial filings of freight railroads. Railroads are required to provide detailed information on their maintenance expenditures broken down by what is being maintained, how much of the expenditures are internal, and whether expenditures are on parts or labor. This provides an ideal environment to study the elasticity of demand for maintenance. I use variation in relative prices driven by variation in exposure to tax policy and the labor component of maintenance expenditures across different types of equipment to help identify the maintenance elasticity of demand. The freight rail results agree with the industry filings that the maintenance elasticity is probably nonzero and large. Although it is questionable to directly apply results from freight railroads to capital accumulation in general, the strong results are a call for microeconomists to put greater effort into estimating the demand for maintenance in nonresidential capital. To my knowledge, this effort is the first.

Next, I illustrate the empirical and quantitative importance of accounting for maintenance with two tax policy applications. My first focus is on investment regressions. Ultimately, these are motivated by a theoretical link between tax policy and investment. For example, Summers (1981) and Chodorow-Reich et al. (2023) bookend a long tradition of using theory to discipline the regression specification. Where the theories differ, they are similar in regarding depreciation as either irrelevant or constant, which typically motivates a regression of an investment variable on a tax term. My model implies that the actual exposure of firms to tax policy depends on their depreciation technologies as well as the tax term. Firms which are more maintenance-elastic are relatively insulated from tax policy changes, which means that their measured investment elasticites are too low. Consequently, cross-sectional regressions involving the tax term from Cummins, Hassett, and Hubbard (1994) to Zwick and Mahon (2017) to Chodorow-Reich et al. (2023) tend to understate the tax elasticity of investment. I repeat a common regression exercise using firm-level data from Compustat and estimate the degree of bias given a grid of values for ω. Second, I quantify the predicted effect of the 2017 Tax Cuts and Jobs Act using the exact same model and calibration as Barro and Furman (2018) except I add endogenous depreciation. Even modest values for the maintenance elasticity imply that the long-run capital-labor ratio is significantly smaller than one would predict using the standard neoclassical growth model. This illustrates the more general principle that our estimates of the physical capital stock are as dubious as those of the intangible capital stock and are contingent upon a rather special application of the perpetual inventory method which may be approximately right from one period to the next, but far from accurate when applied repeatedly. Such criticism applies just as well to this paper, which relies on a slight deviation from the perpetual inventory method but applies more generally to practically all quantitative work.

I wrap up by discussing optimal policy. Expanding the partial equilibrium model into general equilibrium, I prove that the first-best solution involves no distortion between maintenance and investment. I provide a back-of-the-envelope quantification for figuring out the size of the distortion using Lucas (1990) as a benchmark. Because the gains to cutting taxes to zero are from a higher capital-labor ratio, one can roughly think of the magnitude of the distortion as the extent to which it attenuates the increased capital-labor ratio. The optimal policy analysis goes far beyond the current state of the literature on optimal policy with capital maintenance, which is practically nonexistent. A plausible estimate places the cost around 5% consumption-equivalent welfare.

In sum, despite a firm argument from McGrattan and Schmitz Jr. (1999) that maintenance is "too big to ignore," the channel is rarely accounted for in theoretical, empirical, or quantitative tax policy analysis. Indeed, all of the main tax policy analysis models from the government, think tanks, and academia rely on constant depreciation to predict the likely growth and welfare effects of policy (Auerbach et al. 2017). Of course, such models miss out on many parts of reality and by virtue of being models, that is a feature rather than a bug. This paper, with simple theory, empirics, and quantification, aims to convince tax policy researchers of all stripes that including a small adjustment for capital maintenance is worth it.

Literature. This paper connects to a longstanding tradition of using the Hall and Jorgenson (1967) user cost of capital to analyze tax policy. The Hall-Jorgenson approach, which assumes constant depreciation and replacement rates for existing capital, remains the gold standard for analyzing tax policy (Barro and Furman 2018; Chodorow-Reich et al. 2023). However, my work is closer to theoretical work that *deviates* from constant user cost. In particular, Feldstein and Rothschild (1974) study the conditions under which replacement investment is constant, with particular focus on whether the standard user cost formula is generally applicable. Building on that work, McGrattan and Schmitz Jr. (1999) develop a homogeneous capital model of maintenance and investment, with maintenance expenditures pinned down by the relative price of maintenance to investment. I extend their approach to many types of capital goods, connect it to optimal policy, and develop an empirical and quantitative framework. While their observations on tax policy are useful in my approach, their focus on homogeneous capital restricts them from paying close attention to changes in relative demand and they do not provide a link to empirics, optimal policy, or dynamics. Several other papers build on McGrattan and Schmitz Jr. (1999) in the areas of public capital maintenance (Kalaitzidakis and Kalyvitis 2004), cyclical fluctuations (Albonico, Kalyvitis, and Pappa 2014), and investment theory (Boucekkine, Fabbri, and Gozzi 2010; Caunedo and Keller 2020). To my knowledge, my work is the first attempt to estimate depreciation functions, extend to optimal policy, and consider the role of capital heterogeneity.

I also contribute to an empirical literature documenting the relevance of capital maintenance. Goolsbee (1998) and Goolsbee (2004) present direct evidence that the maintenance channel exists. The former examines factors affecting the decision to retire airplanes. Retirement directly relates to maintenance because, rather than maintain an old airplane, a firm simply invests in a new one. As Goolsbee (1998) notes, the capital retirement decision is not economic in the neoclassical growth model. Focusing on an investment tax credit for a 13 year-old Boeing 707, Goolsbee finds that moving the investment tax credit from zero to 10% increases the probability of retirement from 9% to 12%. If we interpret depreciation rates as reflecting the probability an asset becomes useless to the firm in a particular year—whether through obsolescence, retirement, failure, or some other cause—then Goolsbee's finding suggests that the depreciation rate is quite elastic with respect to the tax rate. Taking his estimate seriously suggests that the typical neoclassical approach overstates the elasticity of investment by around 75% (Goolsbee 1998). Relatedly, Goolsbee (2004) convincingly argues that the quality elasticity of capital with respect to the cost of capital is around 0.5%, where quality is roughly measured with maintenance expenditures per unit of capital. Moreover, my empirical estimates relate to work from Grimes (2004), which studies the relationship between maintenance and capital expenditures in the freight rail industry and documents that they are intertemporally substitutable, which is a key part of the theory in this paper. Additionally, economists have documented a clear connection between maintenance and depreciation in the housing literature. For example, Knight and Sirmans (1996) study the effect of maintenance on housing depreciation and find that poorly maintained homes depreciate significantly faster than their well-maintained counterparts, while Harding, Rosenthal, and Sirmans

(2007) find that housing depreciates about 0.5 percentage points less per year after accounting for maintenance. I build on this literature to directly estimate the maintenance demand elasticity with freight rail data.

Capital maintenances "hides" under operating expenses. In that sense, it is a type of investment that is similar in spirit to other types of hidden investment which now dominate the modern literature on intertemporal firm decisions. Discourses on increasingly exotic types of investment ranging from intangibles (Crouzet et al. 2022) to sweat equity (Bhandari and McGrattan 2021) to data (Eeckhout and Veldkamp 2022) and beyond have blown up the traditional understanding of investment as a physical capital expenditure that builds up a physical capital stock and replaced it with a more expansive notion of how and for what purpose firms make intertemporal decisions. The common thread is that firms and entrepreneurs spend real resources with intertemporal implications that are "hidden" in the sense that they do not fall under the category of capital expenditures upon which the early edifice of firm investment theory was developed.

Arguably, the key limitation to this study relates precisely to the other types of hidden investment. Depreciation is made up of two components: obsolescence and physical wear and tear. The type of maintenance in this paper only addresses the latter and not the former because it is entirely about physical capital. However, the majority of the capital stock is arguably intangible (Bhandari and McGrattan 2021), which means that its depreciation is largely obsolescence and hence has little to do with this paper's concept of maintenance.[1] As a result, this study only speaks to the physical capital stock, which is a small share of the total capital stock. However, both quantitative and empirical tax analyses continue to focus almost exclusively on tangible capital. Tax policy models from the Joint Committee on Taxation, the Penn Wharton Budget Center, the Congressional Budget Office, the Tax Foundation and many other workhorse models for tax policy analysis focus largely on tangible capital. This signals that there is utility in measuring tangible capital maintenance properly even if it has to be scaled down in importance by the extent to which intangibles are more significant.

Additionally, there has been significant theoretical work linking utilization to depreciation (Greenwood, Hercowitz, and Huffman 1988; Justiniano, Primiceri, and Tambalotti 2010) and utilization and maintenance together to depreciation (Boucekkine, Fabbri, and Gozzi 2010; Kabir, Tan, and Vardishvili 2023). While undoubtedly correct and important that utilization plays a role in the depreciation of capital and utilization is endogenous, I focus solely on maintenance in this paper because it more clearly isolates the theoretical

1. Exercise of market power would have large effects on depreciation of this kind of capital and in that sense, could be thought of as maintenance.

channel I am interested in.

Finally, this work relates to a theoretical literature on optimal capital taxation in general equilibrium. I prove that it is optimal to not tax capital in the steady state in the benchmark model. One might think that maintenance acts like an untaxed factor in Correia (1996), which could potentially result in a positive optimal tax rate, but that is not the case here. My work extends results from Chari, Nicolini, and Teles (2020), but does not address issues about convergence raised by Straub and Werning (2020). More generally, my results stem from an old literature dating to Lucas (1990) on quantifying the welfare gains to cutting taxes to zero. My results indicate that accounting for the presence of the maintenance distortion may cut them in half.

Roadmap. In Section 2, I develop a theoretical framework to analyze the positive and normative consequences of elastic and heterogeneous demand for capital maintenance. In Section 3, I evaluate the empirical relevance of the maintenance channel for tax policy. In section 4, I show why accounting for maintenance matters for empirical and quantitative tax policy analysis. Section 5 analyzes the welfare consequences of the maintenance-investment distortion and Section 6 concludes.

2 The Transmission of Tax Policy with Capital Maintenance

Before getting into the formal model, it is useful to discuss informally how adding the maintenance channel to the standard investment theory fundamentally alters its predictions. The standard theory says that capital tomorrow K_{t+1} is a function of capital today, a constant depreciation rate δ, and investment X_t, leading to the usual law of motion for capital

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

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. With some production function $F(K_t)$, the economics of optimally choosing investment are straightforward: equate marginal benefit to marginal cost. The marginal benefit of an extra unit of investment today is the marginal product of capital tomorrow, $F_{K_{t+1}}$. The marginal cost consists of four standard objects: the price of investment p, the discount rate r^k, the depreciation rate δ, and the capital tax rate τ. The price and the tax rate play the same role: they directly determine how costly investment is *today*. A higher price or a higher tax rate by definition make it more expensive to purchase capital. Because investment is intertemporal, depreciation and the discount rate tell us how costly investment is given that it will not be used until tomorrow; they are the opportunity cost of forgoing present expenditures for expenditures which only have value in the future. Putting these elements together and assuming Δt small or that the firm is in steady state, we arrive at the standard user cost of capital which motivates an enormous body of empirical and theoretical work in public finance and macroeconomics:

$$F_K = \frac{p}{1-\tau}\left(r^k + \delta\right). \tag{1}$$

It is this paper's contention that a second kind of investment, namely capital maintenance M_t, substantially changes the standard investment theory, which then gives quite different predictions for the effects of tax policy on capital accumulation. Maintenance expenditures are expensed costs on capital, labor, and intermediate inputs to restore, repair, or ensure continued productivity of existing capital, but do not improve the productivity of existing capital. Whereas the standard model gives only one way for the firm to change its capital stock, maintenance evidently gives a second.[2] It is natural to think that, for example, FedEx may either do an excellent job maintaining its existing fleet of vehicles and allow them to age, or to instead to allow them to wear down more quickly and replace vehicles at a greater frequency. Through this example, it becomes clear that maintenance affects the capital stock indirectly through the depreciation rate; a higher intensity of maintenance makes capital last longer. On the other hand, it is difficult to think that the same is true for intangibles. Depreciation is, in principle, two components: obsolescence and physical wear and tear. By definition, only the former can affect intangibles and can perhaps be influenced by exercising market power. This study focuses only on the physical component via maintenance and so abstracts entirely from obsolescence.

More formally, we can write the depreciation rate as $\delta(m_t)$, where $m_t \equiv \frac{M_t}{K_t}$. With that in mind, it is obvious enough why maintenance qualifies as a type of investment, but substantially less obvious why it is a *hidden* investment in the same way that R&D or intangible expenditures are. The reason is that, like intangibles, it is expensed and hence tax-deductible because it disappears under the blanket category of operating expenses. Consequently, maintenance is not capitalized, does not appear in national income data, and we generally do not know how important it is.

A firm intent on choosing a sequence of optimal maintenance expenditures would equate the marginal cost of maintenance against its marginal benefit. The marginal benefit is that capital depreciates slightly slower, which is captured by $-\delta'(m_t)$. The marginal

2. There are, of course, many ways that firms can change their capital stocks beyond investment and maintenance. Albonico, Kalyvitis, and Pappa (2014) and Kabir, Tan, and Vardishvili (2023) along with an old macroeconomic literature give a role to utilization, while Goolsbee (1998) highlights scrappage decisions.

cost is a unit of foregone investment, which is determined by the relative price of maintenance to investment. Letting q_t denote the pre-tax price of maintenance, the firm equates marginal benefit with marginal cost exactly when

$$-\delta'(m_t) = \frac{q_t(1-\tau_t)}{p_t}. \tag{2}$$

That is, firms determine how intensively to maintain their capital based on balancing the marginal benefit of maintaining existing capital against investing in new capital. Because of the preferable tax treatment of maintenance, it is as if tax policy subsidizes maintenance. This leads to an additional element of the user cost of capital, namely that an additional unit of capital must be maintained at price q:

$$F_K = \frac{p}{1-\tau}\left(r^k + \delta(m^*)\right) + qm^*, \tag{3}$$

where m^* is the optimally chosen maintenance rate given prices. One can see immediately how user cost differs between (1) and (3). Compared to (1), there is an additional term for maintenance, which means that the level of user cost is higher. But more importantly, the former is a function only of exogenous parameters whereas the latter is a function of exogenous parameters *and* the endogenous equilibrium allocation of maintenance, which is itself a function of tax policy. Increases in τ cause maintenance to rise and depreciation to decline, thereby offsetting, to some extent, the pernicious effect on capital accumulation induced by the tax increase. In that sense, what really matters is the derivative of user cost with respect to tax policy and not simply its level.

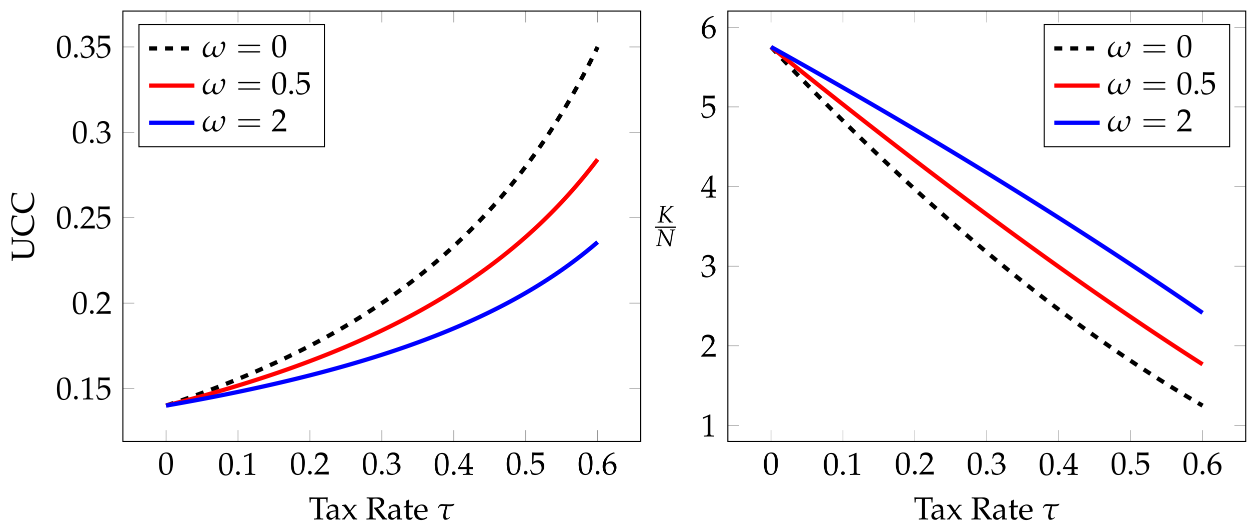


Figure 1: Comparing user costs and capital-labor ratios for differing values of ω. Given ω, γ is set such that user cost is the same at the undistorted steady state. I set $r^k = 0.04$ and $\alpha = 0.4$ for this exercise.

Depending on the elasticity of demand for maintenance, the tax wedge in (2) may yield quite different results for the resulting long-run allocation of capital. For example, suppose output per capita is given by $y_t = k_t^{\alpha}$. Moreover, suppose the depreciation technology is given by $\delta(m) = \gamma m^{-\omega}$, a functional form which will be central to the rest of the paper and which I will explain in greater detail shortly. ω is the maintenance elasticity of depreciation. $\omega = 0$ corresponds to the standard neoclassical investment theory with constant depreciation, while $\omega > 0$ introduces curvature into the depreciation technology. In Figure 1, I plot steady state user cost and the resulting capital-labor ratio for values of $\omega = \{0, 0.5, 2\}$ with the parameter γ set such that initial user cost and the capital-labor ratio are the same when $\tau = 0$. Clearly, as ω rises, which is equivalent to the endogenous response of depreciation becoming stronger, the effect of tax policy on capital accumulation wanes precisely because the user cost of capital becomes relatively inelastic.

The preceding analysis presents a problem for tax policy analysis in the sense that we can no longer hold all else equal when analyzing changes in the user cost of capital induced by tax policy. This point was first made by McGrattan and Schmitz Jr. (1999) and a large share of the preceding discussion simply reiterates the key point of that paper. In the following subsection, I develop a model to formalize the mechanisms described informally above. This builds on McGrattan and Schmitz Jr. (1999) by expanding the neoclassical model to include heterogeneous capital and adjustment costs which, along with a couple of novel theoretical developments, provide a new framework for analyzing tax policy empirically and quantitatively when maintenance is an economic decision.

2.1 Model

Consider a representative firm that produces an output good Y_t with finite N capital types $K_{1,t}, \ldots, K_{N,t}$ and labor H_t according to production technology

$$Y_t = F(K_{1,t}, \ldots, K_{N,t}, H_t), \tag{4}$$

where $F(\cdot)$ is twice continuously differentiable in each argument with positive and diminishing marginal products. The firm owns its own capital stock. Firms choose how much to maintain existing capital in addition to choosing how much to invest in new capital. Following McGrattan and Schmitz Jr. (1999), I impose the following restrictions on the relationship between maintenance and depreciation:

Assumption 1. *A depreciation technology $\delta_i(m_{i,t})$ transforms a rate of maintenance $m_{i,t} \equiv \frac{M_{i,t}}{K_{i,t}}$ into capital $K_{i,t}$. $\delta_i(m_{i,t})$ has the following properties on the domain $m_{i,t} \in (0, \infty)$:*

1. *Strictly positive: $\delta_i(m_{i,t}) > 0$;*
2. *Strictly convex and twice continuously differentiable: $\delta_i'(m_{i,t}) < 0$ and $\delta_i''(m_{i,t}) > 0$;*
3. *The inverse of $-\delta_i'(m_{i,t})$ exists and is strictly positive.*

The restrictions on the depreciation function are to ensure that it is well-behaved. Depreciation cannot be negative with maintenance because that would imply an improvement, which is a capital expenditure, and hence ruled out by definition. The second property guarantees that additional maintenance decreases the depreciation rate; the opposite is intuitively implausible. The third restriction guarantees a positive demand for maintenance.[3] Given a convex adjustment cost $\Psi\left(K_{i,t}, X_{i,t}\right)$, the law of motion for capital type i is given by

$$K_{i,t+1} = \left(1 - \delta_i(m_{i,t})\right) K_{i,t} + X_{i,t} - \Psi\left(K_{i,t}, X_{i,t}\right). \tag{5}$$

For now, I assume that

$$\Psi\left(K_{i,t}, X_{i,t}\right) = \frac{b_i}{2}\left(\frac{X_{i,t}}{K_{i,t}} - \delta_i(m_i)^2\right) K_{i,t},$$

3. This rules out some intuitively plausible functional forms like $\delta_i(m_{i,t}) = a\exp\{-bm_{i,t}\}$ for $a, b > 0$ because some combinations of positive a and b imply a negative demand for maintenance. However, the semi-log form is unattractive because it implies depreciation is linear in marginal tax rate, which is an extreme prediction.

which is a fairly standard adjustment cost in the investment literature. I discuss other variants later on. Note that $\delta_i(m_i)$ is a long-run equilibrium object, which is steady-state depreciation as a function of maintenance.

Every period, the firm chooses how much to maintain capital type i at price $q_{i,t}$ or invest in new capital i at price $p_{i,t}$. Tax policy creates a wedge in that decision. Reflecting prevailing policy practice for decades, maintenance is fully tax-deductible from a profit tax τ_t^c, while investment receives a different tax treatment reflecting investment tax credits and tax depreciation allowances. Let investment tax policy be summarized by the parameter $\tau_{i,t}^x$. One can think of this as combining the investment tax credit and the net present value of tax depreciation allowances which typically show up in a Jorgenson-style user cost approach (*e.g.*, Barro and Furman (2018)). In most models and in practice, these two aspects of the tax system account for most of why taxes differ between asset types. The firm pays out dividends given by

$$d_t = (1 - \tau_t^c)\left(Y_t - w_t H_t - \sum_{i=1}^{N} q_{i,t} M_{i,t}\right) - \sum_{i=1}^{N}(1 - \tau_{i,t}^x) p_{i,t} X_{i,t}. \tag{6}$$

Ultimately, we want to understand the short run and long run effects of tax policy shocks in this environment. Given that, suppose tax policies follow exogenous AR(1) processes given by

$$\tau_{t+1}^c = \rho\tau_t^c + (1-\rho)\tau^c + v_t \tag{7}$$

$$\tau_{i,t+1}^x = \rho\tau_{i,t}^x + (1-\rho)\tau_i^x + v_{i,t}, \quad i = 1, \ldots, N \tag{8}$$

where $v_{i,t}$ and v_t are mean-zero normally distributed shocks, $\rho < 1$ is the persistence of the shock, and τ^c is the steady-state corporate tax rate.

Given a path of prices $P = (p, w, q)$ and tax policies $T = (\tau^c, \tau_i^x)$, exogeneous processes for the tax policies, a discount rate $r^k \geq 0$, the firm chooses sequences of capital, maintenance, investment, and labor to maximize the expected net present value of dividends subject to (5) and (7). This implies the following optimality conditions:

$$F_{H_t} = w_t \tag{9}$$

$$-\delta_i'(m_{i,t})\lambda_{i,t} = (1-\tau_t^c)q_{i,t} \tag{10}$$

$$(1-\tau_{i,t}^x)p_{i,t} = \lambda_{i,t}\left(1 - b_i\left(\frac{X_{i,t}}{K_{i,t}} - \delta_i(m_i)\right)\right) \tag{11}$$

$$\begin{aligned}\lambda_{i,t}\left(1+r^k\right) = \mathbb{E}_t\Bigg\{&(1-\tau_{t+1}^c)F_{K_{i,t+1}} + \lambda_{i,t+1}\Bigg[1 - \delta_i(m_{i,t+1}) + \delta_i'(m_{i,t+1})m_{i,t+1} \\ &- \frac{b_i}{2}\left(\frac{X_{t+1}}{K_{i,t+1}} - \delta_i(m_i)\right)^2 + b_i\left(\frac{X_{i,t+1}}{K_{i,t+1}} - \delta_i(m_i)\right)\frac{X_{i,t+1}}{K_{i,t+1}}\Bigg]\Bigg\}.\end{aligned} \tag{12}$$

where (10) and (12) apply to all capital types $i = 1, \ldots, N$ and $\lambda_{i,t}$ is the multiplier on (5) for capital type i. The system of equations defining the firm's optimality conditions present a different response to tax changes in both the long run and the short run than our existing models for tax analysis. I discuss each in turn.

2.2 Equilibrium Allocations in Steady State

In the long run, there are no adjustment costs, which means that $\lambda_i = (1-\tau_i^x)p_i$. Because of that, permanent changes in tax policy feed into the depreciation rate through permanent changes in maintenance. An increase in the common tax rate τ_t^c decreases the relative price of maintenance, while an increase in $\tau_{i,t}^x$ raises the relative price. In fact, the marginal condition can be written as

$$-\delta_i'(m_i) = (1-\tau_i)\frac{q_i}{p_i},$$

where $1-\tau_i \equiv \frac{1-\tau^c}{1-\tau_i^x}$ is the marginal effective tax rate on capital type i. Toward making a more definitive statement about the effect of tax changes, I impose a functional form on the depreciation technology. Although many functions fit the restrictions in Assumption 1, it turn out that a power function is most convenient for empirical and quantitative applications.[4]

Assumption 2. *The depreciation technology is a power function*

$$\delta_i(m_{i,t}) = \gamma_i m_{i,t}^{-\omega_i}, \quad \gamma_i, \omega_i > 0. \tag{13}$$

4. Greenwood, Hercowitz, and Huffman (1988) assume a concave power function for depreciation as a function of utilization and Kabir, Tan, and Vardishvili (2023) use a related functional form for jointly studying maintenance and utilization.

Given Assumption 2, depreciation is summarized by two parameters: a level parameter γ_i and an elasticity parameter ω_i. ω_i captures the maintenance elasticity of depreciation, while γ_i captures a level effect. For the same elasticity, a higher value of γ_i leads to a higher demand for maintenance, which corresponds to the notion of quality in Goolsbee (2004). Assumption 2 gives two nice properties of the demand for maintenance and the relationship between maintenance and investment.

Proposition 1. *Under Assumption 2,*

1. *The elasticity of demand for the maintenance rate is* $\frac{-1}{1+\omega_i}$.
2. *The elasticity of substitution between the maintenance rate and the investment rate is* $\frac{\omega_i}{1+\omega_i}$, *which is also the price elasticity of the depreciation rate.*

Part 1 of Proposition 1 follows directly from manipulation of the first-order condition for maintenance, while Part 2 follows from combining the steady-state law of motion for capital with the maintenance first-order condition.[5] There are two implications. The first simply refers to measurement. Given data on prices, maintenance, and investment, it is a straightforward task to identify the maintenance elasticity of depreciation. In fact, data on gross investment and prices are sufficient to measure the maintenance elasticity, something I show more formally and apply to a long panel of Compustat firms in Appendix E.[6] Note that while the maintenance rate and depreciation rate move in opposite directions, the absolute value of price sensitivity for maintenance is strictly less than the price sensitivity of depreciation as long $\omega_i > 0$. Indeed, the elasticities themselves move in opposite directions. As $\omega_i \to \infty$, the price elasticity of the depreciation rate approaches one while demand for maintenance becomes perfectly inelastic. Intuitively, that is because a higher ω_i implies that smaller movements in maintenance can generate larger changes in depreciation, so the firm does not need to change its maintenance intensity very much. $\omega_i \to 0$ implies that the elasticity of demand for maintenance approaches one while depreciation becomes price-inelastic. In this case, the level parameter determines maintenance and depreciation. Hence our assumptions on depreciation restrict both depreciation and maintenance price elasticities from having elasticity of demand greater than unity.[7]

5. Note that Proposition 1 is specific to the maintenance *rate* and not the *level*; the maintenance rate of capital type i is a function of parameters specific to its own type, but the level of maintenance is not. Changes in the capital stock of other capital types $j \neq i$ increases the level of maintenance demanded for capital type i, but not the maintenance rate.

6. In Appendix A, I discuss an alternative interpretation of (10) based on measurement error for depreciation rates.

7. This follows from convexity of the depreciation technology.

A more direct way to understand what's going on with maintenance and depreciation is through the user cost of capital. In steady state and assuming $p_i = q_i$,

$$\Psi_i = \frac{r^k + \delta(m_i^*)}{1 - \tau_i} + m_i^*, \tag{14}$$

where I again write m_i^* to emphasize that it is an equilibrium allocation determined by relative prices and not simply a parameter. The larger ω_i is, the more responsive $\delta(m_i^*)$ will be to relative prices and the less responsive m_i^* will be. That acts as an anchor on the user cost and directly attenuates how responsive it can be to changes in tax policy, with a corresponding dampening effect on capital accumulation through the marginal product of capital. This last revelation indicates that the maintenance-investment distortion may severely attenuate the effectiveness of tax policy compared to the standard model.

At this stage, I introduce the notion of the tax elasticity of the user cost of capital, which governs how responsive user cost is to changes in tax policy. This quantity is either irrelevant or unexplored in standard models of investment theory because the user cost is simply a function of exogenous parameters, which means that it is invariant across capital types:

$$\frac{\mathrm{d}\Psi_i}{\mathrm{d}\tau_i}\frac{\tau_i}{\Psi_i} = \frac{\tau_i}{1 - \tau_i}. \tag{15}$$

When $\omega_i > 0$ for at least one capital type, it is no longer true that the tax elasticity is the same for all capital types and indeed will depend on the price sensitivity of depreciation.

Proposition 2. *Under Assumption 2, the tax elasticity of user cost is given by*

$$\varepsilon_i = \frac{\tau_i}{1 - \tau_i}\left(1 - \frac{\omega_i}{1 + \omega_i}\left(\frac{A_i\,(1 - \tau_i)^{\frac{\omega}{1+\omega_i}}}{r^k + A_i\,(1 - \tau_i)^{\frac{\omega_i}{1+\omega_i}}}\right)\right), \tag{16}$$

where $A_i \equiv \gamma_i\,(1 + \omega_i)\,(\gamma_i\omega_i)^{\frac{-\omega_i}{1+\omega_i}}$. When $r^k > 0$, the elasticity is decreasing in ω_i and γ_i. When $r^k = 0$, the elasticity depends only on ω_i and is given by

$$\varepsilon_i = \frac{\tau_i}{1 - \tau_i}\left(1 - \frac{\omega_i}{1 + \omega_i}\right). \tag{17}$$

Proposition 2 is a generalization of the standard investment theory. As long as $\omega_i = 0$, then our analysis collapses to the standard model and depreciation is merely a technical rather than an economic parameter. If, as is almost surely true, maintenance is an economic decision, then constant depreciation models overstate the effects of tax policy on capital accumulation.

Proposition 2 highlights the tight connection between the price elasticities of maintenance and depreciation. (17) can be rewritten as

$$\varepsilon_i = \frac{\tau_i}{1-\tau_i}\frac{1}{1+\omega_i},$$

which makes clear that the traditional channel of tax transmission is proportional to the price elasticity of demand for maintenance. Note, however, that the price elasticity of demand for maintenance and the price elasticity of depreciation are inversely related. Indeed, the assumptions on the depreciation technology require that both have price elasticities less than one[8] Conceptually, this is not important because we can come up with depreciation technologies that exhibit elasticities greater than one. In this context, however, an elastic demand for maintenance would require that $\omega < 1$, which would mean that depreciation rises when firms maintain more intensively. This makes little sense. Moreover, the more price-inelastic maintenance is, the more depreciation will shift on the margin. That is because, for larger values of ω, maintenance does not have to work as hard to move the depreciation rate, which naturally makes it relatively insensitive to prices.

Another interpretation comes from a point made by House (2014) and echoed by Koby and Wolf (2020) and Winberry (2021). Because structures have such a low depreciation rate, they have a larger price semi-elasticity than equipment. This is equivalent to placing all of the emphasis on the γ parameter in Proposition 2. In that sense, my result agrees with theirs because we are both emphasizing the importance of variation in depreciation technologies. However, Proposition 2 also emphasizes the importance of differential curvature in the depreciation technology, which goes a step beyond the usual intuition by noting that the already small depreciation may adjust upward if taxes decline. In principle, that slackens the effect postulated by House (2014).

Assuming Cobb-Douglas production, we get a convenient corollary for Proposition 2.

Corollary 1. *Suppose $r^k \to 0$. With Cobb-Douglas production and one capital type, the tax*

8. This is not a theoretical requirement. A conceptually equivalent functional form like

$$\frac{\gamma}{1-\omega}m^{1-\omega}, \quad \omega > 1$$

implies a relatively inelastic demand for maintenance but an elastic demand for depreciation if $\omega > 1$ as required.

elasticity of capital and output per capita are

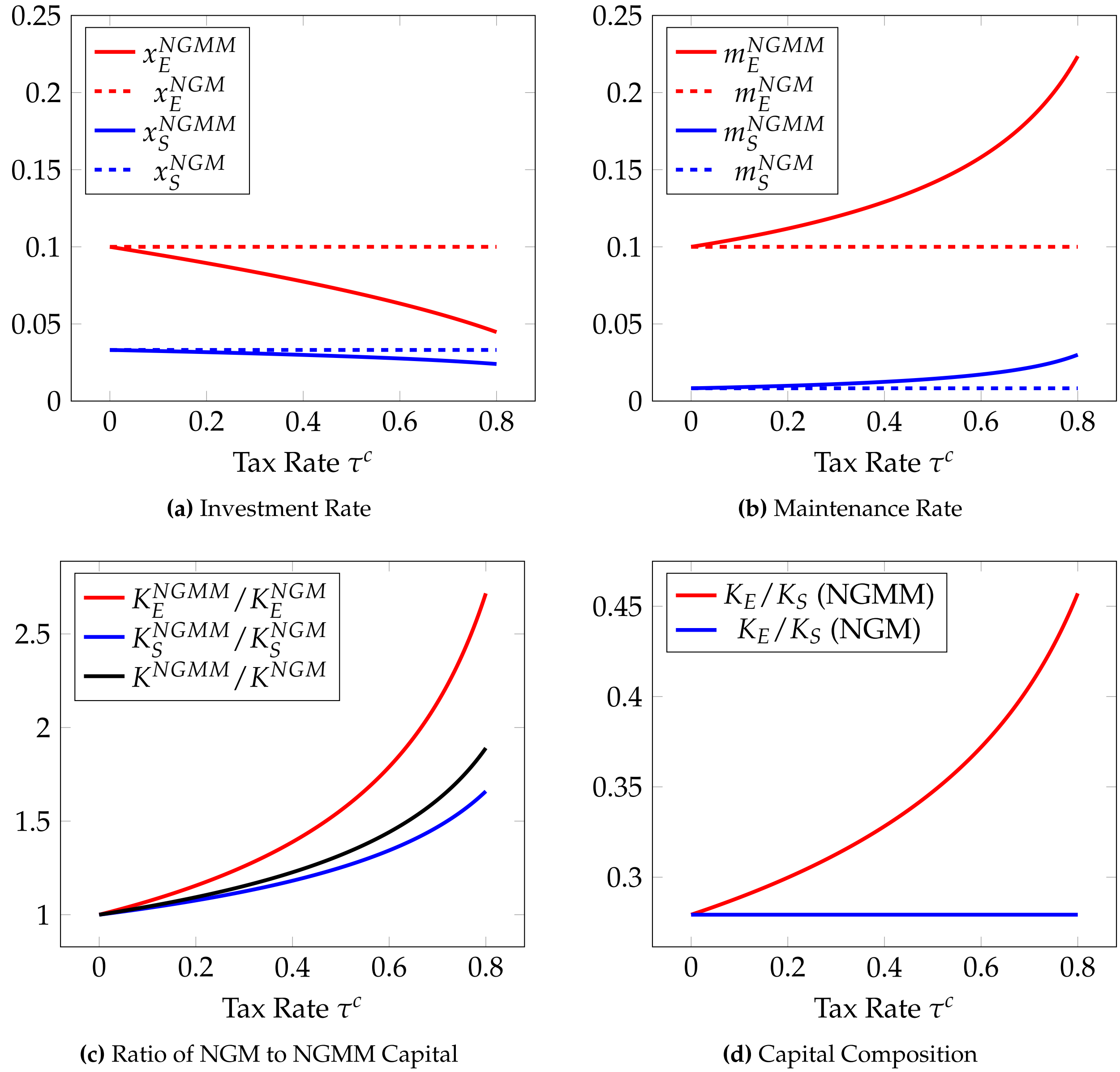
$$\varepsilon_k = -\frac{1}{1-\alpha}\frac{\tau}{1-\tau}\left(1-\frac{\omega}{1+\omega}\right) \tag{18}$$

$$\varepsilon_y = -\frac{\alpha}{1-\alpha}\frac{\tau}{1-\tau}\left(1-\frac{\omega}{1+\omega}\right). \tag{19}$$

The tax elasticity of the capital-labor ratio is one of the most important quantities in tax policy analysis. Indeed, Barro and Furman (2018) note that it drives their results in predicting very large growth effects of the 2017 Tax Cuts and Jobs Act. Quantitatively, higher values of ε_k imply larger welfare gains to cutting capital taxes to zero in Ramsey models. And yet, the existence of the maintenance-investment distortion implies that productivity effects of cutting taxes may be substantially mitigated depending on the value of ω and indeed are observationally equivalent to having a lower capital share. Holding fixed $\alpha = 1/3$, a maintenance elasticity $\omega = 1$ is the same as having a capital share of 0.2, which clearly has large quantitative implications. Additionally, it is clear that as $\omega \to \infty$, $\varepsilon_y \to 0$, which is the same as saying that tax policy becomes irrelevant as the elasticity of demand for maintenance becomes perfectly inelastic. This is not likely, but demonstrates the relevance of figuring out how large the elasticity is empirically.

Proposition 2 also highlights the non-neutrality of tax policy when there are multiple capital types. As long as $r^k > 0$, then any variation in depreciation technologies implies differential tax elasticities. That is, when $r^k > 0$, a sufficient condition for differing tax elasticities of capital is that either $\gamma_i \neq \gamma_j$ or $\omega_i \neq \omega_j$. To illustrate why this matters, consider a firm with two capital types: equipment and structures. In intensive form, steady-state output is given by $y = k_E^{\alpha_E} k_S^{\alpha_S}$. Letting $\alpha_E = \alpha_S = 0.4$, each capital type has its own depreciation technology characterized by (γ_i, ω_i). I set $\omega_S = 0.25$, $\omega_E = 1$, and $\gamma_E = \gamma_S = 0.01$. Under this calibration, the undistorted steady state maintenance rate and investment rate for equipment are $m_E = 0.1$ and $x_E = 0.1$, while the corresponding rates for structures are $m_S = 0.008$ and $x_S = 0.03$. Recall that the steady-state depreciation rate is the investment rate. The quality parameters are equivalent to isolate the effect of the maintenance elasticity. Both equipment and structures are taxed at the same rate τ^c.

From now on, I describe the standard tax analysis as "NGM" corresponding to the neoclassical growth model because it is the starting point of most analyses and the endogenous depreciation model as the NGMM. In Figure 2, I plot the steady-state allocations of investment, maintenance, capital, and the composition of capital for a varying common tax rate τ^c for both the and the NGMM. The NGM is calibrated such that it has the same initial allocations at the undistorted optimum. In Figure 2a, the steady-state investment rate (solid lines) declines for both structures and equipment under the NGMM, while there is no response of the investment rate to tax policy in the NGM (dashed lines). Because equipment has a higher maintenance elasticity than structures, the investment rate responds more for equipment, in line with Proposition 1. Figure 2b shows that as tax rates rise, NGMM maintenance rates strongly respond, while by construction the NGM maintenance rates are constant. Indeed, maintenance rates respond proportionally more than investment rates; that follows from the curvature of the depreciation technology. The key policy question is the long-run effect of taxes on capital allocations. In Figure 2c, I plot the ratio of capital in the NGMM to its corresponding type in the NGM. For the same calibration, the effect of capital tax policy on long-run allocations is attenuated by the maintenance channel; there is about 40% more equipment in the NGMM than the NGM and 20% more structures capital. Figure 2d indicates that uniform tax policy is not neutral when depreciation technologies are not precisely equivalent. Whereas the NGM ratio of equipment to structures is invariant to tax policy, the NGMM ratio is not.



(a) Investment Rate

(b) Maintenance Rate

(c) Ratio of NGM to NGMM Capital

(d) Capital Composition

Figure 2: Comparing NGMM to NGM investment and maintenance rates, capital allocations, and capital composition.

2.3 Dynamic Adjustment

With intuition established about the long run, we can make the analysis more complete by considering the dynamic relationships between maintenance, investment, and depreciation and how closely they approximate the frictionless solution. Let variables with a tilde denote their percent deviation from steady state and let $x_{i,t} \equiv \frac{X_{i,t}}{K_{i,t}}$.

Proposition 3. *Maintenance, investment and depreciation are related through*

$$\widetilde{m}_{i,t} = \frac{1}{1+\omega_i}\left(\frac{\widetilde{\tau}_t^c}{1-\tau^c} - \frac{\widetilde{\tau}_{i,t}^x}{1-\tau_i^x} - b_i\delta_i(m_i)\widetilde{x}_{i,t}\right) \tag{20}$$

$$\widetilde{\delta_i(m_{i,t})} = \frac{-\omega_i}{1+\omega_i}\left(\frac{\widetilde{\tau}_t^c}{1-\tau^c} - \frac{\widetilde{\tau}_{i,t}^x}{1-\tau_i^x} - b_i\delta_i(m_i)\widetilde{x}_{i,t}\right). \tag{21}$$

Proposition 3 follows from manipulating the first-order conditions and log-linearizing around the steady state, which shows that the adjustment cost spills over into maintenance and depreciation adjustment. Appendix B contains the full set of log-linearized conditions along with impulse responses to tax policy shocks. Whereas under the frictionless case, maintenance and depreciation adjust instantaneously, that effect is amplified here by the adjustment cost. With investment unable to rapidly adjust, maintenance adjusts even more and hence the deviation of capital from steady state is decreasing in the adjustment cost. One can see that in Figure 11. Comparing a tax shock for two sets of adjustment costs and maintenance elastictities suggests that when the adjustment cost is larger, capital deviates less from its steady-state value because maintenance responds even more strongly. In that sense, investment and maintenance rates are more substitutable as the adjustment cost increases.

Regardless of the adjustment cost, however, maintenance and investment *levels* comove. This finding echoes similar quantitative and theoretical findings from Albonico, Kalyvitis, and Pappa (2014) and Boucekkine, Fabbri, and Gozzi (2010). The logic is similar for adjustment cost formulations on investment growth as in Christiano, Eichenbaum, and Evans (2005).[9] Note, however, that the adjustment cost function differs from the standard one in the sense that permanent shocks also permanently change the depreciation rate, which means that it is critical for shocks to be temporary for the cost function to make sense.

Consider instead an alternative adjustment cost function given by

$$\Phi\left(K_{i,t+1}, K_{i,t}\right) = \frac{a_i}{2}\left(\frac{K_{i,t+1}}{K_{i,t}} - 1\right)^2 K_{i,t}. \tag{22}$$

This cost function is relatively popular; Albonico, Kalyvitis, and Pappa (2014) adopt this adjustment cost assumption in their study of the cyclical properties of depreciation and

9. One may also want to consider adjustment costs for maintenance, but we have very little evidence on its cyclical properties. Albonico, Kalyvitis, and Pappa (2014) provide model-based evidence that it is procyclical. Moreover, what evidence we do have indicates that adjustment costs for maintenance are minimal (Bitros 1976).

maintenance and Koby and Wolf (2020) use something similar. Here, the optimality condition for maintenance is unchanged from the frictionless case, which means that maintenance and depreciation jump instantaneously in response to a shock. Indeed, the log-linearized optimality conditions for maintenance and depreciation are

$$\widetilde{m}_{i,t} = \frac{1}{1+\omega_i}\left(\frac{\widetilde{\tau}_t^c}{1-\tau^c} - \frac{\widetilde{\tau}_{i,t}^x}{1-\tau_i^x}\right) \tag{23}$$

$$\widetilde{\delta_i(m_{i,t})} = \frac{-\omega_i}{1+\omega_i}\left(\frac{\widetilde{\tau}_t^c}{1-\tau^c} - \frac{\widetilde{\tau}_{i,t}^x}{1-\tau_i^x}\right). \tag{24}$$

Investment reacts more strongly than the constant depreciation case because the immediate change in depreciation moderates the growth of the capital stock, which reduces the adjustment cost per unit of additional investment. Depending on how sluggishly investment responds and the magnitude of the maintenance elasticity, capital may initially shrink on net following a tax cut, but that is a borderline case.

3 Endogenous Maintenance: Two Sources of Evidence

To date, there is little empirical evidence on how capital maintenance responds to relative price changes or, equivalently, to tax policy. The typical sources for analyzing capital expenditures do not have maintenance data. For example, Compustat has no information on maintenance at the microeconomic level and the National Accounts does not collect any data on capital maintenance. This presents a challenge for testing the economic relationship between maintenance and prices. An alternative specification would test the relationship between depreciation and maintenance, but that is even more difficult because depreciation rates are rarely updated by the Bureau of Economic Analysis. [10] In this section, I provide direct empirical evidence of the transmission of tax policy to maintenance rates using two sources of data which, to my knowledge, have not been leveraged before for this purpose. First, I use the industry tables from the Statistics of Income from the Internal Revenue Service, which provides data on maintenance and repair costs. Second, I use microeconomic evidence from freight rail.

The organizing principle for both pieces of evidence comes from the log-linearized

10. Canada has historically collected data at the national level on capital maintenance, but the frequency with which they change the survey makes it difficult to use as a time series and the cross-sectional variation across regions is limited. However, in line with this paper's theory, Statistics Canada has updated their depreciation rates twice in the last twenty years and found an increase in depreciation coinciding with a trending decline in capital tax rates (Baldwin, Liu, and Tanguay 2015).

relationship between the maintenance rate m and the relative price of maintenance q. Given some unit of observation j at time t, the relationship between maintenance and relative prices is roughly

$$\widetilde{m}_{j,t} = -\frac{1}{1+\omega}\widetilde{q}_{j,t}, \tag{25}$$

with some additional terms if there is an investment adjustment cost. Plausibly exogenous variation in relative prices across units and over time are then sufficient to identify the elasticity of demand for maintenance intensity. Under the standard view, the coefficient on a regression of the maintenance rate on the relative price would be equal to one. By contrast, we require demand for the maintenance rate to be relatively inelastic. I subsequently discuss in detail how I apply this at the industry and next at the firm level for each type of evidence.

3.1 Evidence from Tax Records

Corporations report maintenance and repair expenditures as a line item on their tax forms to the Internal Revenue Service (IRS). The IRS reports maintenance by industry at roughly the three-digit NAICS level going back to 1998 and up to 2019. This, to my knowledge, is the only wide-scale collection of maintenance data in the United States. In particular, I use Table 13 of the Statistics of Income's (SOI) Corporate Reports in combination with variation in tax policy exposure by industry over time to estimate the maintenance elasticity of depreciation.

Industries vary in their exposure to tax policy because they differ in their production technologies. Some industries use more structures, while others use more equipment. The end result, due to differential capital taxation, is that marginal effective tax rates vary widely by industry. This fact lies at the center of identification of the effects of tax policy on investment going back to Cummins, Hassett, and Hubbard (1994) in the past to modern studies from Zwick and Mahon (2017) and Chodorow-Reich et al. (2023). Building on this literature, I leverage the BEA's fixed asset data to create a long panel of capital-weighted marginal effective tax rates by industry. I detail how I do this in Appendix D.1. It is largely the same procedure as previous iterations of cross-sectional tax policy analysis from, for example, House and Shapiro (2008).

I take maintenance, investment, and capital data from the SOI corporate reports on c-corporations with positive net income. This excludes filings made with Forms 1120S, 1120-REIT, and 1120-RIC. I focus on firms with positive net income because firms without net income do not have a distorted incentive to maintain existing capital. Because the SOI industries change over time, I focus on using the BEA industries for a consistent mapping rather than NAICS industries. To do that, I map each SOI industry into a corresponding BEA industry, which is convenient because then there is a single marginal effective tax rate for each industry. There are fifty such industries and 49 after I exclude the financial sector. I report summary statistics for the primary variables in Table 5.

The distribution of maintenance rates in Table 5 is quite low relative to the best data we have. Canada is the only country with good national data on maintenance and it has typically been the centerpiece of studies on maintenance (McGrattan and Schmitz Jr. 1999). However, the national maintenance rate in Canada is close to 22%, whereas the maintenance rate here is closer to 5%. That can be partially but not fully explained by the fact that depreciation rates in Canada are roughly twice as high as in the United States (Baldwin, Liu, and Tanguay 2015). A secondary explanation is that it is quite difficult to track maintenance expenditures. Only airlines and freight rail are required to meticulously track maintenance expenditures independently of other types whereas other industries do not have the same incentive. It could easily be the case that a large share of maintenance expenditures go under labor cost or some other part of costs of goods sold. From the perspective of the firm, it is irrelevant how such expenditures are allocated because they are not regulated at all and are tax deductible regardless. With this in mind, I examine freight rail in the following subsection.

With a starting point of (25), I examine panel regressions of the form

$$\tilde{m}_{j,t} = \alpha_j + T_t + \beta\left(1 - \tau_{j,t}\right) + \text{controls} + \epsilon_{j,t}, \tag{26}$$

where α_j is an industry fixed effect and T_t is a time fixed effect. Variation across exogenous policy decisions is sufficient to identify the maintenance elasticity. The main threat to this is if, for example, firms have foresight of tax policy and change their maintenance decisions ex ante (Ramey 2016; Leeper, Richter, and Walker 2012). But following the tax policy literature on cross-sectional analysis, I proceed as if this is not a problem. Table 1 gives regression results for (26). Column 2 uses the investment rate as a control. The results on the tax term are significantly negative and indicate large values for the maintenance elasticity.

	(1)	(2)	(3)
$1-\tau_{j,t}$	-0.175	-0.162	-0.105
	(0.082)	(0.075)	(0.049)
$x_{j,t}$		-0.002	-0.003
		(0.001)	(0.001)
$m_{j,t-1}$			0.450
			(0.064)
$\hat{\omega}$	4.72	5.19	8.49
N	1029	980	966

Table 1: Regression results of the maintenance rate on the tax term for corporations with net income. Standard errors are clustered by BEA industry. The investment rate is net investment scaled by the net capital stock.

The response of the investment rate also corresponds to theory. In particular, the investment rate response is significantly negative. Given the coefficient on the investment rate and assuming steady state depreciation around 10%, that implies the adjustment cost is small and around 0.25. In any case, maintenance responds significantly to relative prices, which has large implications for how seriously we should take the theory in Section 2.

We can contrast this with the maintenance behavior of all corporations, not simply those with positive net income. Theory predicts the effect to be weaker because the optimality condition for maintenance no longer binds if the firm is not taxable; there is no tax benefit to maintaining old capital over investing in new capital. In Table 2, I run the same regression but for all corporations regardless of whether they pay taxes. This is Table 12 in the SOI Tax Stats. Ideally, we would isolate corporations without net income but that is not possible with the available public data. Although the coefficient is smaller, which corresponds to a higher maintenance elasticity, it is statistically indistinguishable from zero in all three models. Hence, maintenance rates do not respond to relative prices.

	(1)	(2)	(3)
$1-\tau_{j,t}$	-0.089	-0.080	-0.031
	(0.067)	(0.065)	(0.021)
$x_{j,t}$		-0.006	-0.008
		(0.003)	(0.003)
$m_{j,t-1}$			0.698
			(0.038)
Num.Obs.	1068	1019	1012
N	1071	1071	1022

Table 2: Regression results of the maintenance rate on the tax term for all corporations. Standard errors are clustered by BEA industry. The investment rate is net investment scaled by the net capital stock.

3.2 Evidence from Freight Rail

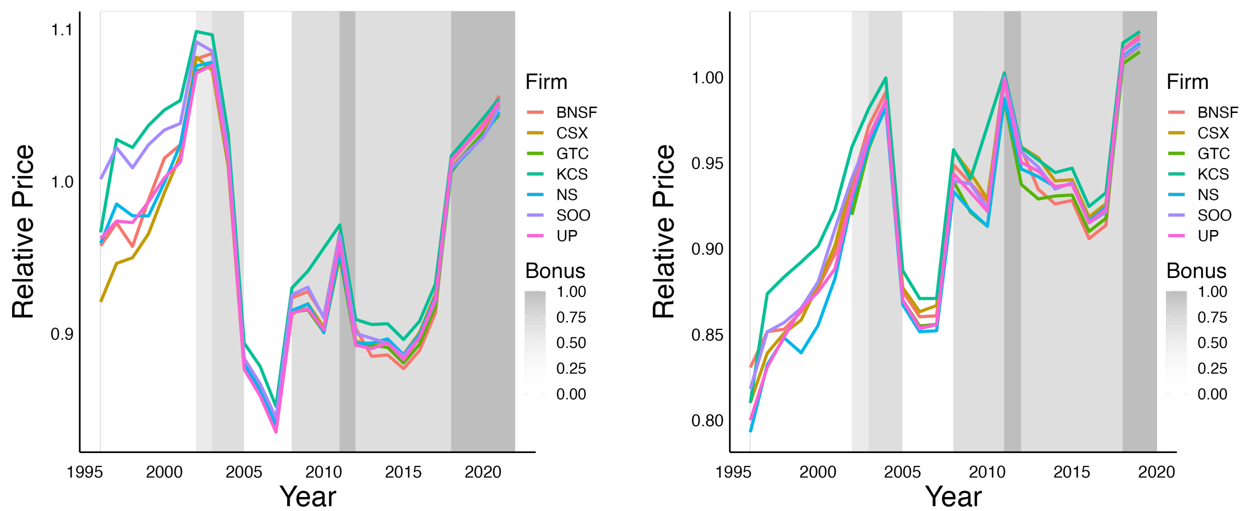
In this subsection, I provide direct evidence of a connection between relative prices and maintenance expenditures from freight railroads. The key advantage of this subsection over the previous one is that we can clearly identify the pre-tax relative prices of maintenance, whereas that is very difficult in the previous subsection. The downside is a loss of power. Only freight rail and airlines are required by law to provide detailed data on their maintenance and repair expenditures. I focus on the former because its maintenance activities are significantly less regulated by the government than the airline industry's. This study follows up on Bitros (1976) and Grimes (2004), who also study the determinants of maintenance policy using freight rail data, but without the objective of studying its response to relative prices.

By regulation, any freight railroad with revenue exceeding \$250 million must file an annual R-1 report with the Surface Transportation Board. The R-1 report can be thought of as a much more granular version of a 10-K filed by a publicly traded corporation. For example, it contains hundreds of line items for individual types of operating expenditures that would normally be summarized in one or two in a 10-K. It also details the size and composition of its property, plant, and equipment in value and quantities, its trackage by state, taxes paid, capital expenditures, and so on. Most importantly, it contains detailed data on maintenance expenditures by capital type as well as how those expenditures were allocated by labor and parts, both internally and externally.

With that in mind, freight rail is an ideal setting to study maintenance decisions. Its capital stock is almost entirely physical and made up of a mix of rolling stock (locomotives and freight cars) and fixed plant. Since 1980, it has largely deregulated and since the mid-1990s, the industry has settled into a stable competitive equilibrium with around seven large companies carrying most of the United States' freight traffic: CSX Industries, Burlington Northern & Santa Fe, Union Pacific, Norfolk Southern, Kansas City Southern, Soo Line, and the Canadian National Railway. All of these railways own their tracks and equipment and have faced relatively little financial trouble over the past 25 years. I focus on how maintenance responds to relative prices in those seven companies from 1996-2019.

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 broken down by labor and material cost. These expenditures are largely maintenance on different aspects of railway operations from tracks to rail ties to electrical systems, and so on. For this paper, I maintain a relatively narrow focus on freight cars and locomotives because they are easiest to identify in the data, although there is probably interdependence between maintenance of one capital type and another.

We require two variables to help identify (25): a maintenance rate and a relative price. I give a detailed discussion of data construction in Appendix D.3 and will go through it briefly here. Maintenance rates come directly from R-1 filings. For each capital type, they are the sum of maintenance and repair expenditures which can be tied directly to the type of capital divided by the book value of the net capital stock. Second, relative prices come from a weighted average of labor and parts prices divided by an investment deflator multiplied by the tax term $1 - \tau_{j,t}$. Labor prices come from the wage index for maintenance workers. Parts prices are from the parts PPI for either locomotives or freight cars from the BLS. The investment deflator is the PPI for either freight cars or locomotives from the BLS. The tax term is constructed by taking advantage of regional variation in tax rates; freight firms pay different taxes because they are in different states and those states differ in how they allow bonus depreciation and levy taxes. With that in mind, relative prices may vary between firms and capital types for three reasons. First, because firms differ in their geographic concentration, they also vary in their exposure to state-level tax policy differences. Second, because capital types differ in their maintenance labor intensities, maintenance prices differ between capital types. Third, investment prices differ for locomotives and freight cars. Putting that together, there is variation between capital types and firms in their exposure to relative price changes.



(a) Freight Cars **(b)** Locomotives

Figure 3: The relative price of maintaining freight cars (left) and locomotives (right). The degree of shading corresponds to the strength of bonus depreciation.

I rely on exactly that variation between firms and capital types in their exposure to relative prices to help identify the coefficient β in the panel regression

$$m_{i,j,t} = \alpha_i + \kappa_j + \beta \tilde{q}_{i,j,t} + \text{Controls} + \epsilon_{i,j,t}, \tag{27}$$

where $m_{i,j,t}$ is the firm i and capital type j maintenance rate at time t, α_i is a firm fixed effect, κ_j is a capital type fixed effect, and $\tilde{q}_{i,j,t}$ is the relative price. The research design is similar in spirit to Zwick and Mahon (2017). I do not use a time fixed effect for the main regressions because the tax treatment is not substantially different enough between firms and types to get very much variation out of the tax term. Instead, I control for growth in real aggregate output and productivity growth of the freight rail sector, where the former is obtained from FRED and the latter from the Bureau of Transportation Statistics.

In Table 3, I present estimates of (27), where standard errors are clustered by firm and capital type. I also include corresponding estimates of the tax term because one may be concerned that chosen maintenance labor intensities are endogenous but policy is not. Throughout all specifications, the coefficient on the relative price is significantly negative. Most estimates of the maintenance elasticity are between 0.4 and 1, while one case estimates a much higher elasticity. In the appendix, Table 7 presents alternative results with a time fixed effect. There, the estimated coefficient on β remains negative but there is not enough variation to say very much about the tax term.

	(1)	(2)	(3)	(4)	(5)	(6)
Relative Price	−0.715	−0.670	−0.144			
	(0.180)	(0.169)	(0.064)			
$(1-\tau_{j,t})$				−0.532	−0.530	−0.641
				(0.269)	(0.269)	(0.249)
Investment Rate		0.108	0.023		0.125	0.021
		(0.022)	(0.056)		(0.024)	(0.049)
Lagged Maintenance Rate			0.658			0.631
			(0.117)			(0.118)
Age			−0.167			−0.249
			(0.064)			(0.088)
$\Delta \log \mathrm{GDP}_t$	−1.005	−1.091	−0.210	−1.005	−1.120	−0.302
	(0.399)	(0.390)	(0.304)	(0.416)	(0.427)	(0.339)
$\Delta \log \mathrm{TFP}_t$	0.216	0.212	0.490	−0.063	−0.057	0.381
	(0.142)	(0.124)	(0.179)	(0.098)	(0.086)	(0.130)
$\hat{\omega}$	0.400	0.493	5.921	0.879	0.888	0.560
N	336	336	320	336	336	320

Table 3: Regression results. The relative price is defined in the main text. The lagged investment rate is the lagged net investment rate scaled by the lagged net stock of capital. Age is the net capital stock divided by the gross capital stock. Standard errors are clustered by firm and capital type.

The largest concerns are likely the small sample size and the lack of significant tax variation between equipment types. We only have around 350 observations, which means that it is difficult to be confident in the results. Moreover, there has to be some concern that the prices are not exogenous. The tax policies surely are, but it is possible that the prices of freight and locomotive parts as well as the prices of freight and locomotive equipment are not exogenous. After all, we have the largest players in the U.S. freight market. At the same time, freight is a global enterprise and the major manufacturers of locomotives and freight cars sell on the international market. For example, General Electric was, for most of the period examined, a major supplier of locomotives around the world.

Despite these concerns, it is nevertheless encouraging that the results are partially in favor of the theory. Indeed, that should not be a surprise. This paper joins a number of others in showing that the maintenance decision is economic. To my knowledge, it is the first that shows it responds to the relative price of maintenance to investment. In a pair of papers, Austan Goolsbee provides some of the best evidence we have. Goolsbee (1998) shows that airplane scrappage responds significantly to tax cuts; airlines buy new planes and scrap old ones following tax cuts. Because newer airplanes require less maintenance and the measured stock of equipment rises, this means that airlines maintain their capital less intensively following tax cuts.[11] Goolsbee (2004) shows that tax cuts induce firms to purchase higher quality capital goods, which in his framework means that they need to be maintained less intensively to achieve the same depreciation rate. That agrees with Figure 2d, which shows that a common tax cut would lead firms to substitute toward capital with a lower γ, or equivalently, higher quality capital goods. Similarly, a number of papers in the housing literature show that maintenance is an economically important decision determined by economic factors (Harding, Rosenthal, and Sirmans 2007).

Taking Stock

Across the data sources, there is not clear agreement on what the maintenance elasticity is, but it is clear that the maintenance rate responds significantly to changes in relative prices. For the remainder of the quantitative exercises in Sections 4 and 5, I highlight a maintenance elasticity of one, but there is not a good reason to think that this is the best estimate. The regressions for freight rail indicate that this may be a plausible value for the maintenance elasticity, but the SOI data indicate it could be much higher. Appendix E.2 shows how to estimate the maintenance elasticity indirectly using the gross investment rate and shows a value in between what the SOI and the freight rail data indicate.

4 Applications to Tax Policy Analysis

In this section, I discuss two applications of the maintenance channel to analyzing tax policy. The first is empirical and discusses bias in typical investment regressions. The second analyzes the implications of maintenance accounting for quantitative tax policy models, with the Barro and Furman (2018) analysis of the 2017 Tax Cuts and Jobs Act as an example.

4.1 Application 1: Investment Regressions

Theory has historically played a large role in motivating regressions of investment on tax policy. Various incarnations of this mirror developments in investment theory from

11. In the model, this should translate into an increase in the depreciation rate, but accounting for vintages gives a more complicated story.

Summers (1981) to Cummins, Hassett, and Hubbard (1994) and on to Chodorow-Reich et al. (2023), all of which use variants of a theory to discipline the empirical analysis. Across the board, standard investment regressions are motivated by the observation that the tax semi-elasticity of user cost is $\frac{1}{1-\tau_j}$, where τ_j is a firm- or industry-specific tax rate. This means that one can ignore the rest of user cost because the parameters are often unknown or imperfectly estimated.

This paper raises the question of whether it is appropriate to ignore the depreciation component of user cost. The key point of this section—and indeed, of this paper—is that if user cost determines incentives for capital accumulation, then a user cost with constant depreciation does not adequately capture the change in incentives following a change in tax policy. To the contrary, Proposition 2 indicates that as long $\omega > 0$, then the change in tax policy incentives for the firm is strictly smaller than a constant depreciation model. To motivate why that matter for empirical tax policy analysis, consider two regressions:

$$\log X_{j,t} = \alpha_j + T_t + \beta_S \frac{1}{1-\tau_{j,t}} + \text{controls} + \varepsilon_{j,t}, \tag{28}$$

$$\log X_{j,t} = \alpha_j + T_t + \beta_\omega \frac{1}{1-\tau_{j,t}} \left(1 - \frac{\omega}{1+\omega}\right) + \text{controls} + \zeta_{j,t}. \tag{29}$$

The first regression is entirely standard in the empirical investment literature. The second, which I argue is a more accurate representation of the change in incentives, accounts for the change in maintenance demand engendered by a change in tax policy. The endogenous maintenance model suggests that the first regression is *conceptually* misspecified. Indeed, if we regress investment on the user cost of capital and assume a constant depreciation rate, then we may dramatically underestimate the elasticity of investment with respect to user cost. Proposition 2 suggests that the actual change in tax rates is smaller than measured by typical investment regressions because of the countervailing effect on depreciation. With the same left-hand side variable, that naturally means the coefficient on tax policy is larger.

Proposition 4. *Assuming adjustment costs are small, the tax elasticity of investment is biased downward. Defining the bias as*

$$Bias = \frac{\widetilde{\beta}_S}{\widetilde{\beta}_\omega},$$

the bias is approximately $\frac{1}{1+\omega}$ as long as ω is identical across capital types and the discount rate is small relative to depreciation.

The bias in Proposition 4 is a *conceptual* error and not an econometric one. From the endogenous maintenance model, the relevant change in tax policy for capital accumulation is the direct change—which is typically on the right-hand side of the regression—net of the effect on depreciation via maintenance. Conceptually, this is more important because we ultimately only care about the change in tax policy to the extent that it affects the capital stock, which is the relevant variable for output and growth. A regression that focuses only on the direct effect does not properly consider the actual change in incentives a firm faces after a tax policy change.

Aside from theoretical considerations, we should care about Proposition 4 because regressions like (28) are exceptionally popular in the public finance literature. Since Cummins, Hassett, and Hubbard (1994), economists have run many variations of it. Indeed, Zwick and Mahon (2017) document around a dozen prominent papers regress investment on the tax term.[12] Moreover, because of the increasing popularity of using micro moments in macro models, partial equilibrium elasticities are often used to calibrate models. Indeed, Koby and Wolf (2020) map the Zwick and Mahon (2017) estimates into a general equilibrium lumpy investment model, but the mapping fails if there is endogenous depreciation.

To explore the extent of the downward bias as a function of ω, I compare the coefficients from versions of (28) and (29) using annual firm-level data from Compustat from 1972-2022. For simplicity, I assign all firms the same ω as an illustration of the principle. The data construction is largely standard and is detailed in Appendix E.2. Just as in Zwick and Mahon (2017), identification comes from variation in exposure to tax policy. The empirical results are in themselves novel—I believe they are the newest update of the Cummins, Hassett, and Hubbard (1994) regressions—and indicate a strongly negative response of investment to tax policy. However, to the extent that we are concerned about the endogeneity of maintenance and hence depreciation, the coefficient in column 1 is biased downward. I illustrate that in Figure 4 for varying values of ω.

12. In all of these papers, identification is possible largely because firms vary in their capital inputs and, because of differential capital taxation, also vary in their exposure to aggregate tax policy, so $\tau_{j,t}$ varies across firms and industries.

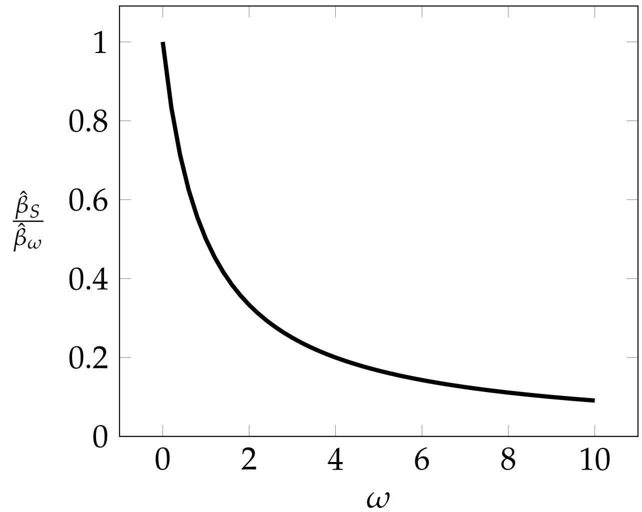


Figure 4: Degree of bias in investment regressions from two-way fixed effect panel regressions of log capital expenditures on $\frac{1}{1-\tau_i}$.

Proposition 4 and the resulting exercise relies on the assumption that the discount rate is small relative to depreciation. We do not have an adequate measurement of depreciation but if we take the BEA's estimates at face value, then firm-level depreciation is approximately the same size as the typical discount rate from Gormsen and Huber (2022). Consequently, the actual bias is closer to $1 - \frac{1}{2}\frac{\omega}{1+\omega}$. Given $\omega \approx 1$, the estimated coefficients are typically about 75% as large as they should be.

A more reserved interpretation of this section is that we have to think carefully about the conceptual purpose of the regression. If the goal is to understand how investment responds to a theoretically coherent definition of the change in incentives according to user cost, then (29) may be more appropriate. The main regressions in Chodorow-Reich et al. (2023) come from a neoclassical model like the one in this paper, except it uses constant depreciation and is oriented toward open economy considerations. This subsection suggests their results are biased downward. On the other hand, the user cost framework may be entirely wrong and one may prefer a more non-parametric approach. This is implicitly the approach of Zwick and Mahon (2017), which instead regresses investment on variation in the net present value of tax depreciation allowances and includes the tax term only for comparison to a different, more theoretically oriented literature.

4.2 Application 2: The Tax Cuts and Jobs Act

Quantitative general equilibrium models form the basis for policy prediction and evaluation. Although they vary in complexity from the quite simple Ramsey model from Barro and Furman (2018) analysis of the 2017 Tax Cuts and Jobs Act (TCJA) to the complex overlapping generations model from the Penn Wharton Budget Model, they all have in common a perpetual inventory equation with constant depreciation to iterate forward the capital stock. Indeed, this feature is shared by Chodorow-Reich et al. (2023), which provides the most sophisticated model-based analysis of TCJA to date. Perhaps the central contention of this paper is that this is neither a locally nor a globally correct approximation to actual movements in the capital stock when maintenance—and hence depreciation—is endogenous. One comes to quite different quantitative predictions about the effects of tax policy in quantitative models when they are calibrated to have reasonable maintenance elasticity parameters such that the large gains predicted by most of these models are cut in half. I illustrate this through the lens of the Barro and Furman (2018) analysis of the TCJA, changing only the law of motion for capital from their model to reflect the one in this paper.

Quantitative Analysis of TCJA

The 2017 Tax Cuts and Jobs Act (TCJA) remains the largest tax reform of the postwar era. It substantially cut corporate tax rates from 35% to 21% and altered tax wedges between assets; lawmakers gave equipment 100% bonus depreciation and altered the cost of capital for different types of intangibles. At the same time, policymakers introduced new measures to combat profit shifting from tax havens abroad. For a full description of the various changes, see Barro and Furman (2018) and Gale et al. (2018).

Here, I focus on the impact of considering maintenance on the predicted long-run effects of the domestic tax changes. Barro and Furman (2018) provide the ideal setting for doing so; they analyze the long-run effects of TCJA through the lens of a standard neoclassical model with heterogeneous capital. Their model features five types of capital (equipment, residential structures, nonresidential structures, R&D intellectual property, and other intellectual property) and two sectors (a corporate and a pass-through sector). Using income share data, they calibrate a Cobb-Douglas production function with those five capital types plus labor for the corporate and pass-through sectors. The Barro and Furman analysis yields promising results for the TCJA, predicting large increases in the capital-labor ratio and, as a direct consequence, significantly higher output per capita. Their approach amounts to simply computing the analytical steady state under different capital tax policies and examining the results while implicitly assuming that the demand for maintenance is perfectly inelastic and zero.

To demonstrate the relevance of accounting for maintenance, I compute the TCJA's predicted effect on the long-run capital-labor ratio for a grid of maintenance elasticities. For each type of capital and given a maintenance elasticity, I set the parameter γ_i such that the pre-reform user cost is the same regardless of the maintenance elasticity. I group each of the five assets into one of two major groups (structures in one category and the remaining three in the rest). Then, for a grid of maintenance elasticities in $[0, 5] \times [0, 5]$, I compute the predicted long-run effect on capital per capita under the assumption that all aspects of the law are permanent and there is no crowd-out or effect on debt finance. The latter two assumptions are just to isolate the maintenance channel.

Denote the long-run gain in output per capita with a positive maintenance elasticity as $k_\omega = K_\omega / L_\omega$ and the benchmark constrant depreciation output per capita as $k_0 = K_0 / L_0$. In Figure 5, I plot the ratio k_ω / k_0. The x-axis corresponds to the value of the maintenance elasticity for intellectual property products and equipment and the y-axis to structures. Lower values mean that the combination of maintenance parameters (with an otherwise identical calibration) lead to a lower predicted effect on capital per capita. The dot at $(1, 1)$ corresponds to both capital types sharing a maintenance elasticity of one. Based on the empirical results in Section 3, this is currently the best estimate we have.

Figure 5 is an indication of the potentially large distortionary consequences of writing the tax code such that the relative price of maintenance to investment is a function the marginal tax rate. While fiscal authorities reliably focus on tax reform for the purpose of achieving long-run growth (Romer and Romer 2010)—and this is especially true in the case of TCJA—they may be inadvertently hindering their own chance at success by overlooking this one quirk in the tax code. Indeed, even if the demand for maintenance responds modestly to relative prices, the predicted effects are much smaller than one would suppose with a constant depreciation model. Given that maintenance may substantially attenuate the effects of capital accumulation, it is plausibly one of the largest distortions in the tax code. I return to this interpretation in the context of optimal taxation and welfare in the following section. Figure 5 indicates how necessary it is to measure the elasticity of demand for maintenance properly. The maintenance channel is of first-order importance and until we understand its elasticity, it is difficult to properly evaluate the actual growth effects of any and all of the postwar tax reforms.

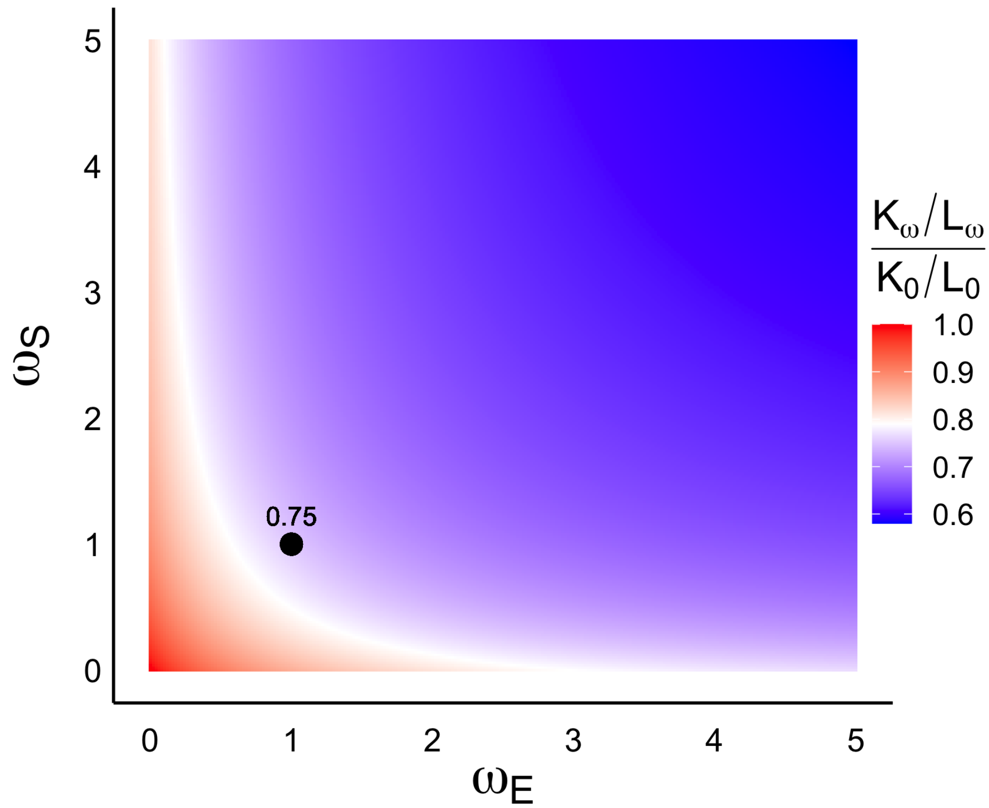


Figure 5: Comparing the NGMM to the NGM, where K_ω/L_ω is the predicted output per capita under the NGMM and K_0/L_0 is the predicted capital per capita under the Barro and Furman benchmark. I group the high-depreciation assets (equipment and intellectual property products) into one category and give them the maintenance elasticity ω_E, with γ_i set to match the pre-reform user cost for each capital type. Low depreciation structures are in the second category and are assigned the maintenance elasticity ω_S.

5 Optimal Policy

The tax elasticity of the capital stock is a key determinant of the direction and quantitative gains from optimal capital tax policy. Under the benchmark neoclassical model with constant depreciation, the welfare gain from cutting taxes to zero is around 10% of consumption-equivalent welfare (Lucas 1990). Although recent results from Straub and Werning (2020) question the finding from Chamley (1986) and Judd (1985) that the optimal tax on capital is zero, Chari, Nicolini, and Teles (2020) reaffirm the Chamley-Judd result in standard macro environments. Throughout, I have shown that maintenance makes the stock of capital more inelastic to tax policy. Naturally, accounting for maintenance reduces those gains. Larger maintenance elasticities attenuate the effect of capital tax cuts, which means the cost of the distortion is approximately the same as the extent to which maintenance attenuates the welfare gain of cutting taxes to zero.

To put a quantitative figure on the importance of maintenance for optimal tax policy, I nest the partial equilibrium model of the firm from Section 2 into the general equilibrium environment of Chari, Nicolini, and Teles (2020). Because the setup is fairly standard and derivation of optimal tax policy is likewise standard, I defer details of both to Appendix C and give a short description here instead. There is no uncertainty. Time is discrete and runs $t = 0, 1, \ldots, \infty$, there is a representative household with isoelastic preferences, and a Ramsey planner setting capital and labor taxes to maximize household utility. The firm is the same as in Section 2 but discounts the future using the household discount factor. In this setting, maintenance does not fundamentally alter the planner's problem. It reduces the tax-elasticity of capital stock but because capital is only tax-inelastic in the limit, the planner still wants to set capital taxes to zero and shift the burden entirely to labor taxes. Indeed, it is straightforward to show that zero capital taxation is optimal across all capital types.[13]

Proposition 5. *Suppose the economy converges to a steady state. The steady state optimal tax on capital is identically zero across all capital types.*
Proof: See Appendix C.2.

In fact, Proposition 5 holds for all periods because I assumed additively separable and homothetic preferences. That is, simply introducing maintenance does nothing to make a Ramsey planner want to distort intertemporal allocations. On the other hand, the quantitative gains from refraining from intertemporal distortions may be substantially smaller than the standard model because the tax elasticity is lower. McGrattan and Schmitz Jr. (1999) point this out in their early work on capital maintenance, but do not quantify it. There is no closed form solution for this because it depends on the multipliers, so I proceed instead with a numerical example.

One Capital Type

The most appropriate welfare benchmark is Lucas (1990). His calibration of an economy similar to ours yields consumption-equivalent welfare gains around 10% from cutting capital taxes to zero, which is an enormous number. In this exercise, I use a similar calibration with $N = 1$ capital type and compute consumption-equivalent welfare from cutting taxes to zero for a range of maintenance elasticities. The case with $\omega = 0$ corresponds directly to the benchmark neoclassical model with constant depreciation.

13. In a second-best setting in which capital has to be taxed, the planner will set capital taxes higher on capital which has a higher maintenance elasticity.

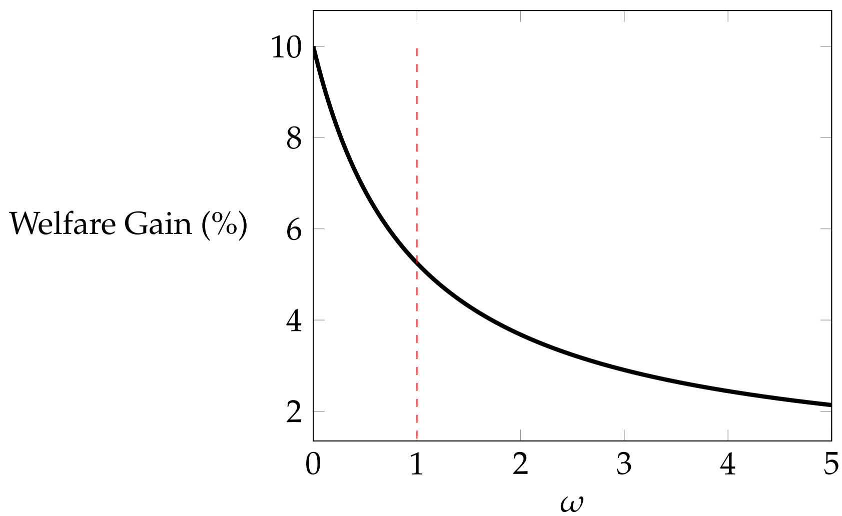


Figure 6: Welfare gains from cutting capital taxes to zero for varying values of ω starting from a marginal tax rate of 40%.

To do the exercise, I set the initial capital tax rate to 40% for each iteration of the maintenance elasticity and set flow utility to $u(c, h) = \log c + \psi \log(1 - h)$. I set ψ so that the agent works 30% of the time when the capital tax rate is 40%. The discount rate is 6% and I calibrate the parameter γ_i so that the depreciation term is 10% for every value of ω when the initial tax rate is 40%. Production is Cobb-Douglas in capital and labor with a capital share of $1/3$. In Figure 6, I plot the gains from cutting capital taxes to zero for varying values of ω starting from a marginal tax rate on capital of 40%. Labor taxes adjust such that the government budget constraint is satisfied. The welfare gain is around 10% for $\omega = 0$, which is approximately the same gain as in Lucas's benchmark. However, the welfare gain declines substantially as ω increases. Indeed, it is nearly halved with a moderate value of $\omega = 1$.

Figure 6 can be understood as reflecting the cost of leaving the maintenance-investment distortion in the tax code *before* lowering tax rates on capital. That is, if maintenance remains distorted before lowering tax rates, then depreciation adjusts upward and capital does not increase as much as expected. In that sense, the government works at cross purposes with itself by leaving the maintenance-investment decision distorted prior to embarking on pro-growth tax policies which litter the history of postwar tax reform (Romer and Romer 2010). At the same time, removing the distortion would induce capital to depreciate faster, so it is far from obvious how to time removing the distortion given that it is already baked into tax codes around the world.

Heterogeneous Capital

In this subsection, I consider instead what happens to the welfare gains from cutting taxes when $N = 2$. The only adjustment to the model is that production is now Cobb-Douglas in two types of capital, which I call equipment and structures. They have equal capital shares summing to 1/3. Initial depreciation is set to 10% for equipment and 3% for structures. The remainder of the calibration is the same.

In section 2.2, I showed that differing depreciation technologies can lead to quite different effects of tax policy despite common tax treatment. For example, the ratio of equipment to structures is equal for all values of the corporate tax rate, all else equal. That is not true when the maintenance channel operates. In Figure 7, I plot the welfare gains for cutting capital taxes to zero when initially both are taxed at 40%. The gradient of the welfare grid indicates that the welfare gain for cutting taxes remains substantial when the maintenance elasticity on structures is very high, but the same is not true for equipment. The intuition follows from examination of Proposition 2. For a given ω, the parameter γ_S is significantly smaller than γ_E because structures last for longer irrespective of maintenance. For structures, that increases the importance of the discount rate as a share of user cost. That means the strength of the maintenance channel is muted relative to equipment.

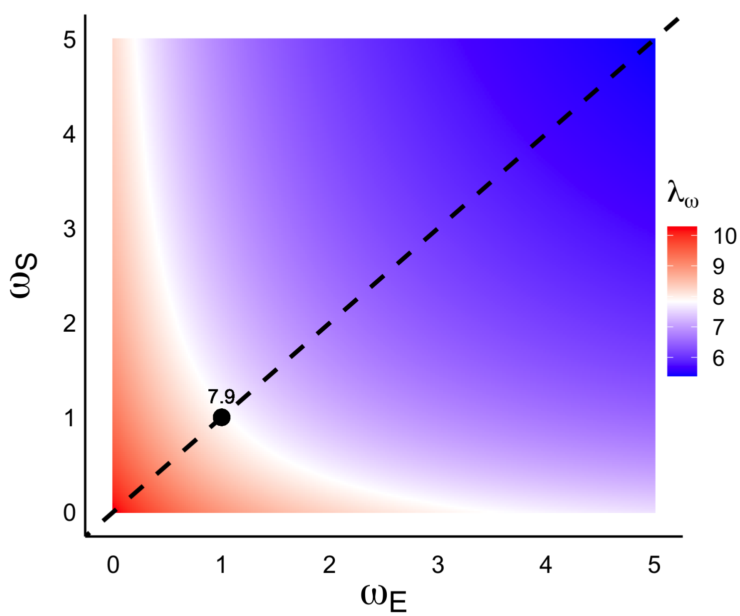
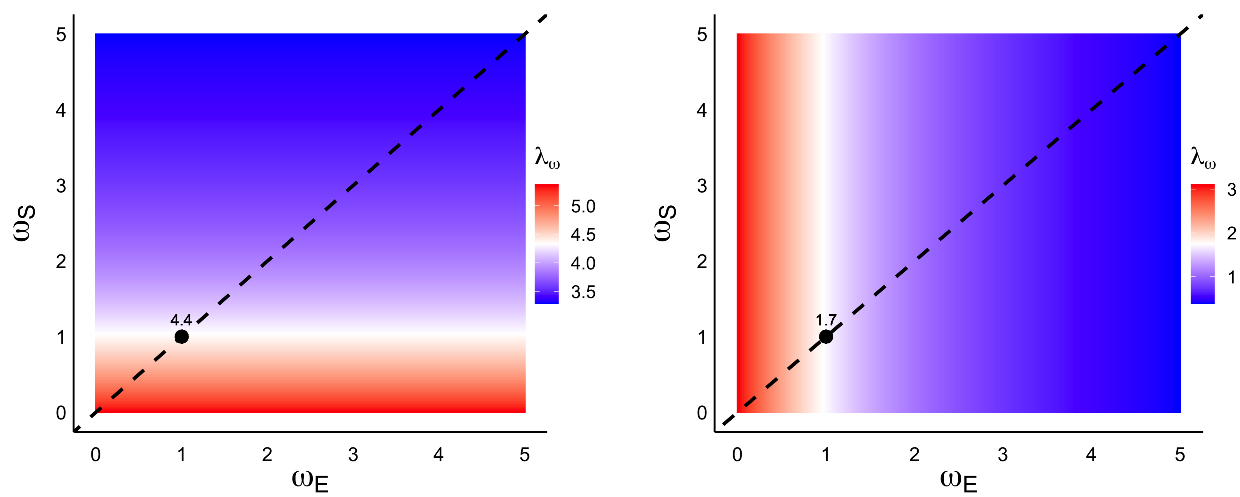


Figure 7: Welfare gain from cutting taxes to zero on from an initial common tax rate of 40%. The calibration is the same as in the exercise for $N = 1$, with the exception that the initial depreciation rate for structures is 3% and for equipment it is 10%. The capital shares are equal and sum to 1/3.

In recent years, the government has increasingly relied on bonus depreciation for stimulus and now growth policy (House and Shapiro 2008; Barro and Furman 2018). This policy cuts the marginal effective tax rate on equipment to zero at the federal level with the caveat that some states do not allow bonus depreciation. In Figure 8, I illustrate the welfare gains from a variant of this policy. On the left, I plot the welfare gains from cutting the tax on structures to zero from 40% assuming that equipment is already untaxed and then I do the same with the roles reversed on the right. Clearly, the welfare gains from cutting taxes to zero for structures far exceeds that for equipment holding the maintenance elasticity fixed. Largely, that is because of variation in depreciation technologies. Maintenance plays a larger role in muting the effects of tax policy when depreciation is large relative to the discount rate and that is more true for equipment than structures. Again, this is in line with the result from House (2014) that structures are more price elastic. Hence it follows that cutting taxes to zero for structures has larger welfare gains in the long run. However, the key distinction here is that because of curvature in the depreciation function, the resulting equilibrium allocations can be quite different than what would be predicted with the constant depreciation model from House (2014).



(a) Structures

(b) Equipment

Figure 8: Welfare gain from cutting taxes to zero on structures (left) and equipment (right). On the left, I experiment with cutting the marginal effective tax rate from 40% to zero holding the equipment tax rate at zero. I do the same but with roles reversed for equipment on the right. The calibration is the same as in the exercise for $N = 1$, with the exception that the initial depreciation rate for structures is 3% and for equipment it is 10%. The capital shares are equal and sum to 1/3.

Congress has largely avoided granting bonus depreciation to structures because it would be too expensive. At the same time, Figure 8 indicates that the gains from doing so would be substantially larger than fixating on equipment. Other factors may mitigate in favor of equipment over structures, but they are not in any of the benchmark tax models. Indeed, we have a recent example of structures getting a large write-off relative to equipment. Until 1981, railroads used retirement-replacement-betterment accounting, which meant that they would only write off capital assets when they retired or replaced them. Following the Economic Recovery Tax Act of 1981, freight railroads received a large tax break by getting to write off a large percentage of their capital stock immediately. Although railroads are only a small percentage of the total capital stock, it was nevertheless significant in terms of revenue. With that in mind, it may be wise to balance out tax cuts for equipment and structures to a greater extent than the 21st century has seen so far.

6 Concluding Remarks

In this paper, I highlight an understudied channel in the transmission of capital tax policy. To my knowledge, the theoretical and empirical results are completely unknown in the otherwise expansive literature on both positive and normative aspects of tax policy. Although I impose additional conditions for the sake of clarity, there are really only three that matter. First, the decision to maintain old capital must be an economic one. That is, the demand curve for maintenance must have some curvature. Second, depreciation technologies must vary between at least two capital types. In other words, at least one capital type must differ from another in its associated demand for maintenance. Finally, maintenance and investment must not be treated identically in the tax code. Although that would be efficient, tax policy generally does not treat maintenance and investment equally. Together, these distinguish the heterogeneous capital neoclassical growth model with maintenance from its traditional counterpart, leading to the relevant positive and normative conclusions together with the subsequent empirical results.

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

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A Optimal Maintenance Policy and Measurement Error

Another interpretation of optimal maintenance is through *measurement error*. Because depreciation is contingent on tax policy, any measure of depreciation is a function of current policy. Note that this has potentially large implications for quantitative analyses of tax policy that rely on user cost. Long-run estimates of the effects of capital taxation will be biased by the extent to which the proposed tax policy change is different from tax policy at the time depreciation was initially measured. This is particularly relevant for the United States, where many measures of depreciation still used today are from the 1970s, when taxes were much higher than today. Canada, which updates depreciation more frequently than the United States, shows a decline of measured depreciation together with business taxes (Baldwin, Liu, and Tanguay 2015). Viewed through the first-order condition for maintenance, the degree of measurement error depends crucially on both parameters ω_i and γ_i. While a positive maintenance elasticity makes measurement possible, the quality parameter determines how much the effect is amplified. For example, the γ parameter for equipment is probably much larger than structures, which means that the degree of measurement error is likely larger in levels for equipment.

The degree of potential for measurement error is useful to illustrate numerically. Suppose there are two capital types: E and S. Depreciation functions are parameterized by $\gamma_E = \gamma_S = 0.01$ with $\omega_E = 1$ and $\omega_S = 0.1$. Hence type E has a higher maintenance elasticity. Suppose depreciation was initially measured when $\tau_E = \tau_S = 50\%$. Let measurement error for capital type $i = E, S$ be defined as

$$\text{Measurement Error}_i = 100 \times \left(\gamma_i \left(\frac{1-\tau_i}{\gamma_i \omega_i} \right)^{\frac{\omega_i}{1+\omega_i}} - \gamma_i \left(\frac{1-0.5}{\gamma_i \omega_i} \right)^{\frac{\omega_i}{1+\omega_i}} \right).$$

A measurement error of two would correspond to actual depreciation two percentage points higher than the official depreciation rate. In Figure 9, I plot measurement error curves for both capital types as a function of the tax rate τ_i. Larger elasticities correspond to larger measurement error.

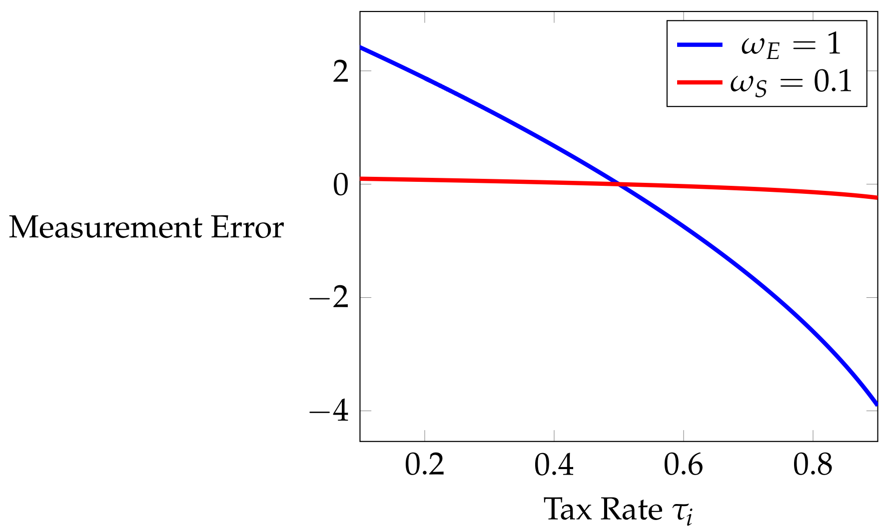

Figure 9: Measurement error curves for differing values of the maintenance elasticity, holding quality fixed at $\gamma_E = \gamma_S = 0.01$.

The quality of capital amplifies the degree of measurement error for a given maintenance elasticity. Now suppose the depreciation functions are parameterized by $\gamma_E = 0.05$ and $\gamma_S = 0.005$ with $\omega_E = \omega_S = 1$. This implies capital type E is lower quality and hence depreciates faster. In Figure 10, I plot measurement error curves for both capital types as a function of the tax rate τ_i. Clearly, the extent of measurement error is more serious for lower quality capital. When the marginal effective tax rate is zero percent, measurement error is five for capital type E compared to two for capital type S. Practically speaking, this may be an important issue for equipment and structures, which have quite different depreciation rates and have both seen large declines in marginal effective tax rates since initial measurement. In quantitative models featuring depreciating capital, failure to account for this may lead to incorrect conclusions.

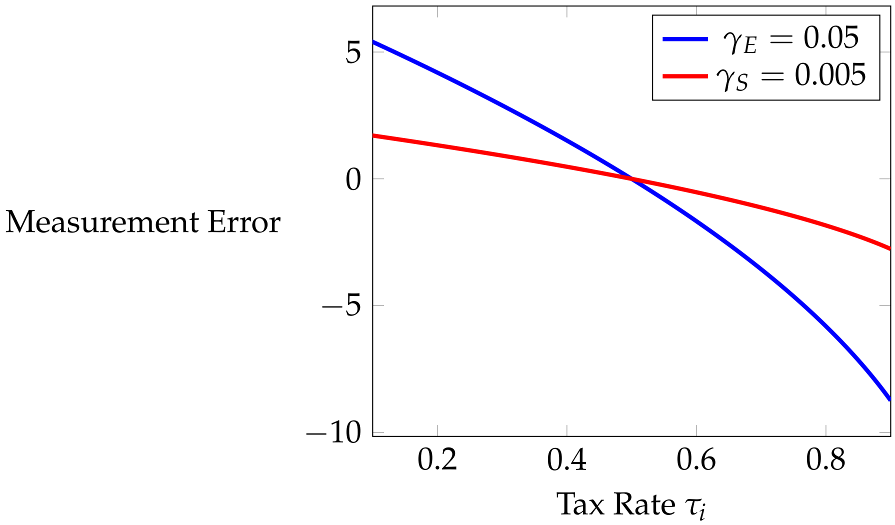

Figure 10: Measurement error curves for differing values of capital quality, holding fixed the maintenance elasticity at $\omega_E = \omega_S = 1$.

B Dynamic Adjustment

The log-linearized system of equations to the firm's problem is

$$\widetilde{w}_t = \frac{F_{HH}H\widetilde{H}_t + \sum_{i=1}^{N} F_{HK_i}K_i\widetilde{K}_{i,t}}{F_H} \tag{30}$$

$$\widetilde{m}_{i,t} = \frac{1}{1+\omega_i}\left(\frac{\widetilde{\tau}_t^c}{1-\tau^c} + \widetilde{\lambda}_{i,t}\right) \tag{31}$$

$$\widetilde{\delta(m_{i,t})} = -\frac{\omega_i}{1+\omega_i}\left(\frac{\widetilde{\tau}_t^c}{1-\tau^c} + \widetilde{\lambda}_{i,t}\right) \tag{32}$$

$$\widetilde{x}_{i,t} = \frac{1}{b_i\delta_i(m_i)}\left(\widetilde{\lambda}_{i,t} + \frac{\widetilde{\tau}_{i,t}^x}{1-\tau_t^x}\right) \tag{33}$$

$$\widetilde{K}_{i,t+1} = \left(1-\gamma_i(\omega_i+1)m_i^{-\omega_i}\right)\widetilde{K}_{i,t} + \widetilde{X}_{i,t}\gamma m_i^{-\omega_i} + \gamma_i\omega_i m^{-\omega_i}\widetilde{M}_{i,t} \tag{34}$$

$$\begin{aligned}\widetilde{\lambda}_{i,t}(1+r^k)(1-\tau_i^x) = \mathbb{E}_t\Bigg\{ & \frac{-F_{K_i}\widetilde{\tau}_{t+1}^c}{1-\tau^c} + \widetilde{\lambda}_{i,t+1}\lambda_i\left(1-\gamma_i(1+\omega_i)m_i^{-\omega_i}\right) \\ & + \lambda b_i\delta_i(m_i)\widetilde{x}_{t+1} + \lambda_i\omega_i\gamma_i\left(1+\omega_i\right)m_i^{-\omega_i}\widetilde{m}_{i,t+1} \\ & + \frac{(1-\tau^c)}{F_{K_i}}\left(F_{K_iH}H\widetilde{H}_{t+1} + \sum_{j=1}^{N} F_{K_iK_j}K_j\widetilde{K}_{j,t+1}\right)\Bigg\}\end{aligned} \tag{35}$$

B.1 $N = 1$

Suppose that there is one capital type and production is Cobb-Douglas in capital and labor. τ_t^c follows the dynamic adjustment cost exercise. I calibrate the tax shock process such that the steady state corporate tax rate declines from 35% to 23%.

Parameter	Value
r^k	0.06
α	0.4
ρ	0.9
τ^c	0.35
τ^x	0.2
ω	1
γ	0.01
b	$\{0, 1, 5, 20\}$

Table 4: Calibrated parameters

Figure 11 plots impulse responses of the corporate tax rate, the capital-labor ratio, and the output-labor ratio in response to a surprise increase in the tax rate by ten percentage points.. Evidently, impulse responses become more hump-shaped as the adjustment cost increases. In extreme cases, when the adjustment cost is very large, the sign of maintenance reverses from the frictionless case, which also makes depreciation switch signs initially.

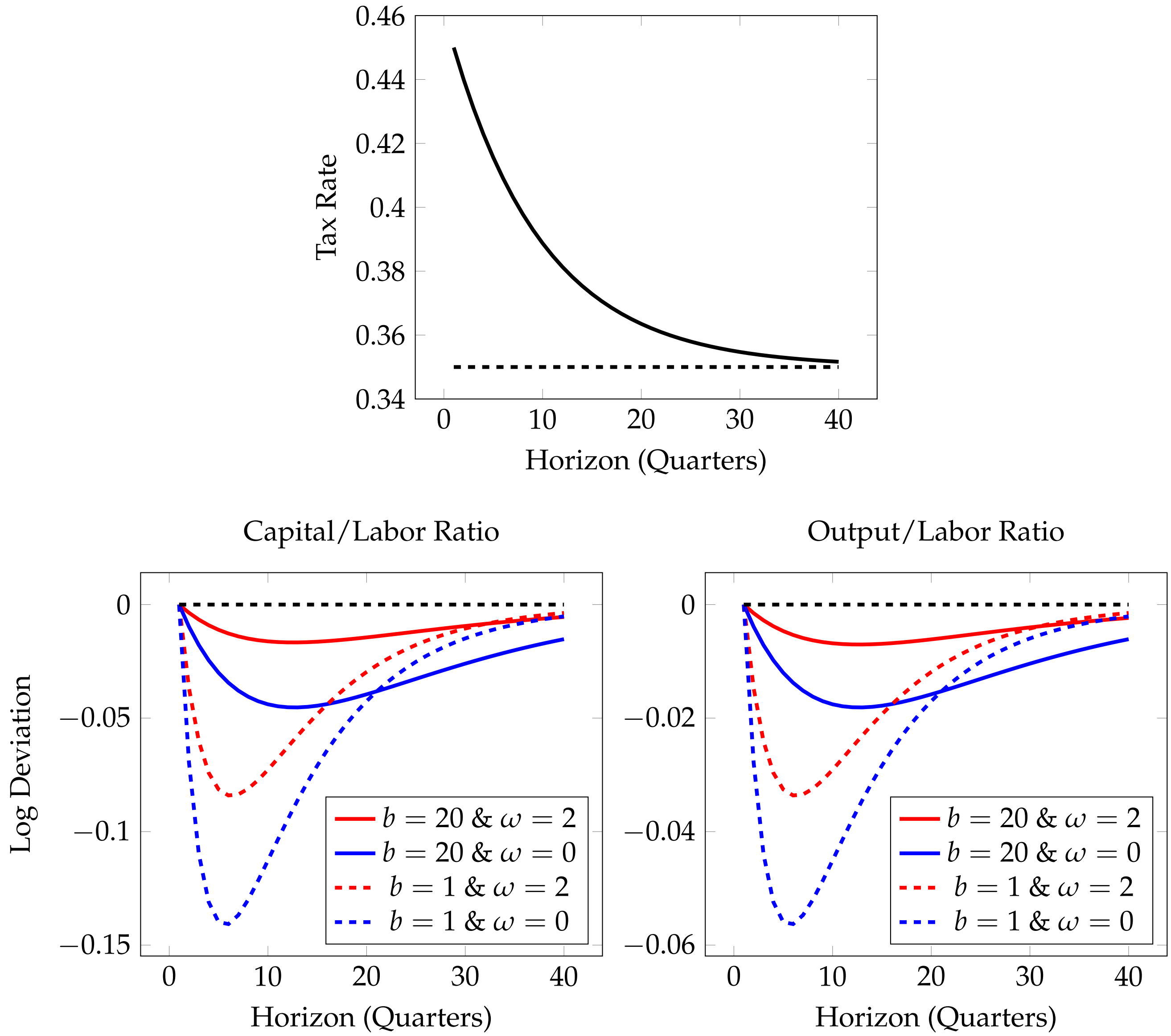

Figure 11: Impulse responses of the capital-labor ratio and output-labor ratio to a surprise decrease in the tax rate from 35% to 45%.

C Optimal Policy

This subsection discusses the model environment for the optimal tax problem. I largely follow the derivation of Chari, Nicolini, and Teles (2020) to show how maintenance alters the benchmark. Time is discrete and runs $t = 0, 1, \ldots, \infty$. There is no uncertainty.

There is a representative firm, a representative household, and a government which sets taxes to maximize household utility. For the sake of clarity, I assume the pre-tax prices of maintenance and investment are equal to one.

Representative Firm. The representative firm is largely the same as in Section 2. It chooses sequences of capital, investment, maintenance, and labor to maximize the present value of dividends $\sum_{t=0}^{\infty} q_t d_t$, where d_t is exactly as in (6). There are three differences. The first, which is inconsequential, is how the firm discounts the future. Letting q_t represent the price of one unit of the period-t good in terms of a good in period zero, the interest rate between periods is given by

$$\frac{q_t}{q_{t+1}} \equiv 1 + r_t, \quad q_0 = 1.$$

Second, I assume that the production function is constant returns to scale. Third, I assume there are no adjustment costs because the ultimate focus is on the steady state. Optimality conditions are the same as in Section 2. Combining these conditions implies that the present discounted value of dividends is given by

$$\sum_{t=0}^{\infty} q_t d_t = \sum_{i=1}^{N} K_{i,0} \Big[\left(1 - \tau_0^c\right) \left(F_{K_{i,0}} - m_{i,0}\right) + \left(1 - \tau_{i,0}^x\right) \left(1 - \delta_i \left(m_{i,0}\right)\right) \Big]. \tag{36}$$

Representative Household. A representative household has preferences over consumption c and labor H given by

$$\sum_{t=0}^{\infty} \beta^t u(c_t, H_t). \tag{37}$$

Because I am explicitly interested in only showing the effect of one deviation from the standard case, suppose preferences are standard in the sense of Chari, Nicolini, and Teles (2020), *i.e.*, they are homothetic and additively separable. $\beta \in (0, 1]$ is the discount factor embodying the required return on capital r^k. The household earns labor income $w_t H_t$ and dividend income from the representative firm and trades shares of the firm s_{t+1} at ex-dividend price p_t, leading to the budget constraint

$$c_t + p_t s_{t+1} + \frac{b_{t+1}}{1+r_t} = (1-\tau_t^h) w_t H_t + p_t s_t + d_t s_t + b_t, \tag{38}$$

where $s_0 = 1$ and initial bonds are b_0. Choosing sequences of consumption, labor, and shares of the firm to maximize (37) subject to (38) and a transversality condition given by $\lim_{T\to\infty} q_{t+1} b_{T+1} \geq$ yields first-order conditions given by

$$-u'(H_t) = (1-\tau_t^h) w_t u'(c_t) \tag{39}$$

$$u'(c_t) = \beta u'(c_{t+1})(1+r_t) \tag{40}$$

$$1 + r_{t+1} = \frac{p_{t+1} + d_{t+1}}{p_t}. \tag{41}$$

We can put together the household budget constraint with the net present value of the firm and the no-Ponzi condition to arrive at a lifetime budget constraint for the household. No-arbitrage clearly requires that the return on each capital type must equal the return on bonds. The transversality condition implies that the price of the stock equals the present value of future dividends, *i.e.*,

$$p_t = \sum_{s=0}^{\infty} \frac{q_{t+1+s}}{q_t} d_{t+1+s}. \tag{42}$$

We can combine the transversality condition and the flow budget constraint to obtain a lifetime budget constraint:

$$\sum_{t=0}^{\infty} q_t \left[c_t - \left(1 - \tau_t^h\right) w_t H_t \right] \leq p_0 s_0 + d_0 s_0 + b_0 \tag{43}$$

Substituting for the price of the stock and applying (36), we arrive at

$$\sum_{t=0}^{\infty} q_t \left[c_t - \left(1 - \tau_t^h\right) w_t H_t \right] \leq W_0, \tag{44}$$

where

$$W_0 \equiv b_0 + \sum_{i=1}^{N} K_{i,0} \Big[\left(1 - \tau_0^c\right) \left(F_{K_{i,0}} - m_{i,0}\right) + \left(1 - \tau_{i,0}^x\right) \left(1 - \delta_i \left(m_{i,0}\right)\right) \Big].$$

Finally, the aggregate resource constraint is

$$c_t + G_t + \sum_{i=1}^{N} \left(X_{i,t} + M_{i,t}\right) = Y_t. \tag{45}$$

I do not explicitly specify the government budget constraint because it is implied by market clearing and the household budget constraint.

Definition 1. *A competitive equilibrium for this economy is a set of allocations* $\{c_t, H_t, d_t, s_t\}$ *and* $\{K_{1,t+1}, \ldots, K_{N,t}, M_{1,t}, \ldots, M_{N,t}\}$*, prices* $\{q_t, p_t, w_t\}$ *and policies* $\{\tau_t^c, \tau_t^h, \tau_{1,t}^x, \ldots, \tau_{N,t}^x\}$ *given initial allocations* $\{K_{0,1}, \ldots, K_{1,N}, b_0, s_0\}$ *such that households maximize utility subject to their constraints, firms maximize the net present value of dividends subject to their constraints, markets clear such that the aggregate resource constraint is satisfied, and* $s_t = 1$ *for* $t = 1, \ldots, \infty$*.*

C.1 The Policy Cost of Maintenance

The first-best problem allows the government to set taxes freely on capital of all types and labor. To characterize first-best policy, I take the primal approach. That is, I substitute prices and taxes from the household's optimality conditions into the budget constraint to obtain the set of implementable allocations:

$$\sum_{t=0}^{\infty} \beta^t \left[u'(c_t)c_t + u'(H_t)H_t \right] \geq u'(c_0)W_0 \tag{46}$$

Proposition 6. *Any implementable allocation satisfies* (45) *and* (46).

I omit the proof because it follows directly from Chari, Nicolini, and Teles (2020). The Ramsey problem is to choose an allocation that maximizes household utility subject to implementability and feasibility. Let Φ be a multiplier on (46) and define the transformed utility function

$$V(c_t, H_t, \Phi) = u(c_t, H_t) + \Phi \left(u'(c_t)c_t + u'(H_t)H_t \right). \tag{47}$$

Now, with the Lagrangian

$$\begin{aligned} \mathcal{J} = \sum_{t=0}^{\infty} \beta^t \Bigg\{ & V(c_t, H_t, \Phi) \\ & + \theta_t \left[F(K_{1,t}, \dots, K_{N,t}, H_t) + \sum_{i=1}^{N} \left[(1 - \delta_i(m_{i,t}))K_{i,t} - K_{i,t+1} - M_{i,t} \right] - G_t - c_t \right] \Bigg\} \\ & - \Phi u'(c_0)W_0 \end{aligned} \tag{48}$$

and the first-order conditions to (48), we can arrive immediately at our main result for this subsection.

C.2 Proof of Proposition 5

Proposition 5. *Suppose the economy converges to a steady state. The steady state optimal tax on capital is identically zero across all capital types.*

Proof. For $t \geq 1$, the first-order conditions to (48) are:

$$V'(c_t) = \beta V'(c_{t+1}) \left(F_{K_{i,t+1}} + 1 - \delta_i(m_{i,t+1}) + \delta_i'(m_{i,t+1}) m_{i,t+1} \right) \quad \text{for } i = 1, \ldots, N \tag{49}$$

$$V'(h_t) = -V'(c_t) F_{h_t} \tag{50}$$

$$-\delta_i'(m_{i,t+1}) = 1 \quad \text{for } i = 1, \ldots, N \tag{51}$$

There are two proof options. First, the more traditional route is to focus on the Euler equations. If the economy converges to a steady state, then $V'(c_t)$ converges to a constant. This is guaranteed immediately from the assumption on preferences. Hence the planner's Euler equation for each capital type becomes

$$1 = \beta \left(F_{K_i} + 1 - \delta_i(m_i) + \delta_i'(m_i) m_i \right). \tag{52}$$

Note, moreover, that $1 + r_t$ must converge to $1/\beta$. Consequently, no arbitrage across bonds and capital requires that

$$1 = \beta \left[\frac{1 - \tau^c}{1 - \tau_i^x} F_K + 1 - \delta_i(m_i) + \delta_i'(m_i) m_i \right] \quad \text{for } i = 1, \ldots, N \tag{53}$$

Clearly, (52) and (53) together imply that $\tau_i \equiv 1 - \frac{1-\tau^c}{1-\tau_i^x} = 0$. However, a simpler route is instead to compare the decentralized first-order condition for maintenance with the planner's. The planner's first-order condition for maintenance features no distortions, from which it is immediate that there are no intertemporal distortions in steady state.

□

D Data

This section details the data construction for Section 3. I start by discussing the construction of tax policy variables because they are central to all three subsections and then sequentially discuss data for the Statistics of Income, freight railroads, and Compustat.

D.1 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 1971-2021, which spans the Asset Depreciation Range (ADR) System from 1971-1981, the Accelerated Cost Recovery System (ACRS) from 1982-1986, and the Modified Accelerated Cost Recovery System from 1987-2021. 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.

Asset-Specific Tax Rates

Define the asset-specific METR as

$$\tau_{i,t}^{a} = 1 - \frac{1 - \tau_t^c}{1 - \mathrm{ITC}_{i,t}^{a} - z_{i,t}^{a} \tau_t^c}, \tag{54}$$

where τ_t^c 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_t^c is straightforward to obtain. Second, the investment tax credit $\mathrm{ITC}_{i,t}$ is slightly more difficult. Investment tax credits vary substantially by asset type but have been irrelevant since the Tax Reform Act of 1986. I take the ITC for each asset from House and Shapiro (2008), who study the effects of bonus depreciation on investment across the same 36 assets from the BEA that I use to construct this database. They originally obtained data on the ITC from Dale Jorgenson.

$z_{i,t}$ is more difficult and requires some level of judgment. Suppose an asset has allowable depreciation $D_{i,t}^{a}$ and define $d_{i,t}^{a}$ 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.

ADR (1971-1981. The ADR period marked a simplification from the earlier Bulletin F period, where there were hundreds of asset classes. However, the ADR period was still more complex than the tax rules that would follow. Most assets were depreciated according to standards that were industry-specific, which makes it challenging to map them to modern BEA tables. However, because the BEA asset categories are relatively broad and the ADR-recommended live lengths are similar among the assets that would go in each category, I simply assign the most common median life length within each category. Because the life length determination requires some judgment, there is surely some degree of error. For equipment, I assume firms follow a double declining balance method, while structures use straightline depreciation. I use the Treasury publication "Asset Depreciation Range System" published in 1971 to assign life lengths.

ACRS (1982-1986). The ACRS simplified the ADR into eight asset classes and significantly decreased depreciation lives. I assigned each BEA asset into its a class using IRS publication 534 and used the double-declining balance method for all assets.

MACRS (1987-Present). 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

$$\tilde{z}^a_{i,t} \begin{cases} \theta + (1-\theta_t) z^a_{i,t} & \text{if eligible} \\ z^a_{i,t} & \text{if ineligible,} \end{cases} \tag{55}$$

where $\tilde{z}^a_{i,t}$ takes the place of $z^a_{i,t}$ in equation 54. 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.

Weights

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,

$$\alpha_{i,j,t} = \frac{k^a_{i,j,t}}{K^a_{j,t}},$$

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

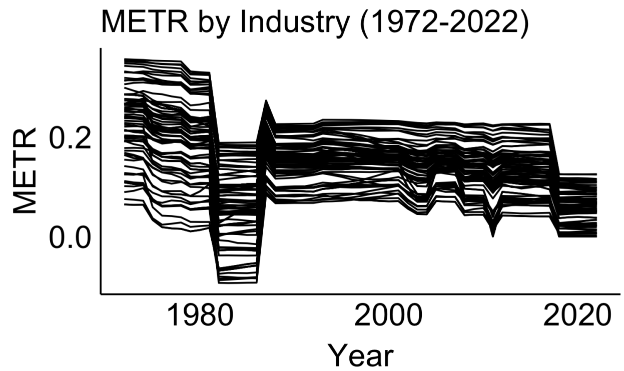

Figure 12: Marginal effective tax rates for NAICs industries from 1971-2022.

rate on industry j is

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

Using the BEA-NAICS bridge, we then have prices and tax rates for each three-digit NAICS industry. I plot the time series of tax rates for each industry in Figure 12.

D.2 SOI

Return Type	Variable	Mean	10th Percentile	Median	90th Percentile	Count
Taxable (Table 13)						
Investment Rate	-0.093	-0.585	0.054	0.485	1029	
$\log K_{j,t}$	16.936	14.954	17.085	18.676	1029	
Maintenance Rate	0.051	0.018	0.039	0.100	1029	
$\log M_{j,t}$	13.729	11.770	13.954	15.347	1029	
$1-\tau_{j,t}$	0.862	0.791	0.858	0.930	1068	
year	2008.114	2000.000	2008.000	2017.000	1029	
All Returns (Table 12)						
Investment Rate	0.038	-0.135	0.063	0.199	1068	
$\log K_{j,t}$	17.368	15.385	17.509	19.108	1068	
Maintenance Rate	0.048	0.018	0.036	0.093	1068	
$\log M_{j,t}$	14.124	12.258	14.268	15.603	1068	
$1-\tau_{j,t}$	0.862	0.791	0.858	0.930	1068	
year	2008.434	2000.000	2008.000	2017.000	1068	

Table 5: Summary statistics for SOI data. The top part of the table corresponds to Table 13 in the SOI tax stats, which contains firms with taxable income. The bottom corresponds to Table 12, which corresponds to all firms (and hence many without taxable income). I filter out industries which have a maintenance rate less than or equal to zero or greater than one. There is some attenuation after 2014 because the IRS switched to reporting more granular industries, so a small share of industries in those years do not disclose maintenance expenditures to maintain confidentiality.

D.3 Freight Rail

Data

This paper uses data from annual R-1 financial reports filed by large freight rail companies to provide evidence on the demand elasticity of maintenance from 1996-2022. R-1 reports contain 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 broken down by labor and material cost. These expenditures are largely maintenance on different aspects of railway operations from tracks to rail ties to electrical systems, and so on. For this paper, I maintain a relatively narrow focus on freight cars and locomotives because they are easiest to identify in the data, although there is probably interdependence between maintenance of one capital type and another.

We need to construct two variables: the maintenance rate and relative prices. I use the sum of Schedule 410 Lines 202-204 for locomotive maintenance and the sum of Schedule 410 Lines 221-223 for freight car maintenance. These expenditures are the only ones which clearly and directly affect only locomotives and freight cars, respectively. I use Schedules 330-335 to construct the denominator of the maintenance rate. Conveniently, the R-1 breaks down property, plant, and equipment into approximately forty different categories, which allows me to isolate which ones are locomotives and freight cars. By comparison, there is no way to distinguish equipment from structures in Compustat. I use the net stock of each capital type as the denominator for the maintenance rate.[14] I also use Schedules 330-335 to extract information on net investment rates and retirements, which are the other main variables in the analysis.

Summary statistics for railroad variables are in Table 6. One can see that maintenance is typically far more important than investment. The net investment rate is on average eight times lower than the maintenance rate for freight cars, while the maintenance rate is about 1.5 times greater for locomotives. This is quite different from the aggregate data we have from Canada, which generally show investment about twice as large as maintenance. The difference plausibly comes down to two factors. First, it is likely the aggregate Canadian data understate the magnitude of maintenance because it is plausible that inter-

14. Of course, this presents a problem because this paper's theory is that accounting with the perpetual inventory method is locally correct, but will sum up to large errors in the long run. Nevertheless, I use the net stock because there is not a better option.

nal maintenance is under-reported. Second, maintenance is almost surely more important for a stable and mature industry than it is for a growing industry. Freight rail is and has been both mature and stable for the last several decades.

Type	Variable	Mean	10th Percentile	Median	90th Percentile	Count
Freight	K	1191188.456	176224.673	1258970.039	2322413.138	175
	M/K	0.221	0.077	0.161	0.462	175
	Main.	221251.537	34224.776	183565.659	506977.748	175
	R/K	0.050	0.007	0.038	0.110	175
	X/K	0.030	-0.063	0.003	0.121	175
Locomotives	K	2079419.150	107459.717	2107594.232	4497553.363	161
	M/K	0.195	0.098	0.157	0.355	161
	Main.	315128.586	34899.122	278999.121	734459.050	161
	R/K	0.049	0.003	0.022	0.120	161
	X/K	0.120	-0.015	0.070	0.238	161

Table 6: Summary statistics for variables from R-1 statements. All variables are deflated by the investment deflator defined in the text except for maintenance, which is deflated with the maintenance deflator. K is the net capital stock, M/K is the maintenance rate, Main. is the level of maintenance, R/K is the ratio of the value of retirements to the net stock capital stock, and X/K is the ratio of net investment to the net capital stock. Data for locomotives are for 1996-2019 and for freight cars from 1996-2021. The difference is because of the availability of price indices.

The main dependent variable of interest is the after-tax relative price of maintenance to investment. There are three components to this:

1. **Price of maintenance.** I take national price indices for the cost of freight and locomotive parts together with a maintenance labor cost index from the Bureau of Labor Statistics. Schedule 410 breaks down maintenance expenditures by labor cost and materials. I use these expenditures to construct weights for labor and materials costs and construct price indices specific to each firm and capital type using those weights.

	(1)	(2)	(3)	(4)
Relative Price	−1.051	−1.005	−0.554	−0.079
	(0.311)	(0.304)	(0.229)	(0.097)
Investment Rate		0.115	0.091	0.031
		(0.023)	(0.014)	(0.039)
Age			−0.544	−0.354
			(0.130)	(0.110)
Lagged Maintenance Rate				0.583
				(0.128)
N.	336	336	336	320

Table 7: Regression results. The relative price is defined in the main text. The investment rate is the net investment rate scaled by the lagged net stock of capital. Age is the net capital stock divided by the gross capital stock. Standard errors are clustered by firm and capital type.

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

3. **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 2019.

Putting items 1-3 together, I plot the relative price of maintenance to investment for each capital type and firm in Figure 3 in the main text. A great deal of the variation between freight and locomotives is driven by differences in labor intensity.

Table 7 present the main results but with a time fixed effect.

E Evidence from Compustat

This section discusses how Compustat is utilized in the paper. Appendix E.1 discusses the regressions from Section 4.1 and Appendix E.2 discusses how indirect evidence from the relationship between gross investment rates and tax policy can help identify the maintenance elasticity.

The data from Compustat are from the period 1972-2022. The filtering steps are fairly standard. To be in the sample, firms must have

- Positive sales, capital expenditures, total assets, and depreciable property;
- A gross investment rate between zero and one;
- An industry code;
- At least two consecutive years of data.

I use the historical NAICS code variable (naicsh) for industries after 1985. Prior to 1985, I use Decelles and Schaller (2021) to map SIC to NAICS codes. If firms have a gap in the data, then I treat them as separate firms. The main variables are capital expenditures (capx), sales (sale), capital stock (ppent), and total assets (at). Firms are matched to industry tax rates described in Appendix D.1 using the BEA's industry crosswalk. Summary statistics are in Table 8.

Variable	Mean	10th Percentile	Median	90th Percentile	Count
$\log at_{j,t}$	5.521	2.175	5.459	8.900	226453
$\log X_{j,t}$	1.921	-1.778	1.907	5.690	226453
$\log K_{j,t}$	3.754	0.153	3.609	7.633	226453
$\Delta \log \text{Sale}_{j,t}$	0.062	-0.201	0.066	0.336	200524
$1 - \tau_{j,t}$	0.860	0.790	0.849	0.937	226453
$\frac{X_{j,t}}{K_{j,t-1}}$	0.246	0.047	0.185	0.545	226453
year	1999.772	1981.000	2000.000	2017.000	226453

Table 8: Summary statistics for Compustat variables.

E.1 Regressions from Section 4.1

Table 9 presents regression results for (28) spanning the years 1973-2022 along with standard errors clustered by firm. I find a large and negative effect on investment. To my knowledge, this is the longest estimate of the effect of tax policy on investment using Compustat. Zwick and Mahon (2017) and Koby and Wolf (2020) do a comparable exercise from 1993 onward. The identication strategy is similar to Cummins, Hassett, and Hubbard (1994) and uses cross-sectional differences in exposure to tax policy.

	(1)	(2)	(3)	(4)
$\frac{1}{1-\tau_{j,t}}$	-1.796	-0.872	-0.700	-0.699
	(0.273)	(0.158)	(0.125)	(0.121)
$\log \text{Assets}_{j,t}$		0.997	0.717	0.685
		(0.007)	(0.007)	(0.007)
$\log X_{j,t-1}$			0.310	0.325
			(0.005)	(0.005)
$\Delta \log \text{Sale}_{j,t}$				0.233
				(0.009)
N	226453	226453	200524	200524

Table 9: Regression results for (28). The dependent variable is log capital expenditures from 1973-2022. Standard errors are clustered by firm.

E.2 Indirect Evidence of the Maintenance Elasticity

As a final step, we can generate indirect evidence on the maintenance elasticity using the model in Section 2. Proposition 1 yields the result that the elasticity of substitution between the maintenance rate and the investment rate is $\frac{\omega}{1+\omega}$. Suppose firms differ in their capital compositions so that γ_j varies between firms and the firm-specific marginal effective tax rate differs for the same reason.. In steady state, each firm j's gross investment rate is

$$\frac{X_j}{K_j} = \gamma_j \left(\frac{1-\tau_j}{\gamma_j \omega} \right)^{\frac{\omega}{1+\omega}}.$$

Taking logs,

$$\log x_j = C_j + \frac{\omega}{1+\omega} \log(1-\tau_j) \tag{56}$$

where C_j is a constant. A regression of the log gross investment rate on the tax term is therefore informative about the maintenance elasticity. On the other hand, this requires similarly restrictive assumption as in Koby and Wolf (2020), which maps the partial equilibrium price elasticity of investment to a general equilibrium model. In particular, firms must face no financial frictions and the cross-section of firms must be roughly in steady state. Given that I will study (56) with Compustat data, the first assumption is plausible. The second assumption is implausible without controlling for sources of growth for the firm. On the other hand, even if neither of those assumptions hold in practice, what we find in the data would be biased downward. Finally, we must assume that the maintenance elasticity does not vary by firm.

I estimate the panel regression

$$\log x_{j,t} = \alpha_j + T_t + \beta \log(1-\tau_{j,t}) + \text{controls} + \varepsilon_{j,t}$$

where α_j is a firm fixed effect, T_t is a time fixed effect, and $\beta \equiv \frac{\omega}{1+\omega}$ maps into the maintenance elasticity. Using annual data from Compustat from 1973-2022, I construct the gross investment rates using the ratio of capital expenditures (CapX) to the net stock of property, plant, and equipment (PPENT). This paper's theory suggests that the denominator is mismeasured, but the degree of bias is small in a static regression. Following Cummins, Hassett, and Hubbard (1994) and Zwick and Mahon (2017), I construct industry-specific tax rates by matching BEA industry fixed asset data to the corresponding assets within the tax code. Differences between firms in exposure to tax policy give the necessary variation to identify the coefficient on tax policy. I then match these tax rates to firms based on their historical industry codes.

Results for the regression are in Table 10 with standard errors clustered by firm. The first column contains no controls, while columns 2-4 contain controls for size using the firm's total assets, sales growth, and the lagged investment rate. In principle, these controls help mitigate concerns about the steady state assumption. Across all specifications, the coefficient on tax policy is large and positive. In the fifth row, I show the point estimate for $\hat{\omega} = \hat{\beta}/(1 - \hat{\beta})$ with associated standard errors computed with the delta method. Column 1 indicates a maintenance elasticity close to six after inversion, while Column 4, which is probably the most trustworthy regression, indicates a value around 1.5. However, only the third and fourth columns have statistically significantly positive maintenance elasticities at the ten percent level. Naturally, that is because dividing a normally distributed variable by a normally distributed variable—which is what I do to estimate $\hat{\omega}$—results in the Cauchy distribution, which has poor statistical properties for the second moment.

	(1)	(2)	(3)	(4)
$\log(1-\tau_{j,t})$	0.852	0.629	0.553	0.609
	(0.179)	(0.182)	(0.147)	(0.141)
$\log\ \text{Assets}_{j,t}$		0.200	0.124	0.096
		(0.007)	(0.006)	(0.006)
$\log(x_{j,t-1})$			0.288	0.286
			(0.005)	(0.005)
$\Delta\log\ \text{Sales}_{j,t}$				0.364
				(0.011)
$\hat{\omega}$	5.749	1.694	1.237	1.555
	(8.145)	(1.324)	(0.733)	(0.923)
N	226453	226453	200524	200524

Table 10: Regression results for indirect estimation using Compustat data from 1973-2022. Standard errors clustered by firm. The second row from the bottom estimates $\hat{\omega} = \hat{\beta}/(1-\hat{\beta})$ and computes standard errors using the delta method.