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Can Corporate Income Tax Cuts Stimulate Innovation?

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Abstract

We hypothesize that corporate income taxes distort firms' incentives to innovate by reducing their pledgeable income. Using a differences-in-differences methodology, we document that large corporate income tax cuts boost corporate innovation. We find a similar but opposite effect for tax increases. Most of the change in innovation occurs 2 or more years after the tax change, and there's no effect before the tax change. Exploring the mechanisms, we show that tax cuts have a stronger impact on innovation for firms with weaker governance, greater financial constraints, fewer tangible assets, smaller patent stock, and a greater degree of tax avoidance.

I. Introduction

There has been a growing debate among politicians and policy makers, both at the state and federal levels, about the impact of taxes on investment, growth, and firm value. The focus has predominantly been on corporate income tax cuts because, as the Congressional Budget Office (2017) reports, the United States has the highest top statutory corporate income tax rate among the Group of 20 (G20) nations. Without a systematic examination, however, especially one that focuses

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on the long term, it is difficult to evaluate the importance of corporate income taxes.

In this article, we examine the impact of corporate income tax cuts on corporate innovation. Hall, Jaffe, and Trajtenberg (2005) and Kogan, Papanikolaou, Seru, and Stoffman (2017) demonstrate that innovation significantly increases firm value and growth.[1] More broadly, the seminal work by Solow (1957) and Romer (1990) shows that innovation is the most important driver of long-term economic growth. Recent research in economics and finance has studied the impact of corporate income taxes on firm investment and business activity (Cummins, Hassett, and Hubbard (1996), Giroud and Rauh (2019)). Less is known, however, about how tax cuts can affect long-term firm output and performance. By looking at innovation, we fill the gap in the literature by tracing a possible channel through which corporate income taxes can influence firm value and long-term growth. We theoretically argue and empirically document that corporate income tax cuts significantly affect innovation by changing firms' pledgeable income and improving their incentives to innovate. We also provide motivation and evidence for several unexplored mechanisms through which that relationship occurs.

To overcome identification challenges, we use staggered changes in state corporate income tax rates that are largely exogenous to the decision of the individual firm to innovate. We eliminate the impact of time-varying economy-wide shocks (e.g., changes in monetary policy and federal regulation) by comparing the change in innovation in a treatment group of firms that experienced a tax change to a control group of firms that did not experience a change over the same time period. We also eliminate omitted-variable biases that could result from cross-country studies due to large differences in unobservable country-specific characteristics. State tax changes are staggered over time, which can put the same firm in both the treatment and control groups over our time period, allowing us to control for unobservable firm characteristics.

There are two opposing theoretical views about the relationship between corporate income tax cuts and innovation. The first view contends that corporate income taxes distort the incentives of firms to innovate. In Appendix A, we develop a simple model that analyzes the impact of corporate income taxes on firm behavior in the presence of agency problems. We use Tirole's (2006) notion of pledgeable income to demonstrate that in the presence of private benefits of control and differential effort, higher taxes make it more lucrative for managers and other employees to shirk by enjoying the quiet life or undertaking routine projects rather than working hard and innovating. Consequently, projects that would not be undertaken when taxes are high will become profitable and will be undertaken if taxes are reduced because they become incentive compatible. The results from the model also imply that increases in after-tax profits do not have to finance the entire innovative project to motivate the firm to undertake it. Even small changes in tax rates can lead to large changes in innovation if, on the margin, they provide

[1]Kogan et al. (2017) document that a 1-standard-deviation increase in an aggregate innovation index is associated with a 1.6%–6.5% increase in economic output and a 0.6%–3.5% increase in total factor productivity over a horizon of 5 years. They also find that firms with a 1-standard-deviation increase in their innovation output experience higher growth of 2.5%–4.6% over a period of 5 years.

enough incentives for managers to exert time and effort and switch from undertaking routine projects to innovative projects.

We show that pledgeable income depends on firms' after-tax profits as well as on the size of the private benefits of control and the assets at hand, such as internal funds, physical assets, patent stock, and other tangible and intangible assets that can be used in the innovative project. We then derive several predictions from the model that allow us to trace some of the mechanisms through which corporate income tax cuts affect innovation. We demonstrate that the impact of tax cuts is greater for firms with weaker governance, for financially constrained firms, and for firms with fewer tangible assets and a smaller patent stock.

In addition to increasing pledgeable income, there are at least two other reasons why corporate income tax cuts might stimulate innovation. First, innovative firms often save their after-tax profits and use the internal cash as a cushion during difficult times. Internal cash, combined with imperfect external capital markets, allows greater flexibility and tolerance of experimentation, which, according to Manso (2011), is key to motivating innovation. Because innovation is a highly uncertain process, firms with more cash savings will be better suited to weather unfavorable outcomes and continue to innovate. Second, innovative firms often prefer to use after-tax internal funds for innovative projects (Brown, Fazzari, and Petersen (2009)) rather than tap external markets. In addition, Brown, Martinsson, and Petersen (2012) document that financial constraints are an important deterrent to research and development (R&D). Therefore, we hypothesize that ceteris paribus, tax cuts will relieve financial constraints, increase firms' internal funds, and lead to higher innovation.

The alternative view argues that corporate income tax cuts either do not matter or have a negative impact on innovation, for the following reasons: First, any possible tax decrease may result in an increase in the state budget deficit or in a decrease in state government spending on public goods, such as research, education, and infrastructure. As a result, there would be fewer positive spillover effects on firms, which will in turn inhibit their innovative output. This is the criticism that has been levied on the 2012 Kansas tax cuts and on the 2017 tax cuts enacted at the federal level by the Trump administration. Second, changes in state taxes, even large ones, could have only a small effect on firms and not significantly change their innovation policies. Finally, assuming all R&D expenditures are tax deductible, perfect capital markets, and no private benefits of control or asymmetric information, tax rates would not matter, and any project with a positive net present value (NPV) will be financed no matter how high tax rates are. If a project is profitable (has a positive NPV) on a pretax basis, it will be profitable on an after-tax basis because both revenues and expenses are multiplied by the tax rate. The tax rate will only determine how the economic pie is divided; it will not affect its size.

The two views just presented generate opposing testable predictions. To ensure consistency and relevance, we examine the impact of tax cuts on innovation using significant decreases of at least 100 basis points (bps) (e.g., from 7% to 6%) in the top-bracket state corporate income tax rate from 1988 to 2006. We use statutory rather than effective tax rates because the former is outside of the control of the individual firm, whereas the latter is endogenous.[2] Although prior studies typically use company headquarters to define states, in many cases a firm's corporate office is not where its major operations are located. To better identify the most relevant state to which the tax rate is applied, we use the most mentioned state in a firm's 10-K reports based on data from Garcia and Norli (2012). We follow the existing literature (e.g., Hall, Jaffe, and Trajtenberg (2001)) and use patents and citations per patent to measure the quantity and quality of innovation.

We find that tax cuts significantly increase the number of patents and citations per patent. The effect on citations per patent is stronger, suggesting that the quality of innovation is affected even more by changes in taxes. Firms operating in a state that implements a tax cut create 0.63 and 0.79 more patents 3 and 4 years later, respectively, relative to otherwise similar firms that do not have a tax cut. These are increases of approximately 1.2% and 1.4% of 1 standard deviation. In terms of innovation quality, firms receive 0.75 more citations per patent 3 and 4 years after a major tax decrease, which are increases of approximately 5.4% of 1 standard deviation. We also find that tax increases have a negative and significant effect on innovation, although the economic magnitude is smaller. The symmetric effect that we document is consistent with our main hypothesis and with Giroud and Rauh (2019), who find that both large state tax increases and decreases have a significant effect on the number of establishments and employees.

This finding is novel and substantially different from a recent article by Mukherjee, Singh, and Zaldokas (2017) that also studies the impact of corporate income taxes on innovation but fails to find an effect for tax cuts. Tax cuts are the main focus of our article and a topic of contentious contemporary policy debate. In contrast to our article, Mukherjee et al. (2017) suggest that government policies to cut corporate income taxes at the state level and, if we extrapolate, at the federal level will not matter. In addition, unlike Mukherjee et al. (2017), we also examine several previously unexplored mechanisms to better understand why tax cuts are an important driver of corporate innovation. Finally, as we explain in our discussion section, their methodology and variable definition of tax decreases do not allow for a proper evaluation of the long-term effects of tax cuts.

Having illuminated our understanding of whether tax cuts affect innovation, our next step is to explore the specific channels through which this relationship may occur. Understanding the mechanisms is important for two reasons. First, it improves our understanding of how taxes work and provides better insight for future research and policy making. Second, it also reduces the concern that the relation between taxes and innovation is spurious and driven by other changes that may have occurred at the same time. Such a criticism will have the burden of explaining not only the main relation but also all the channels that we document. After exploring the channels in separate regressions and also together in the same regression, we find that corporate governance, financial constraints, collateral, and tax-avoidance channels capture distinct aspects of the relation between corporate income taxes and innovation.

[2]As we show in Section V.C, the statutory rates are strongly positively related to the actual state income taxes firms pay.

We first test the argument that tax cuts increase firms' pledgeable income by reducing the incentives of managers to shirk or engage in routine projects. If that is the case, firms with weaker governance (where the incentives to shirk are greater) will benefit more from tax cuts. To test this hypothesis derived from our model, we use the hostile takeover index developed by Cain, McKeon, and Solomon (2017). Consistent with our hypothesis, we find that the effect of tax cuts on innovation is significantly larger for firms with weaker corporate governance.

Next, we argue that tax cuts increase firms' pledgeable income by increasing the availability of financial resources and relieving financial constraints. To test this hypothesis, we use several measures of financial constraints based on Whited and Wu (2006), Kaplan and Zingales (1997), and Hadlock and Pierce (2010). We find that the positive impact of tax decreases on the number of citations per patent is greater for financially constrained firms. We also find that smaller firms and firms with smaller free-cash cushions are affected more by tax changes.

Consistent with the assets-at-hand hypothesis, we also provide evidence that firms with fewer tangible assets are affected more by tax cuts. Tangible assets are easier to liquidate, and therefore firms with fewer tangible assets have lower pledgeable income. We also argue that although firms mainly use tangible assets as collateral, intangible assets such as the current patent stock can also be used as collateral by innovative firms (Hochberg, Serrano, and Ziedonis (2015)). Motivated by this idea, we further examine a firm's existing patent stock and find evidence that firms with a lower patent stock benefit more from tax cuts.

Taxes may also affect innovation by distorting firm behavior and resource allocation and encouraging firms to engage in tax-shifting activities. There are two opposing predictions. On the one hand, firms that avoid taxes would be less affected by tax cuts because they have already shifted their tax burden. On the other hand, both tax avoidance and innovation require scarce resources, such as managerial and employee creativity and effort.[3] When the return on tax avoidance increases relative to the return on innovation, firms will shift more resources to tax avoidance. We examine the tax-avoidance hypothesis using an indicator of tax avoidance based on industry- and size-adjusted cash effective tax rates (Dyreng, Hanlon, and Maydew (2008)). The results support the second prediction. We find that the impact of tax cuts on the number of citations per patent is greater for firms that engage more in tax avoidance. This finding is again consistent with our general hypothesis that tax cuts improve the allocation of resources and firms' incentives to innovate.

We further investigate whether state corporate income taxes affect the observable inputs to innovation. We find a significant positive impact of tax decreases on R&D expenditures starting 1 year after the tax change. Similarly, there is a significant negative impact of tax increases on R&D expenditures, indicating a symmetric effect. We also find significant effects for executive incentive compensation, after-tax cash flow, and external finance, suggesting that major corporate income tax cuts have a significant impact on the inputs to innovation that are subsequently used to generate higher innovative output.

[3]For example, top managers of Apple and Google have spent numerous hours responding to legislators about their tax practices instead of focusing on innovative strategies.

By employing tax changes that are largely outside of the control of the individual firm and a differences-in-differences (DID) methodology, we address many of the potential endogeneity concerns in our main analysis. We also control for numerous observable time-variant factors, time fixed effects, and unobservable time-invariant characteristics, such as corporate culture and risk aversion, by using firm fixed effects. Moreover, we pursue several strategies that further mitigate residual biases that could stem from reverse causality or omitted variables. First, we conduct a dynamic analysis and demonstrate that most of the impact of tax cuts on innovation occurs 2 or more years after the tax cuts are implemented. Second, we restrict tax cuts to those that are unanticipated and also use a narrative approach to identify exogenous tax cuts that are passed independently of local economic conditions. Third, we control for additional fixed effects and state-level variables such as other tax-related policies. Fourth, we conduct a falsification test and find that tax cuts have the opposite effect on firms in neighboring states. Together, this evidence further reduces the possibility that our results are driven by omitted variables or alternative policy changes.

The article contributes to several strands of literature. First, we build on and complement the previous literature that examines the relation between taxes and firm investment and financing decisions (Cummins et al. (1996), Hassett and Hubbard (2002), Djankov, Ganser, McLiesh, Ramalho, and Shleifer (2010), Heider and Ljungqvist (2015), and Giroud and Rauh (2019)). Different from the extant research, we show that private benefits of control and differential effort are essential for understanding the impact of taxes on the incentives to innovate. We focus on innovative output rather than input and, unlike Mukherjee et al. (2017), demonstrate that both corporate income tax decreases and increases have a significant impact on the quantity and quality of innovation. We also propose and document several mechanisms through which taxes affect innovation. In addition, to the best of our knowledge, this is the first tax article to use a novel measure, different from firm headquarters, to better identify the relevant state for corporate income tax purposes.

Second, we contribute to the literature on financial constraints and R&D. A number of studies (e.g., Himmelberg and Petersen (1994), Bhagat and Welch (1995), and Hall and Lerner (2010)) find mixed evidence on how financing frictions affect R&D in the United States and other countries. Using changes in state corporate income taxes as an exogenous shock to financial constraints and examining innovation outputs, we lend additional support to studies (e.g., Hall (1992), Brown et al. (2009), (2012)) showing that financial constraints reduce R&D and innovation. More broadly, we also contribute to the literature examining the impact of financial constraints on firm behavior, which is a central question in both corporate finance (e.g., Kaplan and Zingales (1997)) and asset pricing (e.g., Whited and Wu (2006)).

Finally, current academic research has extensively debated the role of taxes in promoting economic growth (e.g., Romer and Romer (2010), Barro and Redlick (2011), and Ramey (2011)). However, the existing evidence is conflicting, and several unresolved issues still remain. First, most of the prior research has looked at short-term economic growth. Less is known about how taxes affect long-term economic growth. Second, there is little evidence on the specific channels through which taxes affect growth. Third, it is often difficult to control for simultaneity and omitted-variable biases in a macroeconomic setting. We contribute to this important debate by focusing on corporate innovation as a source of long-term economic growth and use staggered changes in state corporate income tax rates for identification. In doing so, we provide indirect evidence of a possible channel through which corporate income taxes can affect economic growth.

The rest of the article is organized as follows: Section II describes the data and the empirical methodology. Section III presents the main empirical results. Section IV investigates the channels through which taxes affect innovation. Section V provides additional endogeneity and robustness tests. Section VI compares our methodology and results to related research. Section VII concludes. In Appendix A, we present a simple theoretical model that formalizes some of the intuitive arguments presented in the Introduction that motivate the relationship between corporate income taxes and innovation.

II. Data and Variable Construction

We acquire state corporate income tax information from the University of Michigan's World Tax Database, *The Book of the States*, and the Tax Foundation. Garcia and Norli (2012) provide the number of times a state is mentioned in a firm's 10-K reports, which we use to determine the most relevant state to which the tax rate is applied. The historical states of incorporation and location come from the Compact Disclosure database and the parsed 10-K data from Bill McDonald's Web site (https://sraf.nd.edu).

The sample is constructed by selecting all U.S. publicly traded firms from the National Bureau of Economic Research (NBER) patent file[4] that have financial data available in the Standard & Poor's (S&P) Compustat database. We also include all firms from Compustat that operate in the same 4-digit Standard Industrial Classification (SIC) industries as the firms in the patent database but do not have patents. Including these firms alleviates sample-selection concerns because the sampling procedure is independent of whether the firm has patents or not. A drawback of this approach may be that for some firms or industries, patenting might not be an accurate measure of innovation, or some industries might not be innovative at all. To address these concerns, we also conduct our analysis only on innovative companies or industries and find similar and generally stronger results.

We start our sample in 1988 due to the availability of Compact Disclosure, which is used to construct an alternative measure of the most relevant state. Only firms that are incorporated and headquartered in the United States are included. Firms in the financial (SIC = 6), utilities (SIC = 49), and public (SIC = 9) sectors are excluded. The final sample includes 87,564 firm-years based on 8,013 firms over the period of 1988–2006.

[4]For a detailed description of the patent data set, see Hall et al. (2001).

A. Main Explanatory Variables: Major Decreases and Increases in State Corporate Income Tax Rates

To examine the impact of corporate income taxes on innovation, we need to properly define the tax signals that would most likely affect firm incentives. There are two issues to consider here. First, innovation is a long-term activity that requires a significant amount of both tangible and intangible firm resources. Thus, it is unlikely that firms will react to small tax changes, especially those that are expected to be reversed. Firms are more likely to respond to large tax changes that may signal a change in tax policy that lasts for an extended period of time. Second, as Griliches (1990) argues, the innovation lag is poorly defined because it may take years from the change in incentives to the creation of patents. Therefore, looking at numerous small tax changes that could be reversed within 1 or 2 years will introduce noise into our estimates. Our measure of tax changes largely avoid these two problems.

Specifically, in order to identify more permanent tax signals that are likely to have a long-lasting impact on corporate innovation, we focus on major state corporate income tax changes that are not reversed in 3 years. The key explanatory variable in our analysis is an indicator, TAXDECR_{st}, which takes a value of 1 if at time t in state s there has been a major decrease in the state corporate income tax rate, and 0 otherwise.[5] A major change in tax rates is defined as a change of greater than or equal to 100 bps (e.g., from 7% to 6%) that is enacted in 1 or 2 consecutive years, as long as that change is not reverted within the next 3 years. A major tax decrease is reverted if the tax rate is raised to a level at or above the level prior to the tax decrease, and a major tax increase is reverted if the tax rate is lowered to a level at or below the level prior to the tax increase. If a tax change is reverted within the next 3 years, it is not considered a change, and the tax variable retains a value of 0. If the change is reverted more than 3 years later, the tax variable takes a value of 1 in the year of the change and any year after when the change is present, and it switches back to 0 if the change is reverted.[6]

In addition, we create another variable, TAXINCR_{st}, that is equal to 1 if at time t in state s there has been a major (as previously defined) increase in the state corporate income tax rate, and 0 otherwise. We conduct analysis with that variable and find results consistent with our hypothesis and with previous findings in the literature, but we focus our investigation predominantly on tax cuts. We also create a combined categorical tax variable, TAXCHG_{st}, which equals 1 if at time t in state s there has been a major increase in state corporate income tax rates, -1 if at time t in state s there has been a major decrease in state corporate income tax rates, and 0 otherwise. In our sample, the average major tax decrease is 150 bps, and the average major tax increase is also 150 bps, which is 22% of the average top marginal state tax rate of 6.9%. In other words, a major tax decrease or increase represents a 22% change in the tax rate on average.

[5]We choose to use indicator variables to implement a DID methodology and for the dynamic analysis described next. For robustness, we use the actual change in the tax rate (i.e., from 1% to 3.75%) or the percentage change in the tax rate instead of a dummy and find similar results.

[6]For example, New Hampshire experienced a major tax decrease in 1994, and the tax rate returned to the level prior to the change in 1999. In this case, the tax decrease indicator equals 1 for the years 1994–1998, and 0 for all other years.

To identify the major tax changes, we use state tax rate data from the University of Michigan's World Tax Database, *The Book of the States*, and the Tax Foundation. The World Tax Database provides state corporate tax rates from 1941 to 2002, and the Tax Foundation provides state corporate tax rates from 2000 to 2013. We check these data with the state corporate income tax rates reported in *The Book of the States* to ensure consistency and accuracy. For states with multiple tax brackets, we focus on changes in the top tax bracket while accounting for tax surcharges. The major tax increases and decreases are identified in Table 1. From 1988 to 2006, 10 states experienced a major tax increase, and 8 states experienced a major tax decrease.[7]

We also verify our major tax changes with the lists of tax changes from Heider and Ljungqvist (2015) and Giroud and Rauh (2019).[8] There are a few small differences between the 3 sets of tax changes, which we verify using other data sources, and we perform robustness checks to make sure the differences do not affect our results. In Heider and Ljungqvist's (2015) article, there are 90 tax changes during our sample period. Of the 90 tax changes, 33 are changes of 25 bps or smaller, 12 are changes of greater than 25 bps and less than 50 bps, and 21 are reversals within 3 years. Although 27 of the 90 tax changes are changes that are greater than or equal to 100 bps that are enacted in 1 or 2 consecutive years, 6 are reverted within 3 years, and 3 additional ones are already included in the

TABLE 1
Significant Changes in State Corporate Income Tax Rates

Table 1 reports major state corporate income tax increases and decreases from 1988 to 2006. The identification procedure is described in greater detail in Section II.A.

State	Year of Tax Decrease	Year of Tax Increase
Alabama		2001
Arizona	1999	
Connecticut	1999	
Kentucky	2005	
Missouri		1990
Nebraska		1991
New Hampshire	1994	1999
New York	2000	1990
North Carolina		1991
North Dakota	2005	
Oklahoma		1990
Pennsylvania	1995	1991
Rhode Island		1989
South Carolina	1989	
Vermont		1997

[7]Of the 15 distinct states that experienced major tax changes, only 2 states (Arizona and Connecticut) have multiple major tax changes in the same direction. Arizona has major tax decreases in 1990, 1999, and 2001. Because we cannot use all 3 years to create the tax-decrease variable, we choose the year 1999 because there are only 63 firm-year observations prior to 1990, and 2001 is already included in the treatment period, where the tax-decrease indicator equals 1. For robustness, we also use 1990 and 2001 to create the tax-decrease variable and find similar results. Connecticut has tax decreases in 1999 and 2000. We use the year 1999 to create the tax-decrease variable because 2000 is already included in the treatment period, where the tax decrease indicator equals 1. As another robustness check, we also use a count variable to accommodate multiple tax changes in the same direction and find similar results.

[8]We thank the authors for sharing their data.

treatment period of an earlier tax change in the same direction.[9] Giroud and Rauh (2019) also use a list of 56 state corporate income tax changes of greater than or equal to 100 bps from 1978 to 2011 for their DID analysis, which is similar to the specification that we use. When restricted to our sample period, they have 21 large tax changes, where 2 are reversals within 1 year, and 3 are already included in the treatment period of an earlier tax change in the same direction. Therefore, our list of large tax changes is very similar to the ones based on Heider and Ljungqvist (2015) and Giroud and Rauh (2019) after removing reversals within 3 years and tax changes that are already included in the treatment period of an earlier tax change in the same direction.

B. Determining the Most Relevant State for Corporate Income Tax Purposes

There are several challenges associated with determining the most relevant state for tax purposes. In practice, state tax is assessed based on 3 main firm characteristics: percentage of sales, percentage of employees, and percentage of physical assets in a given state. Different states assign different weights to these 3 characteristics and use different apportionment formulas. Unfortunately, specific information on these 3 components is not publicly available. Therefore, we approximate the most relevant state to which the tax rate is applied by deducing where the firm conducts most of its business.

To this end, we follow Garcia and Norli (2012), who compute the number of times a 10-K report mentions a U.S. state name for all 10-K filings from the U.S. Securities and Exchange Commission (SEC) online database from 1994 to 2008. These annual reports contain detailed information regarding the firm's operations and financial performance during the year. More importantly, these reports can also contain information on the location of the firm's sales, property, and employees in different geographic areas. For example, firms may list factories by state under the Properties section or report sales in stores by state under the Business section. To capture these locations, Garcia and Norli (2012) count the occurrence of state names in 4 sections: "Item 1: Business," "Item 2: Properties," "Item 6: Consolidated Financial Data," and "Item 7: Management's Discussion and Analysis." The approach taken by much of the previous literature is to use the state of company headquarters based on the assumption that most of the business operations of that company are generated in the headquarters state. Although this assumption is often reasonable, in many cases, it is not correct. For example, Boeing is currently headquartered in Illinois, whereas its main factory is located in Washington. According to its Web site, as of May 29, 2014, 81,305 of its 168,693 employees were located in Washington, compared with approximately 600 employees in Illinois. Because a firm's corporate office may not be where its major operations are located, we do not use the state of headquarters as the most relevant state for tax purposes in the main analysis.

The state count data consist of 84,117 firm-year observations for 11,811 publicly traded firms from 1994 to 2008. For each firm-year observation, each state's

[9]For example, Missouri had a significant tax decrease in 1992 that was reversed in 1993, so these 2 years are not included in the list of major changes.

share of the total number of state counts is reported. California, Texas, New York, Florida, and Illinois are among the most mentioned states, whereas Rhode Island, South Dakota, and North Dakota are among the least mentioned states. To the extent that the state mentions in 10-K filings are related to the location of the firm's sales, properties, and employees, more frequently mentioned states tend to be more important for tax purposes than less frequently mentioned states. Consistent with this idea, we show in Section V.C that the amount of state taxes paid is significantly related to tax changes in the most mentioned state but is not related to tax changes in the least mentioned state.

To construct the relevant state for firms in our sample, we first find the most mentioned state for each firm-year observation, then use the most frequently occurring most mentioned state across all years for a given firm as the most relevant state for that firm. In our main analysis, we use a single time-invariant state that is mentioned the most for each firm during the sample period to match a firm's long-run planning horizon and also to alleviate problems with endogenous firm reallocations across states. For robustness tests, we also use the time-varying most mentioned state, the top 3 most mentioned states, and other variations, and we obtain similar findings. For reference, for 36% of the firms in the sample, the most mentioned state is different from the state of the headquarters. Finally, in Section V.C, we perform a series of robustness checks to ensure that our results are not driven by the definition of the relevant state. For instance, instead of the most mentioned state, we also use alternative definitions of the most relevant state based on the headquarters, the locations of the patent grants, and subsidiary locations and find similar results.

C. Construction of the Dependent Variables

The main dependent variables are 2 metrics for innovative output: the number of patents to measure the quantity of innovation and the number of citations per patent to measure the quality of innovation.[10] The first metric, PATENT, is a patent count for each firm in each year. The relevant year is the application year, which occurs closer to the actual innovation and far before the innovation is incorporated into a finished product ready for the market (Griliches, Pakes, and Hall (1987), Hall et al. (2001)).

The second metric, CIT/PAT, assesses the significance or quality of innovative output. Pakes and Shankerman (1984) and Griliches et al. (1987) show that the distribution of the value of patents is extremely skewed, and most of the value is concentrated in a small number of highly cited patents. Hall et al. (2005) and Atanassov (2013), among others, demonstrate that patent citations are a good measure of the value of innovations. Intuitively, the rationale behind using patent citations to identify important innovations is that if firms are willing to further invest in a project that is building on a previous patent, they have to cite that patent. This, in turn, implies that the cited patent is technologically influential and economically important.

Patent citations, however, suffer from a truncation bias because they are received for many years after the patent is applied for and granted. For example, a

[10] All variables are defined in greater detail in Appendix B.

patent that was created in 1988 will have much more time to receive citations than a patent created in 1995 because the sample of patent citations ends in 2006. Thus, for the main analysis, we correct for truncation bias using the quasi-structural method suggested by Hall et al. (2001), which multiplies each patent citation by an index created by econometrically estimating the distribution of the citation lag (the time from the application of the patent until a citation is received). For robustness, we also correct for the truncation bias by using an alternative fixed-effects method and find similar results, as shown in the Supplementary Material.

D. Control Variables

Control variables include ln(SALES), RD/SALES (R&D expenditures/sales), LEVERAGE (total debt/total assets), PROFITABILITY (earnings before interest, depreciation, taxes, and amortization (EBIDTA)/total assets), TANGIBILITY (net property, plant, and equipment (PPENT)/total assets), $\ln(K/L)$ (natural logarithm of PPENT/no. of employees), RATING (an indicator that equals 1 if firm-year has a debt rating from S&P), ln(AGE), HERFINDAHL, HERFINDAHL^2, ln(REALGSP) (natural logarithm of real gross state product (GSP) per capita), UNEMPRATE (state-level unemployment rate), GSPGROW (rate of change in state GSP), GSPGROWLAG (GSP growth rate from the previous year), TAXES/GSP (total state tax revenue/GSP), and ln(POP) (natural logarithm of state population). Firm-level variables come from Compustat. State-level variables come from the Bureau of Economic Analysis, the Cleveland Federal Reserve, and the U.S. Census.

In the empirical specification where innovation is the dependent variable, we follow Hall and Ziedonis (2001), among others, and include firm size, ln(SALES), as a control variable. We also control for R&D expenditures by scaling the raw amount by net sales, rather than total assets, because both variables are flow variables from the income statement. Our results are robust to scaling R&D expenditures by total assets. Following Aghion, Bloom, Blundell, Griffith, and Howitt (2005), we control for industry competition using the Herfindahl index constructed at the 4-digit SIC level. We also use the squared Herfindahl index to control for nonlinear effects of industry concentration. All accounting variables are winsorized at the 1st and 99th percentiles to remove the influence of extreme outliers.

E. Model Specification

We use a DID methodology by estimating the following model:

$$y_{is(t+n)} = \alpha_t + \beta_i + \gamma \text{TAXDECR}_{st} + \delta X_{ist} + \epsilon_{ist}, \tag{1}$$

where i indexes firms; s indexes the most mentioned state; t indexes time; $y_{is(t+n)}$ is the dependent variable, which is either $\ln(1+\text{PATENT})$ or $\ln(1+\text{CIT/PAT})$; and n is equal to 1, 2, 3, or 4. TAXDECR_{st} is an indicator that takes a value of 1 if at time t in state s there has been a major decrease in the state corporate income tax rate, and 0 otherwise. X_{ist} is a vector of control variables described earlier. We control for time-invariant unobservable firm characteristics by using firm fixed effects β_i. Year indicator variables α_t control for economy-wide shocks, such as

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changes in federal fiscal and monetary policy and federal regulations, which vary by year and do not vary across states.

We use a log-linear model when the dependent variable is the number of patents or the number of citations per patent because they are count variables. The log-linear model is preferred to the Poisson model because the Poisson model is nonlinear, and when it is estimated with fixed effects, the maximum-likelihood algorithm drops all firms that do not change their innovation throughout the sample period (see Chamberlain (1980) for more details). Because those firms might carry valuable information, excluding them from the analysis might weaken the power of the tests and introduce noise in the estimation procedure.

To control for serial correlation, we cluster the standard errors at the firm level as suggested by Petersen (2009). For robustness, we also cluster the standard errors by year, by the state of location, and by state and year. We obtain similar findings in all cases, as shown in Table IA.1 of the Supplementary Material. Because the dependent variables, measures of innovative output, are slow moving and have uncertain lags, we use a DID methodology to capture changes in firm-level innovative output, following prior studies in the literature (e.g., Atanassov (2013), Acharya, Baghai, and Subramanian (2014), and Cornaggia, Mao, Tian, and Wolfe (2015)). Compared with the fixed-effects approach, as we illustrate in the Supplementary Material with a simple example, the first-difference approach may not be well suited to capture changes in innovative output when the lags are uncertain.

To understand the DID approach, it is helpful to consider an example. The following table reports state-level means and standard errors. In 1999, Arizona experienced a significant tax reduction from 9% to 8% (an 11% decrease). Suppose we want to estimate the effect of this tax reduction in Arizona on innovation, which is measured as ln(1 + PATENT). The first difference is to subtract the level of innovation (0.081) before the change from the level of innovation (0.106) after the change for firms whose most relevant state is Arizona. However, economy-wide shocks may occur at the same time and affect the change in innovation. To control for such factors, we calculate the same difference at the same time in a control state (e.g., Mississippi) that does not experience a tax change at that time. The difference of these two differences, which is 0.034, represents the incremental effect of the tax decrease on firm innovation.

	Before 1999	After 1999	Δ ln(1+PATENT)
Arizona	0.081 (0.004)	0.106 (0.008)	0.025 (0.009)
Mississippi	0.092 (0.006)	0.083 (0.007)	−0.009 (0.009)
Δln(1+PATENT)	−0.011 (0.007)	0.023 (0.011)	0.034 (0.013)

The tests used in this article are even more stringent than the simple intuition provided above because they control not only for state-wide differences but also for other firm-specific unobservable differences. Another advantage is that different states introduce the tax changes at different times, which allows the firms operating in a given state to be in both the treatment and control groups at different points in time.

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F. Summary Statistics

Table 2 presents the summary statistics. The average firm in the sample has 5.1 patents and 3.9 truncation-adjusted citations per patent. The standard deviations are large, suggesting that most of the innovation comes from a small number of highly innovative firms. Approximately 7.6% of the firm-years in the sample have a significant tax decrease, and approximately 7.6% have a significant tax increase. The average firm spends 25% of sales on R&D and has a debt-to-assets ratio of 0.26.

III. Multivariate Results

A. Tax Cuts and Corporate Innovation

We first study how tax cuts affect the quantity of innovation, measured by the number of patents created by firms. As Griliches (1990) argues, the innovation lag (from the initial investment to the actual patent) is poorly defined. Therefore, our dependent variable measures the number of patents from 1 to 4 years into the future. The full set of results for years 1 to 4 is reported in the Supplementary Material. For brevity, we present the main results for years 3 and 4 in Table 3A.

TABLE 2
Summary Statistics

Table 2 reports summary statistics for the key variables used in the analysis. The sample period is from 1988 to 2006. Patent information comes from the National Bureau of Economic Research (NBER) patent data set provided by Hall et al. (2001). This data set includes the number of patents by each firm and the (truncation-adjusted) number of citations received by each patent. We select all U.S. public firms from the NBER patent file that have financial data available in the Standard & Poor's (S&P) Compustat database. Firms in the financial (Standard Industrial Classification (SIC) = 6), utilities (SIC = 49), and public (SIC = 9) sectors are excluded. We also include all the firms in Compustat that operate in the same SIC industries as the firms in the patent database but do not have patents. Variable constructions are explained in Appendix B.

Variable	Mean	Std. Dev.
PATENT	5.1280	54.9939
CIT/PAT	3.9498	13.8133
TAXDECR	0.0755	0.2642
TAXINCR	0.0758	0.2647
TAXCHG	0.0003	0.3890
ln(SALES)	4.4281	2.4836
RD/SALES	0.2505	0.9866
LEVERAGE	0.2629	0.3089
PROFITABILITY	0.0038	0.4025
TANGIBILITY	0.2698	0.2232
ln(K/L)	3.1324	1.5394
RATING	0.1909	0.3930
ln(AGE)	2.1465	0.9511
HERFINDAHL	0.2218	0.1723
ln(REALGSP)	10.5366	0.1757
UNEMPRATE	5.5618	1.4602
GSPGROW	0.0339	0.0243
GSPGROWLAG	0.0341	0.0248
TAXES/GSP	0.0451	0.0090
ln(POP)	16.0718	0.9689
WWFINCON	0.3434	0.4748
KZFINCON	0.3284	0.4696
HPFINCON	0.3302	0.4703
INTANGIBLE	0.3334	0.4714
PATENT_STOCK	0.1187	0.3674
ANTITAKEOVER_INDEX	−0.0702	0.0837
TAXAVOID	0.3223	0.4674
STATE_TAXES/PRETAX_INCOME (%)	2.7557	5.9809

TABLE 3A

Tax Changes and the Number of Patents

Table 3A reports the results relating the number of patents, ln(1+PATENT), to tax changes using a sample of firm-year observations from 1988 to 2006. TAXDECR is an indicator variable equal to 1 if there has been a significant tax decrease in the largest state of business of firm i, and 0 otherwise. TAXINCR is an indicator variable equal to 1 if there has been a significant tax increase in the largest state of business of firm i, and 0 otherwise. TAXCHG is an indicator variable equal to 1 if there has been a significant tax increase in the largest state of business of firm i, equal to −1 if there has been a significant tax decrease in the largest state of business of firm i, and 0 otherwise. Due to space limitations, the construction of the control variables is explained in Appendix B. All regressions are estimated with time and firm fixed effects (FE), and the standard errors in parentheses are clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	$\ln(1+\text{PATENT})_{t+n}$					
	$t+3$	$t+4$	$t+3$	$t+4$	$t+3$	$t+4$
	1	2	3	4	5	6
TAXDECR	0.098*** (0.032)	0.121*** (0.039)				
TAXINCR			−0.041** (0.020)	−0.051** (0.023)		
TAXCHG					−0.048*** (0.016)	−0.059*** (0.020)
ln(SALES)	0.029*** (0.006)	0.019*** (0.007)	0.029*** (0.006)	0.019*** (0.007)	0.029*** (0.006)	0.019*** (0.007)
RD/SALES	0.026*** (0.006)	0.021*** (0.007)	0.026*** (0.006)	0.021*** (0.007)	0.026*** (0.006)	0.021*** (0.007)
LEVERAGE	−0.072*** (0.013)	−0.079*** (0.015)	−0.071*** (0.013)	−0.078*** (0.015)	−0.071*** (0.013)	−0.078*** (0.015)
PROFITABILITY	−0.003 (0.010)	0.000 (0.011)	−0.002 (0.010)	0.001 (0.011)	−0.002 (0.010)	0.001 (0.011)
TANGIBILITY	0.220*** (0.037)	0.292*** (0.043)	0.219*** (0.037)	0.290*** (0.043)	0.220*** (0.037)	0.291*** (0.043)
$\ln(K/L)$	−0.014*** (0.003)	−0.014*** (0.003)	−0.014*** (0.003)	−0.014*** (0.004)	−0.014*** (0.003)	−0.014*** (0.003)
RATING	−0.008 (0.023)	−0.018 (0.026)	−0.008 (0.023)	−0.018 (0.026)	−0.008 (0.023)	−0.018 (0.026)
ln(AGE)	0.001 (0.003)	0.003 (0.003)	0.001 (0.003)	0.003 (0.003)	0.001 (0.003)	0.003 (0.003)
HERFINDAHL	0.798*** (0.170)	0.865*** (0.204)	0.795*** (0.170)	0.861*** (0.204)	0.797*** (0.170)	0.864*** (0.204)
HERFINDAHL^2	−0.766*** (0.175)	−0.816*** (0.202)	−0.764*** (0.176)	−0.813*** (0.202)	−0.765*** (0.175)	−0.815*** (0.202)
ln(REALGSP)	−0.836*** (0.198)	−1.000*** (0.225)	−0.865*** (0.198)	−1.036*** (0.226)	−0.835*** (0.199)	−0.999*** (0.226)
UNEMPRATE	0.002 (0.006)	0.003 (0.007)	0.001 (0.006)	0.001 (0.007)	0.002 (0.006)	0.002 (0.007)
GSPGROW	0.765*** (0.161)	0.759*** (0.175)	0.787*** (0.162)	0.787*** (0.177)	0.761*** (0.161)	0.755*** (0.175)
GSPGROWLAG	0.508*** (0.155)	0.676*** (0.162)	0.514*** (0.158)	0.686*** (0.164)	0.478*** (0.157)	0.640*** (0.161)
TAXES/GSP	4.836** (1.919)	2.923 (1.998)	4.388** (1.948)	2.379 (2.040)	5.060*** (1.952)	3.197 (2.032)
ln(POP)	0.989*** (0.153)	1.081*** (0.181)	0.916*** (0.155)	0.990*** (0.185)	0.973*** (0.154)	1.061*** (0.183)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	73,065	68,203	73,065	68,203	73,065	68,203
R^2	0.720	0.698	0.720	0.697	0.720	0.698

Following equation (1), we estimate an ordinary least squares (OLS) model of ln(1+PATENT) on one of the 3 tax variables: TAXDECR, TAXINCR, and TAXCHG. The estimates in columns 1 and 2 of Table 3A show that tax decreases are significantly and positively related to the number of patents, which has not been previously documented and is the more important finding in light of the current debate about state and federal tax cuts. These estimates suggest that firms create 0.63 and 0.79 more patents 3 and 4 years after a major tax decrease, respectively.[11] Whether this is a small or a big change depends on the distribution: An increase of 0.63 is a much larger change in a tight distribution than in a dispersed distribution. Therefore, to put the changes in perspective, we compare these numbers to the standard deviation of patents and find that these increases in patents are approximately 1.2% and 1.4% of 1 standard deviation (54.99) above the mean. In other words, the variation in innovation quantity attributable to the tax cuts represents 1.2% and 1.4% of the variability in innovation quantity 3 and 4 years later, respectively. This approach of assessing economic significance by taking into account the distribution of dependent variables has also been used by many previous studies (e.g., Edelen and Warner (2001), Lowry and Schwert (2004), Becker (2006), Acharya, Almeida, and Campello (2013), and Matvos, Seru, and Silva (2018)).

In columns 3 and 4 of Table 3A, we find that tax increases are significantly and negatively related to the number of patents. These estimates suggest that firms produce 0.25 and 0.30 fewer patents 3 and 4 years after a major tax increase, which are reductions of approximately 0.5% and 0.6% of 1 standard deviation below the mean, respectively. In columns 5 and 6, we use the combined tax change measure and find a significant negative relation between TAXCHG and the number of patents. Other results from Table 3A show that larger firms and firms with more R&D expenditures, less leverage, and more tangible assets create a greater number of patents. Consistent with Aghion et al. (2005), there is a nonlinear (inverted-U) relation between industry concentration and innovation. We also observe significant relations between the number of patents and several state-level economic variables.

In Table 3B, we examine the impact of tax changes on the number of citations per patent, which is a measure of the quality of innovation. The results in columns 1 and 2 show a significant positive relation between tax decreases and the number of citations per patent, whereas the results in columns 3 and 4 show a significant negative relation between tax increases and the number of citations per patent. Thus, these results suggest that tax changes not only impact the quantity of innovation but also the quality, which is the more important measure of innovative output (Griliches (1990), Hall et al. (2005)). In terms of economic significance, the estimates in columns 1 and 2 suggest that on average, firms receive 0.75 and 0.75 more citations per patent 3 and 4 years after a major tax decrease, which are increases of approximately 5.4% and 5.4% of 1 standard deviation (13.81) above the mean, respectively. Similarly, the estimates in columns 3 and 4 suggest that firms receive 0.35 and 0.37 fewer citations per patent 3 and 4 years after a major tax increase, which are reductions of approximately 2.6% and 2.7% of 1 standard deviation below the mean, respectively.

The magnitude of our estimates is comparable to previous studies in the innovation literature that use state-level changes.[12] Although from the definition, the

[11] To be more precise, the increase of 0.63 does not apply only to year 3. The DID estimate indicates that firms create 0.63 more patents for 3 or more years after a major tax decrease.

[12] For example, using the estimates from Chava, Oettl, Subramanian, and Subramanian (2013), we calculate that after intrastate banking deregulation, young and private firms create 11.8% (=$0.23 \times 125.15/243.96$) of 1 standard deviation fewer patents and receive 13.0% (=$0.32 \times 2011.74/4953.52$) of 1 standard deviation fewer total citations. Using the estimates from Acharya et al. (2014), we

TABLE 3B

Tax Changes and the Number of Citations per Patent

Table 3B relates the number of citations per patent, ln(1+CIT/PAT), to tax changes using a sample of firm-year observations from 1988 to 2006. TAXDECR is an indicator variable equal to 1 if there has been a significant tax decrease in the largest state of business of firm *i*, and 0 otherwise. TAXINCR is an indicator variable equal to 1 if there has been a significant tax increase in the largest state of business of firm *i*, and 0 otherwise. TAXCHG is an indicator variable equal to 1 if there has been a significant tax increase in the largest state of business of firm *i*, equal to −1 if there has been a significant tax decrease in the largest state of business of firm *i*, and 0 otherwise. Due to space limitations, the construction of the control variables is explained in Appendix B. All regressions are estimated with time and firm fixed effects (FE), and the standard errors in parentheses are clustered at the firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$
	1	2	3	4	5	6
TAXDECR	0.141***	0.141***				
	(0.034)	(0.035)				
TAXINCR			−0.074***	−0.078***		
			(0.027)	(0.028)		
TAXCHG					−0.075***	−0.076***
					(0.020)	(0.020)
ln(SALES)	−0.002	−0.006	−0.002	−0.006	−0.002	−0.006
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
RD/SALES	0.026***	0.022***	0.027***	0.022***	0.026***	0.022***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
LEVERAGE	−0.067***	−0.079***	−0.066***	−0.078***	−0.066***	−0.078***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
PROFITABILITY	0.000	−0.001	0.001	0.000	0.001	−0.000
	(0.014)	(0.015)	(0.014)	(0.015)	(0.014)	(0.015)
TANGIBILITY	0.278***	0.293***	0.277***	0.292***	0.278***	0.293***
	(0.045)	(0.048)	(0.045)	(0.049)	(0.045)	(0.049)
ln(K/L)	−0.018***	−0.017***	−0.018***	−0.017***	−0.018***	−0.017***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
RATING	−0.013	−0.008	−0.013	−0.008	−0.013	−0.008
	(0.027)	(0.028)	(0.027)	(0.028)	(0.027)	(0.028)
ln(AGE)	−0.001	0.003	−0.001	0.003	−0.001	0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
HERFINDAHL	0.843***	0.771***	0.839***	0.766***	0.842***	0.770***
	(0.225)	(0.238)	(0.226)	(0.238)	(0.225)	(0.238)
HERFINDAHL^2	−0.894***	−0.826***	−0.891***	−0.823***	−0.893***	−0.826***
	(0.231)	(0.241)	(0.232)	(0.241)	(0.231)	(0.241)
ln(REALGSP)	−1.319***	−1.280***	−1.351***	−1.310***	−1.311***	−1.270***
	(0.225)	(0.234)	(0.225)	(0.235)	(0.225)	(0.234)
UNEMPRATE	−0.013*	−0.014*	−0.015**	−0.016**	−0.014*	−0.015*
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
GSPGROW	0.364*	0.484**	0.388*	0.507**	0.353*	0.472**
	(0.209)	(0.218)	(0.210)	(0.218)	(0.209)	(0.217)
GSPGROWLAG	0.386**	0.277	0.376**	0.264	0.333*	0.222
	(0.187)	(0.190)	(0.187)	(0.189)	(0.186)	(0.188)
TAXES/GSP	−2.795	−3.878*	−3.173	−4.195*	−2.305	−3.356
	(2.101)	(2.249)	(2.130)	(2.282)	(2.119)	(2.267)
ln(POP)	0.950***	1.003***	0.857***	0.911***	0.938***	0.992***
	(0.233)	(0.255)	(0.233)	(0.255)	(0.234)	(0.256)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	73,065	68,203	73,065	68,203	73,065	68,203
R^2	0.567	0.560	0.566	0.560	0.567	0.560

1% major tax changes may seem small (i.e., from 7% to 8%), this is just the lower bound. The average major tax increase is 1.5%, and the average major tax decrease is also 1.5%. That represents 22% of the average top marginal state tax rate of 6.9%. Therefore, instead of relating the change in innovation to a 1% change in

calculate that after the adoption of the good-faith clause of wrongful discharge laws, firms create 3.2% (=0.122 × 6.552/25.326) of 1 standard deviation more patents and receive 4.6% (=0.188 × 52.438/216.107) of 1 standard deviation more citations. These comparisons demonstrate that our results are economically significant and, yet, not dramatically large to suspect that something else is driving the results.

tax rates, we should consider the economic significance as a 22% average reduction in the state tax rate leading to a 12.3% (0.63/5.128) and 15.4% (0.79/5.128) average increase in patent count 3 and 4 years after the major tax cut, respectively. Similarly, a 22% increase in the state tax rate leads to a 4.9% (0.25/5.128) and 5.9% (0.30/5.128) decrease in patent count 3 and 4 years after the major tax increase, respectively. Although these effects are still substantial, they are not as large as they may appear. Furthermore, the effect of tax cuts may not be continuous and smooth but in the form of discrete jumps. Tax cuts usually provide the marginal dollar incentive to switch an innovative project from being a negative-NPV to a positive-NPV project. Consider the simple model in Appendix A. Even a dollar increase in the after-tax profit can raise the pledgeable income above $\bar{A}$, which would incentivize the manager to undertake the innovative project instead of shirking and pursuing the routine project. Therefore, the actual tax cut may be small in dollar amount, but if it provides enough incentives on the margin for managers to switch from routine to innovative projects, it can have a much larger economic effect.

Overall, Tables 3A and 3B demonstrate strong support for our main hypothesis that tax cuts have a significant positive impact on both the quantity and the quality of corporate innovation.

B. Dynamic Analysis of Tax Changes

Next, we address potential concerns of reverse causality by examining if there are any preexisting trends in innovative activity that were followed by tax cuts. One possibility is that if tax decreases were implemented in response to political pressure from a broad coalition of firms that started to experience a decline in innovation, then we should see an effect prior to the enactment of tax reductions. However, if such a pre-trend is driving our results, we should see a negative correlation between tax cuts and innovation. Therefore, we can reject this possibility even without conducting any additional tests. Note that a scenario where a decline in innovation led to the implementation of tax cuts, which in turn caused innovation to increase, is very consistent with our hypothesis. Another potential concern is that, despite stringent controls for firm- and state-level characteristics, certain economic conditions that we somehow fail to control for are driving both innovation and tax changes. In that case, we may also see an effect prior to the enactment of tax changes.

To address these potential concerns, we conduct 2 tests. First, we examine whether prior economic conditions can predict tax changes. In Table IA.2 of the Supplementary Material, we test whether state-level variables such as GSP, unemployment rate, and GSP growth rate from the prior year can predict tax decreases and increases in the current year. The regression results do not show a significant relation between these prior economic conditions and tax changes. Importantly, there is no evidence that economic conditions are systematically improving prior to a major tax cut or systematically deteriorating prior to a major tax increase, which is not consistent with the alternative story that firms are responding to economic conditions directly, rather than to tax changes.

Second, we directly examine whether innovative activities are changing prior to tax changes. To do so, we create 7 indicator variables for each of the 3 tax measures in Table 4 that allow us to investigate the dynamics of tax changes and their impact on innovation. The model is specified as follows for a tax decrease:

$$
\begin{aligned}
(2) \quad y_{ist} = {} & \alpha_t + \beta_i + \gamma_1 \text{TAXDECR\_MINUS\_2}_{st} \\
& + \gamma_2 \text{TAXDECR\_MINUS\_1}_{st} + \gamma_3 \text{TAXDECR\_0}_{st} \\
& + \gamma_4 \text{TAXDECR\_PLUS\_1}_{st} + \gamma_5 \text{TAXDECR\_PLUS\_2}_{st} \\
& + \gamma_6 \text{TAXDECR\_PLUS\_3}_{st} \\
& + \gamma_7 \text{TAXDECR\_PLUS\_4\_AND\_MORE}_{st} + \delta X_{ist} + \epsilon_{ist},
\end{aligned}
$$

where i indexes firms, s indexes the most mentioned state, and t indexes time; y_{ist} is the dependent variable, which is either ln(1+PATENT) or ln(1+CIT/PAT); and X_{ist} is a vector of control variables used in equation (1). We also control for firm fixed effects β_i and year fixed effects α_t. The 7 tax indicators are defined in Table 4. In particular, the indicators TAXDECR_MINUS_2 and TAXDECR_MINUS_1 allow us to see if there is any change in innovation 1 or 2 years *before* the tax decrease is enacted.

TABLE 4

Tax Changes and Innovation Dynamics

Table 4 reports the results relating the number of patents and the (truncation-adjusted) number of citations per patent to the dynamics of tax changes. We estimate the ordinary least squares (OLS) model of ln(1+PATENT) or ln(1+CIT/PAT) on TAXVAR_MINUS_2, which is an indicator variable equal to 1 if it is 2 years before a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; on TAXVAR_MINUS_1, which is an indicator variable equal to 1 if it is 1 year before a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; on TAXVAR_0, which is an indicator variable equal to 1 if it is the year when a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; TAXVAR_PLUS_1, which is an indicator variable equal to 1 if it is 1 year after a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; TAXVAR_PLUS_2, which is an indicator variable equal to 1 if it is 2 years after a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; TAXVAR_PLUS_3, which is an indicator variable equal to 1 if it is 3 years after a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; and on TAXVAR_PLUS_4_AND_MORE, which is an indicator variable equal to 1 if it is 4 or more years after a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise. The same set of controls from Table 3 is used, which includes ln(SALES), RD/SALES, LEVERAGE, PROFITABILITY, TANGIBILITY, ln(K/L), RATING, ln(AGE), HERFINDAHL, HERFINDAHL^2, ln(REALGSP), UNEMPRATE, GSPGROW, GSPGROWLAG, TAXES/GSP, and ln(POP). All regressions are estimated with time and firm fixed effects (FE), and the standard errors reported in parentheses are corrected for the panel in all the models and are clustered at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	ln(1+PATENT)$_t$			ln(1+CIT/PAT)$_t$		
	TAXDECR	TAXINCR	TAXCHG	TAXDECR	TAXINCR	TAXCHG
TAXVAR	1	2	3	4	5	6
TAXVAR_MINUS_2	−0.023	−0.001	0.006	−0.037	−0.032	0.008
	(0.018)	(0.024)	(0.014)	(0.034)	(0.048)	(0.028)
TAXVAR_MINUS_1	−0.025	0.007	0.008	−0.031	−0.058	−0.014
	(0.019)	(0.025)	(0.014)	(0.034)	(0.047)	(0.028)
TAXVAR_0	−0.028	0.003	0.006	0.025	0.005	0.025
	(0.023)	(0.025)	(0.020)	(0.039)	(0.049)	(0.026)
TAXVAR_PLUS_1	−0.017	−0.007	0.012	0.036	−0.067	−0.010
	(0.024)	(0.023)	(0.013)	(0.041)	(0.048)	(0.025)
TAXVAR_PLUS_2	0.012	−0.025	−0.011	0.104**	−0.076*	−0.049*
	(0.026)	(0.023)	(0.015)	(0.044)	(0.045)	(0.028)
TAXVAR_PLUS_3	0.036	−0.038*	−0.029**	0.133***	−0.133***	−0.095***
	(0.026)	(0.022)	(0.014)	(0.047)	(0.042)	(0.029)
TAXVAR_PLUS_4_AND_MORE	0.065**	−0.044**	−0.038***	0.197***	−0.137***	−0.106***
	(0.032)	(0.019)	(0.015)	(0.047)	(0.032)	(0.022)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	87,564	87,564	87,564	87,564	87,564	87,564
R^2	0.763	0.763	0.763	0.574	0.573	0.574

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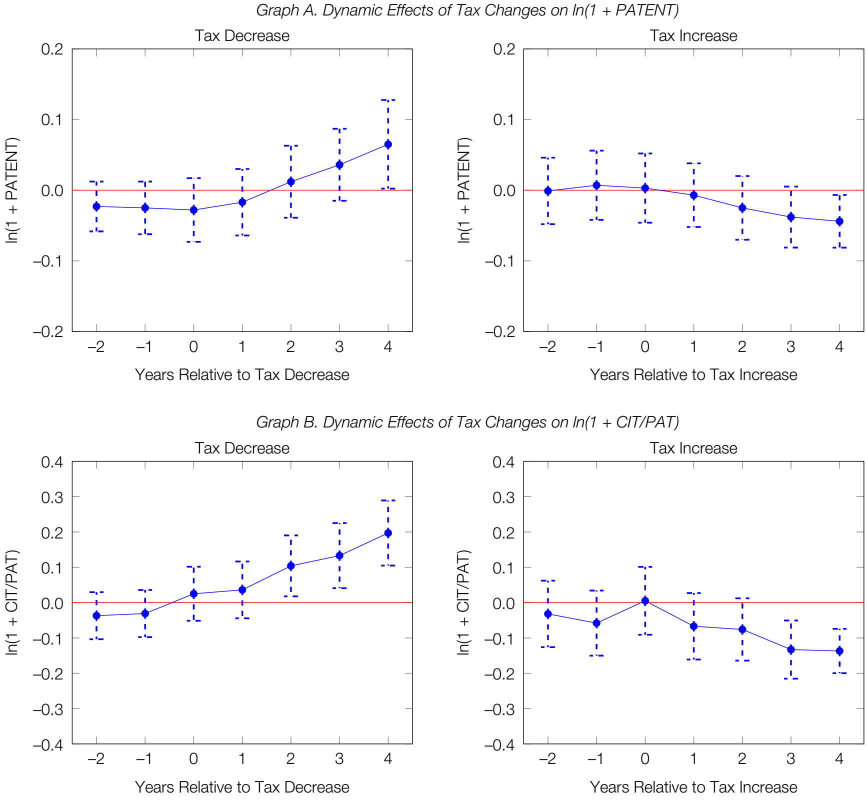
Following equation (2), we conduct the dynamic analysis of the impact of tax changes on corporate innovation in Table 4, and the corresponding plots based on these regression results are presented in Figure 1. In columns 1–3, we examine innovation quantity, and in columns 4–6, we study innovation quality. We find a significant positive effect of a tax decrease on the number of patents starting in year 4 and a significant negative effect of a tax increase on the number of patents starting in year 3. At the same time, there is no relation between tax changes and innovation in the years prior to the change, which is consistent with the assumption that there are no preexisting trends of changes in innovation before tax changes are enacted. This pattern is also confirmed in Figure 1, where the upper and lower bounds of the 95% confidence interval at years $t-2$ and $t-1$ include 0, indicating that these effects are statistically indistinguishable from 0.

In column 4 of Table 4, we find a significant positive effect of TAXDECR on innovation quality 2 or more years after the tax decrease. Importantly, there is

FIGURE 1

Tax Changes and Innovation Dynamics

Graphs A and B of Figure 1 relate the number of patents and the truncation-adjusted number of citations per patent to the dynamics of tax changes. The solid lines represent the difference in innovation outputs between treatment and control groups based on the differences-in-differences regressions reported in Table 4. The dotted lines represent the 95% confidence intervals with upper and lower bounds.



no relation between tax decreases and innovation in the years prior to the change, suggesting that there are no preexisting trends of an increase in innovation before a major tax cut. This pattern is again confirmed in Figure 1, where the upper and lower bounds of the 95% confidence interval at years $t-2$ and $t-1$ include 0. In column 5, we find a significant negative effect of TAXINCR on innovation quality 2 or more years after the tax increase, and there is no relation between tax increases and innovation in the years prior to the change. These patterns are consistent with other studies in the literature (e.g., Atanassov (2013), Acharya et al. (2014)) that use different state-level shocks. It is also worth noting that we do not find a significant effect of tax changes on innovation quality in the year of the tax change (t) and the following year ($t+1$), which is consistent with the notion that innovation is a long-term process and that its lag is poorly defined, as suggested by the prior literature (e.g., Griliches (1990), Hall et al. (2001)).

Together, the evidence in Tables 3 and 4 suggests that major increases and decreases in state corporate income taxes have a significant impact on the quantity and, especially, the quality of corporate innovation. For brevity in the rest of the article, we focus on the quality of innovation, measured by the number of citations per patent, because it is the more important measure of innovation. Moreover, inputs to the innovative process, such as effort and creativity, tend to have a greater impact on the quality rather than the quantity of innovative output. Unreported results are similar for the number of patents.

C. Tax Cuts and R&D Expenditures

As we discuss in our theoretical model, state corporate income taxes can affect the incentives of various stakeholders to increase their investment in time, effort, and money in the innovative process. There are several inputs in the creation of innovation. Some of them (e.g., R&D expenditures) are observable and easier to measure. Others (e.g., creativity, time, and work effort) are mostly unobservable. In this section, we examine if the impact of tax cuts on innovative output is partly transmitted through R&D expenditures.

We test this prediction in Table 5, where the dependent variable is R&D expenditures divided by sales. Because some firms have no R&D expenditures and including these firms in an empirical model with firm fixed effects would bias the estimates of the tax change toward 0, we exclude firms that never report positive R&D during the sample period. We focus instead on firms that report at least one positive R&D during the sample period. The mean and standard deviation of R&D over sales in this sample is 0.4335 and 1.2626, respectively.

Because we do not know ex ante when tax changes would begin to have an effect on R&D expenditures and how long the effect would last, we use a dynamic setup similar to Table 4 to examine the impact of tax changes on R&D expenditures. In column 1, we find a significant positive effect of tax decreases on R&D expenditures starting in year 1 and lasting until year 4 and after. The effects are also economically significant. The coefficients in column 1 suggest that firms increase R&D expenditures following major tax cuts by 9.4% (0.119/1.2626), 12.1% (0.153/1.2626), 11.2% (0.141/1.2626), and 6.2% (0.078/1.2626) of 1 standard deviation of R&D over sales (1.2626) in years 1, 2, 3, and 4 or more, respectively. At the same time, there is no relation between tax decreases and R&D

TABLE 5

Tax Changes and R&D Expenditures

Table 5 reports the results relating the research and development (R&D) expenditures to the dynamics of tax changes. We further exclude firms that never report positive R&D expenditures in any year during the entire sample period. We estimate the ordinary least squares (OLS) model of RD/SALES on TAXVAR_MINUS_2, which is an indicator variable equal to 1 if it is 2 years before a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; on TAXVAR_MINUS_1, which is an indicator variable equal to 1 if it is 1 year before a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; on TAXVAR_0, which is an indicator variable equal to 1 if it is the year when a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; TAXVAR_PLUS_1, which is an indicator variable equal to 1 if it is 1 year after a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; TAXVAR_PLUS_2, which is an indicator variable equal to 1 if it is 2 years after a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; TAXVAR_PLUS_3, which is an indicator variable equal to 1 if it is 3 years after a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise; and on TAXVAR_PLUS_4_AND_MORE, which is an indicator variable equal to 1 if it is 4 or more years after a significant tax change is enacted in the largest state of business of firm i, and 0 otherwise. Controls include ln(SALES), LEVERAGE, PROFITABILITY, TANGIBILITY, ln(K/L), RATING, ln(AGE), HERFINDAHL, HERFINDAHL^2, ln(REALGSP), UNEMPRATE, GSPGROW, GSPGROWLAG, TAXES/GSP, and ln(POP). All regressions are estimated with time and firm fixed effects (FE), and the standard errors reported in parentheses are corrected for the panel in all the models and are clustered at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	RD/SALES$_t$		
	TAXDECR	TAXINCR	TAXCHG
TAXVAR	1	2	3
TAXVAR_MINUS_2	−0.025	−0.038	−0.007
	(0.032)	(0.039)	(0.026)
TAXVAR_MINUS_1	−0.004	−0.036	−0.016
	(0.037)	(0.044)	(0.030)
TAXVAR_0	0.051	−0.066	−0.029
	(0.045)	(0.044)	(0.029)
TAXVAR_PLUS_1	0.119**	−0.075*	−0.070***
	(0.048)	(0.039)	(0.027)
TAXVAR_PLUS_2	0.153***	−0.100***	−0.101***
	(0.050)	(0.035)	(0.028)
TAXVAR_PLUS_3	0.141***	−0.104***	−0.098***
	(0.048)	(0.033)	(0.027)
TAXVAR_PLUS_4_AND_MORE	0.078*	−0.027	−0.027
	(0.047)	(0.029)	(0.021)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
No. of obs.	50,229	50,229	50,229
R^2	0.762	0.762	0.762

expenditures in the years prior to the change. In column 2, we find a significant negative effect of tax increases on R&D expenditures starting in year 1 and lasting until year 3. In terms of economic effects, these coefficients suggest that firms reduce R&D expenditures following major tax increases by 5.9% (−0.075/1.2626), 7.9% (−0.100/1.2626), and 8.2% (−0.104/1.2626) of 1 standard deviation of R&D over sales (1.2626) in years 1, 2, and 3, respectively. In sum, tax changes generally have a significant impact on R&D expenditures starting 1 year after the tax changes, whereas they generally have a significant impact on innovation outputs starting 2 or more years after the tax changes. This pattern is consistent with a causal chain of events that changes in taxes lead to a change in inputs in the form of R&D expenditures that is followed by a change in innovation outputs.

Besides R&D expenditures, there are other inputs in the creation of innovation, although they are mostly unobservable. As indirect evidence of work effort, we examine incentive compensation in Table IA.3 of the Supplementary Material. We find evidence that the average stock-option-based compensation to top-level executives increases after a major tax decrease and decreases after a major tax increase. In terms of economic effects, the estimates translate into an increase of \$179K after a major tax decrease and a decrease of \$336K after a major tax increase, which are approximately 4.9% and 9.1% of 1 standard deviation of option-based compensation, respectively.

The increases in R&D expenditures and incentive compensation after major tax cuts may be supported by an increase in the after-tax cash flows. We investigate this conjecture in Table IA.3 of the Supplementary Material and find a significant increase of 0.048 (approximately a 5.7% standard-deviation change) in the after-tax cash flows after a major tax cut and a significant decrease of 0.016 (approximately a 1.9% standard-deviation change) after a major tax increase. In addition, we also examine changes in external financing in the form of equity and debt issues in Table IA.4 of the Supplementary Material and find a significant increase after major tax cuts for financially constrained firms. Together, these results suggest that after major tax cuts, firms experience increases in R&D expenditures and incentive compensation, which are likely supported by an influx of both internal and external funds. Economically, the impact of major tax cuts on inputs of innovation (ranging from 4.9% to 12.1% of 1 standard deviation) is commensurate with the impact on outputs of innovation (5.4% of 1 standard deviation for citations per patent), suggesting that the effects are internally consistent.

IV. Exploring the Mechanisms

Based on our theoretical motivation and the model developed in Appendix A, we hypothesize that corporate income taxes may distort the incentives of the firm and its stakeholders to optimally invest time, effort, and money in innovative activities. The rest of the article examines several possible channels through which lower tax rates can increase firms' pledgeable income and consequently boost innovation: relieving financial constraints, reducing the negative impact of smaller collateral, reducing the negative impact of weak corporate governance, and improving resource allocation by decreasing tax avoidance. These channels have not yet been explored in the literature on the real effects of taxes. Understanding the mechanisms that drive the relation between taxes and innovation is important for two main reasons. First, it improves our understanding of how taxes work and provides better insight into future research and policy making. Second, it reduces the concern that the relation between taxes and innovation is spurious and driven by other changes that may have occurred at the same time. Such a criticism will have the burden of explaining not only the main results presented in Section III but also all the findings in this section.

A. Tax Cuts, Financial Constraints, and Innovation

Our theoretical model demonstrates that lower tax rates increase pledgeable income, thus allowing firms to obtain additional financing, extract greater effort from management and innovative employees, and increase their investment in innovative projects. If some firms do not need much additional financing, either because they hold enough cash or because it is less costly for them to tap into external markets, then the decline in tax rates will not have a big impact on innovation. Conversely, we predict that more financially constrained firms will benefit more from a tax decrease because their pledgeable income may increase above the required threshold to undertake the project. By the same rationale, our model predicts that firms that are more financially constrained will experience a greater decline in innovation from a tax increase than firms that are less financially constrained.

Table 6 presents the results. In Panel A, we construct a measure of financial constraints using the Whited and Wu (WW) (2006) index, which is based on coefficients obtained from a structural model. Following the literature (e.g., Farre-Mensa and Ljungqvist (2016)), we sort firms into terciles each year based on their WW index values, and the indicator, WWFINCON, equals 1 for firms in the top tercile. In columns 1 and 2, the coefficients on the interaction term between tax cuts and WWFINCON are positive and significant. Specifically, the positive impact of tax decreases on the number of citations per patent 3 and 4 years into the future is 104% and 157% greater, respectively, for firms that are more financially constrained. In columns 3 and 4 of Panel A, we also document that the coefficients on the interaction term between tax increases and WWFINCON are both negative, whereas only year 4 is significant. This result suggests that the impact of tax increases is larger for firms that are more financially constrained.

In a related test, we examine if smaller firms benefit more from tax decreases. Ceteris paribus, smaller firms have greater informational asymmetries and are thus more financially constrained. These firms are also more constrained in terms of attracting and keeping talented employees. Consistent with the prediction, we find that the positive impact of tax decreases is larger for smaller firms in Panel B of Table 6. This result provides additional relief for the concern that our results could be driven by the lobbying efforts of a few large firms that expect an increase in their innovative output for reasons unrelated to taxes and then lobby for tax cuts. If this was the case, we would see that larger firms benefit more from the tax decrease. The results for size interaction also provide some indirect evidence that innovative inputs, such as creativity and work effort, may be driving the documented relations. The rationale is that such resources as entrepreneurial creativity and effort tend to be more important in smaller firms where the manager is directly responsible for most key decision making.

Next, we conduct several additional tests in Table IA.4 of the Supplementary Material. First, instead of using the WW (2006) index, we use alternative measures of financial constraints from Kaplan and Zingales (1997) and Hadlock and Pierce (2010), and we find similar interactive effects. Second, we examine the role of cash in a test related to the financial constraint channel. In particular, we test whether firms with deeper cash pockets are less affected by tax changes than firms with less cash, motivated by Manso (2011). Because cash holdings are affected by different motives, such as precautionary reasons or changing growth opportunities, we follow Opler, Pinkowitz, Stulz, and Williamson (1999) and Dittmar and Mahrt-Smith (2007) and compute excess cash as the actual cash level minus the

TABLE 6
Tax Changes, Financial Constraints, and Innovation

Table 6 examines the role of financial constraints. We estimate the ordinary least squares (OLS) model of ln(1+CIT/PAT) on TAXDECR, which is an indicator variable equal to 1 (0 otherwise) if there has been a significant tax decrease in the largest state of business of firm *i*, or TAXINCR, which is an indicator variable equal to 1 (0 otherwise) if there has been a significant tax increase in the largest state of business of firm *i*, and its interaction with WWFINCON in Panel A and ln(SALES) in Panel B. WWFINCON is an indicator variable equal to 1 if the firm is in the highest tercile of the yearly Whited and Wu (2006) financial constraint index, and 0 otherwise. The same set of controls from Table 3 is used, which includes ln(SALES), RD/SALES, LEVERAGE, PROFITABILITY, TANGIBILITY, ln(K/L), RATING, ln(AGE), HERFINDAHL, HERFINDAHL^2, ln(REALGSP), UNEMPRATE, GSPGROW, GSPGROWLAG, TAXES/GSP, and ln(POP). All regressions are estimated with time and firm fixed effects (FE), and the standard errors reported in the parentheses are corrected for the panel in all the models and are clustered at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, **, and **** indicate significance at the 10%, 5%, and 1% levels, respectively.

	ln(1+CIT/PAT)$_{t+3}$	ln(1+CIT/PAT)$_{t+4}$	ln(1+CIT/PAT)$_{t+3}$	ln(1+CIT/PAT)$_{t+4}$
	1	2	3	4
Panel A. Using the Whited and Wu Measure of Financial Constraints				
TAXDECR	0.101***	0.084**		
	(0.039)	(0.039)		
TAXDECR × WWFINCON	0.105***	0.132***		
	(0.035)	(0.034)		
TAXINCR			−0.066**	−0.056*
			(0.032)	(0.032)
TAXINCR × WWFINCON			−0.002	−0.056*
			(0.036)	(0.033)
WWFINCON	−0.058***	−0.083***	−0.050***	−0.068***
	(0.011)	(0.011)	(0.010)	(0.010)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	67,656	63,322	67,656	63,322
R^2	0.571	0.566	0.571	0.566
Panel B. Using Firm Size Measured by Sales				
TAXDECR	0.382***	0.395***		
	(0.068)	(0.070)		
TAXDECR × ln(SALES)	−0.048***	−0.050***		
	(0.014)	(0.014)		
TAXINCR			−0.176***	−0.197***
			(0.052)	(0.054)
TAXINCR × ln(SALES)			0.023**	0.026**
			(0.011)	(0.011)
ln(SALES)	0.001	−0.003	−0.003	−0.008
	(0.008)	(0.008)	(0.008)	(0.008)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	73,065	68,203	73,065	68,203
R^2	0.567	0.561	0.567	0.560

predicted cash level from the first-stage regression.[13] The interaction results are consistent with the prediction that firms with more excess cash reserves are less affected by tax changes. Finally, we examine whether tax changes affect firms' ability to raise external financing, especially for financially constrained firms.

[13]The first-stage cash-level OLS regression is ln(cash/sales) = −0.239 × ln(assets) − 0.004 × cash flow/assets + 0.047 × working capital/assets + 0.022 × market-to-book + 1.039 × capital expenditures (CAPEX)/assets − 0.369 × leverage + 1.008 × industry sigma + 0.503 × R&D/sales + 0.122 × dividend dummy + 0.212 × bond rating dummy + year fixed effects (FE) + firm FE + e.

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We do not find a significant effect for unconstrained firms. However, for financially constrained firms, a tax decrease is followed by a significant increase in the amount of external financing.[14] Economically, financially constrained firms that experience a major tax cut increase external financing by 0.019 and 0.022 1 and 2 years later, which are increases of approximately 5.8% and 6.7% of 1 standard deviation (0.327). This finding suggests that tax decreases facilitate external financing and relieve financial constraints.

In sum, more financially constrained firms, smaller firms, and firms with less excess cash reserves benefit more from tax cuts. Although less financially constrained firms are affected less, the impact of tax decreases on innovation quality for those firms is still significant economically and statistically, suggesting that financial constraints are not the only mechanism through which taxes affect innovation.

B. Tax Cuts, Collateral, and Innovation

In this section, we continue our investigation of how firms with lower pledgeable income are more sensitive to tax changes. We focus here on collateral, which mainly comes from tangible assets but could also arise from intangible assets (e.g., previous patent stock). We conduct two tests in Table 7. The first investigates whether firms with fewer tangible assets that are often used as collateral benefit more from tax decreases. The second examines if firms with lower patent stock at the time of the tax cut benefit more.

In Panel A of Table 7, we sort firms into terciles each year based on their asset tangibility, which is calculated as net property, plant, and equipment divided by total assets. The indicator, INTANGIBLE, equals 1 for firms in the bottom tercile of the tangibility measure, and 0 otherwise. We then interact INTANGIBLE with the tax decrease indicator in columns 1 and 2. The coefficient on the interaction term is positive and significant, suggesting that the impact of tax decreases is larger for firms with fewer tangible assets. Specifically, the positive impact of tax decreases on the number of citations per patent 3 and 4 years into the future is 114% and 119% greater, respectively, for firms with fewer tangible assets. In columns 3 and 4, the coefficients on the interaction term are both negative and significant, suggesting that the impact of tax increases is larger for firms with fewer tangible assets.

In Panel B of Table 7, we test whether firms with a lower patent stock at the time of the tax change will benefit more from tax decreases. This investigation is motivated by the previous literature (Hochberg, Serrano, and Ziedonis (2015), (2018)), which argues that the patent stock has significant value because it can be used as collateral to attract additional financing. For a given firm in year t, its patent stock is calculated as the total number of patents the firm has accumulated over the last 20 years, divided by total assets.[15] We normalize the cumulative

[14]We do not find a significant negative effect for tax increases. This can be due to different reasons. For instance, a tax increase may not lead to a reduction in external financing because it can make debt financing more attractive due to greater tax savings from interest payments.

[15]The rolling period of 20 years is motivated by the term of a patent, which is 20 years from the filing date for applications filed on or after June 8, 1995, and either 17 years from the issue date or 20 years from the filing date for applications filed before June 8, 1995.

TABLE 7

Tax Changes, Collateral, and Innovation

Table 7 examines the role of collateral. We estimate the ordinary least squares (OLS) model of ln(1+CIT/PAT) on TAXDECR, which is an indicator variable equal to 1 if there has been a significant tax decrease in the largest state of business of firm *i*, and 0 otherwise, or TAXINCR, which is an indicator variable equal to 1 if there has been a significant tax increase in the largest state of business of firm *i*, and 0 otherwise, and its interaction with INTANGIBLE in Panel A or PATENT_STOCK in Panel B. INTANGIBLE is an indicator variable equal to 1 if the firm is in the lowest tercile of the tangibility measure (PPENT/AT), and 0 otherwise. PATENT_STOCK is the total number of patents the firm has created in the last 20 years from year $t-19$ to year t, divided by total assets in year t. The same set of controls from Table 3 is used, which includes ln(SALES), RD/SALES, LEVERAGE, PROFITABILITY, TANGIBILITY, ln(K/L), RATING, ln(AGE), HERFINDAHL, HERFINDAHL^2, ln(REALGSP), UNEMPRATE, GSPGROW, GSPGROWLAG, TAXES/GSP, and ln(POP). All regressions are estimated with time and firm fixed effects (FE), and the standard errors reported in parentheses are corrected for the panel in all the models and are clustered at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$
	1	2	3	4
Panel A. Interactions with Intangible Assets				
TAXDECR	0.115***	0.114***		
	(0.037)	(0.038)		
TAXDECR × INTANGIBLE	0.131***	0.136***		
	(0.043)	(0.044)		
TAXINCR			−0.054*	−0.064**
			(0.030)	(0.031)
TAXINCR × INTANGIBLE			−0.083**	−0.058
			(0.040)	(0.040)
INTANGIBLE	0.013	0.002	0.027*	0.014
	(0.016)	(0.016)	(0.015)	(0.016)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	73,065	68,203	73,065	68,203
R^2	0.567	0.560	0.567	0.560
Panel B. Interactions with Patent Stock				
TAXDECR	0.199***	0.191***		
	(0.033)	(0.033)		
TAXDECR × PATENT_STOCK	−0.498***	−0.424***		
	(0.077)	(0.083)		
TAXINCR			−0.104***	−0.109***
			(0.026)	(0.027)
TAXINCR × PATENT_STOCK			0.313***	0.318***
			(0.068)	(0.066)
PATENT_STOCK	−0.297***	−0.313***	−0.349***	−0.362***
	(0.036)	(0.037)	(0.036)	(0.038)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	73,065	68,203	73,065	68,203
R^2	0.571	0.565	0.570	0.564

patent count by total assets in order to account for the effect of firm size because larger firms tend to have more patents.[16] We then interact the patent-stock measure with the tax-decrease indicator, and the results indicate that the impact of tax decreases and increases is larger for firms with a lower patent stock.

Together, the results support the model's prediction that firms with less collateral, either in the form of tangible assets or patent stock, are more sensitive to tax cuts, consistent with the pledgeable-income rationale. We find results that are

[16]For robustness, we also normalize the cumulative patent count by sales and find similar results.

similar in magnitude but opposite in sign for tax increases, suggesting a symmetric effect.

C. Tax Cuts, Governance, and Innovation

As Tirole (2006) explains, managers in firms with weaker corporate governance enjoy greater private benefits of control because they are not monitored and disciplined properly. As hypothesized in the Introduction and in the theoretical model in Appendix A, a reduction in the tax rate will have a stronger impact on innovation for firms with weaker corporate governance if the additional after-tax profit increases their pledgeable income and provides them with better incentives to exert effort and innovate, rather than shirk and enjoy the private benefits of control. Also, firms with weaker corporate governance cannot raise external financing as easily because shareholders are concerned that they will not get an adequate return on their investment (Shleifer and Vishny (1997)).

To proxy for the strength of corporate governance, we use the threat of hostile takeovers, which has been documented as one of the most important mechanisms through which shareholders exercise their power (Jensen (1988)). We measure the threat of hostile takeovers with the takeover index developed by Cain et al. (2017). The coverage of this takeover index (i.e., 14,441 firms from 1965 to 2011) is much better than the G-index from Gompers, Ishii, and Metrick (2003), which covers mostly firms in the S&P 500 index. The G-index is also subject to serious endogeneity concerns. Recent studies (Bertrand and Mullainathan (2003), Atanassov (2013)) have used exogenous measures, such as the passage of business combination (BC) laws, to measure the threat of hostile takeovers. Similar to the BC laws, the takeover index mainly focuses on state-level variation in the takeover environment that is largely exogenous to firm-level decisions. Thus, we use the takeover index from Cain et al. (2017), which is richer and more comprehensive than the BC laws alone.

The takeover index is based on the passage of 13 different types of state anti-takeover laws, 1 federal statute, and 3 state standards of review, where higher values indicate a higher threat of hostile takeovers. For ease of interpretation, we create an anti-takeover index by multiplying the takeover index by -1 so that higher index values correspond to lower hostile takeover hazard or weaker governance. To examine the governance hypothesis, we interact the tax-decrease indicator with the anti-takeover index and test whether firms facing less discipline from the takeover market are affected differentially by tax changes.

The results are reported in Table 8. We first note that the anti-takeover index is negatively related to the number of citations per patent, consistent with Atanassov (2013). In columns 1 and 2, the coefficients on the interaction term between tax decreases and the anti-takeover index indicate that the positive effect of tax decreases on innovation is larger for firms subject to weaker governance. A 1-standard-deviation increase in the anti-takeover index (0.0837) increases the positive effect of tax decreases on the number of citations per patent by 64% and 64% at 3 and 4 years into the future, respectively. In columns 3 and 4, the coefficients on the interaction term between tax increases and the anti-takeover index are negative and statistically significant. Overall, the evidence is consistent with

TABLE 8
Tax Changes, Governance, and Innovation

Table 8 examines the role of corporate governance. We estimate the ordinary least squares (OLS) model of ln(1+CIT/PAT) on TAXDECR, which is an indicator variable equal to 1 if there has been a significant tax decrease in the largest state of business of firm *i*, and 0 otherwise, or TAXINCR, which is an indicator variable equal to 1 if there has been a significant tax increase in the largest state of business of firm *i*, and 0 otherwise, and its interaction with the ANTITAKEOVER_INDEX, which is developed by Cain et al. (2017) and constructed based on the passage of 13 different types of state takeover laws, 1 federal statute, and 3 state standards of review, where higher values indicate lower hostile takeover hazard. The same set of controls from Table 3 is used, which includes ln(SALES), RD/SALES, LEVERAGE, PROFITABILITY, TANGIBILITY, ln(K/L), RATING, ln(AGE), HERFINDAHL, HERFINDAHL^2, ln(REALGSP), UNEMPRATE, GSPGROW, GSPGROWLAG, TAXES/GSP, and ln(POP). All regressions are estimated with time and firm fixed effects (FE), and the standard errors reported in parentheses are corrected for the panel in all the models and are clustered at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

	ln(1+CIT/PAT)$_{t+3}$	ln(1+CIT/PAT)$_{t+4}$	ln(1+CIT/PAT)$_{t+3}$	ln(1+CIT/PAT)$_{t+4}$
	1	2	3	4
TAXDECR	0.316***	0.324***		
	(0.042)	(0.042)		
TAXDECR × ANTITAKEOVER_INDEX	2.403***	2.490***		
	(0.533)	(0.542)		
TAXINCR			−0.113***	−0.120***
			(0.032)	(0.033)
TAXINCR × ANTITAKEOVER_INDEX			−0.468**	−0.506**
			(0.233)	(0.243)
ANTITAKEOVER_INDEX	−0.698***	−0.583***	−0.623***	−0.503***
	(0.179)	(0.187)	(0.182)	(0.187)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	69,934	65,329	69,934	65,329
R^2	0.570	0.564	0.569	0.563

the prediction that the impact of tax changes is stronger for firms with greater private benefits of control.

D. Tax Cuts, Tax Avoidance, and Innovation

The extent to which firms actively minimize their tax burden is an important factor discussed in the literature that could moderate the relationship between corporate income taxes and firm investment, output, and financial performance. In this section, we examine if tax avoidance can affect the impact of tax cuts on innovation. There are two opposing hypotheses. The null hypothesis states that tax cuts will have a smaller effect on firms that avoid taxes more because they are better at adjusting the effective tax rate and minimizing the tax burden. As a result, the prediction is that the interaction term between tax decreases and tax avoidance will be negative.

The alternative hypothesis states that the tax cuts will have a greater impact on firms that avoid taxes more. Let's consider a firm operating on a concave production possibilities frontier that keeps firm value constant. The firm will shift resources along the frontier based on which activity has the greatest marginal impact on firm value. Because the frontier is concave, there will be decreasing marginal returns to shifting resources from one activity to the other. Let's assume for simplicity that there are only two activities that affect firm value: tax minimization and innovation. If tax rates go up, to preserve firm value and because of concavity due to the specialization of resources, the firm will shift disproportionately more resources from innovative projects to dealing with tax avoidance. If tax rates go down, the firm will shift disproportionately more resources from dealing with tax avoidance to innovative projects. If these resources are better suited for innovative projects (because the production possibilities frontier between innovation and tax avoidance is concave), the negative impact of tax increases on innovation will be greater for firms that engage more in tax avoidance than firms that do not. Similarly, the positive impact of tax decreases on innovation will be greater for firms that engage more in tax avoidance than for firms that do not. As a result, the prediction is that the interaction term between corporate income tax cuts and tax avoidance will be positive.

Following Dyreng et al. (2008), we use the long-run cash effective tax rate, ETR, to measure the degree of tax avoidance, which is based on the firm's ability to pay a low amount of cash taxes per dollar of pretax earnings over a long period of time. We also adjust for industry and size effects following Balakrishnan, Blouin, and Guay (2019). Every year, we sort firms into terciles based on their industry- and size-adjusted ETRs. Our key variable, TAXAVOID, equals 1 if the firm is in the bottom tercile, and 0 otherwise. To test the tax-avoidance hypothesis, we interact the tax-decrease or tax-increase indicator with our TAXAVOID measure. We use this interaction term to test whether firms that avoid taxes more are impacted differentially by tax changes.

The results in Table 9 support the alternative hypothesis. We document that firms that avoid taxes more are affected by tax changes to a greater extent. Specifically, the positive impact of tax decreases on the number of citations per patent 3 and 4 years into the future is 150% and 169% greater, respectively, for firms

TABLE 9

Tax Changes, Tax Avoidance, and Innovation

Table 9 examines the role of tax avoidance. We estimate the ordinary least squares (OLS) model of ln(1+CIT/PAT) on TAXDECR, which is an indicator variable equal to 1 if there has been a significant tax decrease in the largest state of business of firm *i*, and 0 otherwise, or TAXINCR, which is an indicator variable equal to 1 if there has been a significant tax increase in the largest state of business of firm *i*, and 0 otherwise, and its interaction with TAXAVOID, which is an indicator variable for firms in the lowest tercile of yearly industry- and size-adjusted cash effective tax rate. The same set of controls from Table 3 is used, which includes ln(SALES), RD/SALES, LEVERAGE, PROFITABILITY, TANGIBILITY, ln(K/L), RATING, ln(AGE), HERFINDAHL, HERFINDAHL^2, ln(REALGSP), UNEMPRATE, GSPGROW, GSPGROWLAG, TAXES/GSP, and ln(POP). All regressions are estimated with time and firm fixed effects (FE), and the standard errors reported in parentheses are corrected for the panel in all the models and are clustered at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	ln(1+CIT/PAT)$_{t+3}$	ln(1+CIT/PAT)$_{t+4}$	ln(1+CIT/PAT)$_{t+3}$	ln(1+CIT/PAT)$_{t+4}$
	1	2	3	4
TAXDECR	0.115**	0.108**		
	(0.047)	(0.046)		
TAXDECR × TAXAVOID	0.173***	0.182***		
	(0.043)	(0.041)		
TAXINCR			−0.087*	−0.087*
			(0.046)	(0.048)
TAXINCR × TAXAVOID			−0.051	−0.126***
			(0.045)	(0.045)
TAXAVOID	−0.053***	−0.051***	−0.035**	−0.026*
	(0.014)	(0.015)	(0.014)	(0.015)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	43,022	40,046	43,022	40,046
R^2	0.582	0.571	0.581	0.570

with greater tax avoidance. The negative impact of tax increases on the number of citations per patent is also greater for firms that avoid taxes more. For robustness, we exclude firms with persistent negative earnings and find similar results in Table IA.5 of the Supplementary Material. In sum, the evidence suggests that lower taxes are more beneficial for firms that engage more in tax avoidance. This evidence is again consistent with our general hypothesis that tax cuts improve firms' incentives to innovate.

This section has explored several possible channels through which corporate income taxes can affect innovation and finds evidence for each of these channels separately. Finally, we examine the effect of all mechanisms together in Table 10 in order to see if a particular mechanism dominates or if each of them has an independent effect. To assess these possibilities, we first calculate correlations between the mechanism measures and find that the correlations are small, ranging from 0.01 to 0.32. Furthermore, the regression results in Table 10 show that all of the interactions have the same signs as before and are mostly statistically significant, suggesting that all of the channels that we explore, namely, financial constraints, collateral, governance, and tax avoidance, play an important role in explaining the relation between corporate income taxes and innovation.

V. Tax Cuts and Innovation: Additional Tests for Endogeneity and Robustness Checks

A. Robustness of Tax Signals

In this section, we perform several robustness checks for the tax signals that are used to construct the main measures. As suggested by Hennessy and Strebulaev (2015), measured treatment responses may not uncover causal effects if the policy changes are anticipated. We address this concern in two ways. First, we already documented that there is no significant relation between tax cuts and innovation in the years prior to the tax changes in Table 4. This finding alleviates the concern of potential anticipated effects because the impact on innovation should show up earlier if firms do anticipate future changes in taxes. Second, Hennessy and Strebulaev (2015) show that a necessary and sufficient condition for a correct inference of causal effects is for the policy variable to be a Martingale, which in this case means that state tax rates should follow a random walk. Ljungqvist and Smolyansky (2016) test the null hypothesis of a random walk using state corporate income tax rates from 1969 to 2013. They fail to reject the null in all cases when the states are tested separately. When taking into account that some states may base their tax policy on those of their neighbors, the null is only rejected in the New England region at the 10% level. Therefore, we exclude firms located in New England states (i.e., Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont) in Panel A of Table 11 and obtain similar results, suggesting that our findings are robust to controlling for potential anticipation effects.

To further address the concern that tax cuts may be driven by local economic conditions that can affect innovation directly, we examine exogenous tax changes defined using a narrative approach. Following Romer and Romer (2010), we search news articles using LexisNexis to identify state corporate income tax

TABLE 10
Tax Changes, Mechanisms, and Innovation

Table 10 examines the role of financial constraints, collateral, governance, and tax avoidance together. We estimate the ordinary least squares (OLS) model of ln(1+CIT/PAT) on TAXDECR, which is an indicator variable equal to 1 if there has been a significant tax decrease in the largest state of business of firm *i*, and 0 otherwise, or TAXINCR, which is an indicator variable equal to 1 if there has been a significant tax increase in the largest state of business of firm *i*, and 0 otherwise, and its interaction with WWFINCON, INTANGIBLE, PATENT_STOCK, ANTITAKEOVER_INDEX, and TAXAVOID. The same set of controls from Table 3 is used, which includes ln(SALES), RD/SALES, LEVERAGE, PROFITABILITY, TANGIBILITY, ln(*K*/), RATING, ln(AGE), HERFINDAHL, HERFINDAHL^2, ln(REALGSP), UNEMPRATE, GSPGROW, GSPGROWLAG, TAXES/GSP, and ln(POP). Due to space limitations, the construction of the variables is explained in Appendix B. All regressions are estimated with time and firm fixed effects (FE), and the standard errors reported in parentheses are corrected for the panel in all the models and are clustered at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$
	1	2	3	4
TAXDECR	0.328***	0.306***		
	(0.059)	(0.059)		
TAXINCR			−0.155**	−0.128**
			(0.061)	(0.061)
TAXDECR × WWFINCON	0.109***	0.110***		
	(0.036)	(0.034)		
TAXINCR × WWFINCON			−0.045	−0.105***
			(0.044)	(0.040)
WWFINCON	−0.051***	−0.070***	−0.040***	−0.053***
	(0.013)	(0.014)	(0.013)	(0.013)
TAXDECR × INTANGIBLE	0.109**	0.118***		
	(0.048)	(0.045)		
TAXINCR × INTANGIBLE			−0.158***	−0.167***
			(0.057)	(0.054)
INTANGIBLE	0.005	−0.022	0.025	−0.000
	(0.023)	(0.023)	(0.022)	(0.022)
TAXDECR × PATENT_STOCK	−0.539***	−0.454***		
	(0.112)	(0.108)		
TAXINCR × PATENT_STOCK			0.447***	0.411***
			(0.105)	(0.101)
PATENT_STOCK	−0.381***	−0.316***	−0.475***	−0.398***
	(0.067)	(0.074)	(0.069)	(0.076)
TAXDECR × ANTITAKEOVER_INDEX	2.328***	2.236***		
	(0.609)	(0.578)		
TAXINCR × ANTITAKEOVER_INDEX			−0.604*	−0.526
			(0.311)	(0.328)
ANTITAKEOVER_INDEX	−0.732***	−0.685***	−0.650***	−0.614**
	(0.236)	(0.239)	(0.250)	(0.251)
TAXDECR × TAXAVOID	0.143***	0.147***		
	(0.039)	(0.036)		
TAXINCR × TAXAVOID			−0.051	−0.128***
			(0.044)	(0.044)
TAXAVOID	−0.050***	−0.046***	−0.034**	−0.024
	(0.015)	(0.015)	(0.015)	(0.015)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	41,334	38,509	41,334	38,509
R^2	0.590	0.579	0.588	0.578

changes that are passed independently of existing and future economic conditions. According to Romer and Romer (2010), tax changes that are passed with the motivation of dealing with an inherited budget deficit or achieving some long-run goal (e.g., increased fairness or a smaller role for government) are classified as exogenous. We redefine the main measures based on these exogenous tax changes and

TABLE 11

Robustness of Tax Signals

Table 11 tests the robustness of the tax signals. We estimate the ordinary least squares (OLS) model of ln(1+CIT/PAT) on TAXDECR or TAXINCR. In Panel A, we examine unanticipated tax changes by excluding firms located in New England states, where the null hypothesis of state corporate income taxes following a random walk is rejected. In Panel B, we define the tax-increase and tax-decrease indicators based on exogenous tax changes that are passed independently of local economic conditions using a narrative approach. In Panel C, we use the original major tax changes of 100 basis points (bps) or greater, but we also include short-term reversals within 3 years. In Panel D, we create the tax-increase and tax-decrease indicators based on major tax changes of 50 bps or greater instead of 100 bps or greater. In Panel E, the treatment group sample (firms that experience a tax decrease or a tax increase) are restricted to 5 years before and after the tax change. The same set of controls from Table 3 is used, which includes ln(SALES), RD/SALES, LEVERAGE, PROFITABILITY, TANGIBILITY, ln(K/L), RATING, ln(AGE), HERFINDAHL, HERFINDAHL^2, ln(REALGSP), UNEMPRATE, GSPGROW, GSPGROWLAG, TAXES/GSP, and ln(POP). All regressions are estimated with time and firm fixed effects (FE), and the standard errors reported in parentheses are corrected for the panel in all the models and are clustered at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, **, and *** indicate significance at the 1%, 5%, and 10% levels, respectively.

	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$
	TAXDECR	TAXDECR	TAXINCR	TAXINCR
TAXVAR	1	2	3	4
Panel A. Unanticipated Tax Changes				
TAXVAR	0.152***	0.157***	−0.071***	−0.071**
	(0.035)	(0.036)	(0.027)	(0.028)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	68,224	63,722	68,224	63,722
Panel B. Exogenous Tax Changes According to the Narrative Approach				
TAXVAR	0.167***	0.170***	−0.089***	−0.088***
	(0.038)	(0.038)	(0.032)	(0.034)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	73,065	68,203	73,065	68,203
Panel C. Tax Changes Including Short-Term Reversals				
TAXVAR	0.140***	0.142***	−0.066**	−0.068**
	(0.034)	(0.034)	(0.026)	(0.028)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	73,065	68,203	73,065	68,203
Panel D. Tax Changes of 50 bps or Greater				
TAXVAR	0.134***	0.140***	−0.043*	−0.050**
	(0.033)	(0.034)	(0.024)	(0.025)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	73,065	68,203	73,065	68,203
Panel E. Restricting the Treatment Group Sample to 5 Years before and after the Tax Change				
TAXVAR	0.143***	0.148***	−0.052**	−0.062***
	(0.030)	(0.029)	(0.023)	(0.024)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	67,950	63,344	69,178	64,582

find that these changes still significantly affect innovation, as presented in Panel B of Table 11.

When we construct our main tax variables, we do not consider significant tax changes that are reversed within 3 years. To address the concern that firms may

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react to these fleeting tax changes because they may not know that the changes will be reversed so quickly, we include these short-term reversals when constructing the main tax measures in Panel C of Table 11. We also create the tax-increase and tax-decrease indicators based on major tax changes of 50 bps or greater, instead of 100 bps or greater, and find a similar, although predictably weaker, impact on innovation, as shown in Panel D. To address the potential concern that the treatment period is too long after the tax change, we restrict the treatment-group sample (firms that experienced a tax decrease or increase) to 5 years before and after the tax change in Panel E of Table 11. In all of these panels, the key estimates are similar to those in our main analysis.

B. Addressing Additional Endogeneity Concerns

The changes in state corporate taxes are mostly exogenous to the innovative activity of the individual firm. There is no evidence suggesting that there is a coordinated effort by firms that experience an *increase* in their innovative activity and consequently lobby for tax reductions. It is also hard to understand why firms would do that in the first place. Also, it is important to understand that for many of the firms in the sample, the state where firms conduct most of their operations and where they pay income taxes are different from the state where the patenting activity occurs. This adds another layer of protection from the concern that economic factors could be driving the changes in both taxes and innovation. Nevertheless, in this section, we pursue a number of strategies to further address endogeneity concerns.

1. Controlling for Additional State-Level Variables and State-Specific Time Trends

We investigate a possible omitted-variable bias in several ways. In Panel A of Table 12, we directly control for a number of state-level variables. First, we control for changes in state capital gain tax rates, state personal income tax rates, and state R&D tax credit rates. State capital gain tax and personal income tax data come from Daniel Feenberg's Web site (http://users.nber.org/taxsim/state-rates). We obtain historical state-level R&D tax credit rates from Wilson (2009), who shows that these tax incentives are effective in increasing R&D investment within the state. Similar to the construction of our main tax measures, we create 3 indicator variables based on state capital gain tax changes, state personal income tax changes, and state R&D tax credit changes. The indicator variable is equal to 1 if at time t in state s there has been a major increase in the tax rate or tax credit, equal to -1 if there has been a major decrease, and 0 otherwise. A major change is defined as greater than or equal to 100 bps (e.g., from 7% to 6%), as long as that change is not reverted within the next 3 years.[17]

Second, we control for the political affiliation of the state governor and the legislature using data from Klarner (2013). GOVERNOR_PARTY is an indicator that equals 1 if the governor is a Democrat, -1 if the governor is a Republican, and 0 otherwise. LEGISLATURE_PARTY is an indicator that equals 1 if Democrats control both chambers, -1 if Republicans control both chambers, and 0 otherwise.

[17]For robustness, we use continuous measures of the last 3 variables and still find that our main results are unaffected.

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The idea here is that political affiliation could be driving both tax changes and innovation.

Third, some industries may have growth opportunities that induce them to lobby for tax changes or are spuriously correlated with tax changes for another reason. Moreover, if these industries are geographically clustered in certain

TABLE 12

Addressing Additional Endogeneity Concerns

In Panel A of Table 12, we control for additional state-level variables: a state capital gain tax change indicator, a state personal income tax change indicator, a state R&D tax credit change indicator, a governor party indicator, a legislature party indicator, state-level labor share (the fraction of gross state product (GSP) in state *s* and year *t* from mining, construction, manufacturing, transportation, trade, finance, services, or government industries), and labor-force concentration (the sum of the squared labor shares for state *s* in year *t*). In Panel B, state-specific time trends and industry–year fixed effects (FE) are included. In Panel C, the results from a falsification test using tax changes in neighboring states are reported. TAXDECR_IN_NEIGHBORING_STATES is an indicator variable equal to 1 if there has been a significant tax decrease in any of the neighboring states of firm *i*, and 0 otherwise. TAXINCR_IN_NEIGHBORING_STATES is an indicator variable equal to 1 if there has been a significant tax increase in any of the neighboring states of firm *i*, and 0 otherwise. In Panel D, the regression uses a system generalized method of moments (GMM) method to jointly estimate equation (1) in first differences and in levels. The same set of controls from Table 3 is used. All regressions are estimated with time and firm fixed effects (FE), and the standard errors in parentheses are clustered at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, ** and *** indicate significance at the 10%, 5%, and 1% respectively.

	$\ln(1+CIT/PAT)_{t+3}$	$\ln(1+CIT/PAT)_{t+4}$	$\ln(1+CIT/PAT)_{t+3}$	$\ln(1+CIT/PAT)_{t+4}$
	1	2	3	4
Panel A. Controlling for Additional State-Level Variables				
TAXDECR	0.131***	0.127***		
	(0.034)	(0.034)		
TAXINCR			−0.090***	−0.089***
			(0.029)	(0.030)
STATE_CAPITAL_GAIN_TAXCHG	0.089**	0.192***	0.083*	0.186***
	(0.045)	(0.053)	(0.045)	(0.053)
STATE_PERSONAL_INCOME_TAXCHG	0.040	−0.060	0.041	−0.058
	(0.048)	(0.056)	(0.048)	(0.056)
STATE_R&D_TAX_CREDIT_CHG	−0.032	−0.036	−0.039*	−0.042*
	(0.022)	(0.023)	(0.022)	(0.023)
GOVERNOR_PARTY	−0.018***	−0.013***	−0.018***	−0.013***
	(0.004)	(0.004)	(0.004)	(0.004)
LEGISLATURE_PARTY	−0.020***	−0.028***	−0.020***	−0.028***
	(0.007)	(0.007)	(0.007)	(0.007)
MINING	0.007	−0.001	0.005	−0.003
	(0.009)	(0.009)	(0.009)	(0.009)
CONSTRUCTION	0.041**	0.041**	0.042**	0.043**
	(0.017)	(0.017)	(0.018)	(0.018)
MANUFACTURING	0.031***	0.027***	0.030***	0.026***
	(0.008)	(0.008)	(0.008)	(0.008)
TRANSPORTATION	−0.005	0.005	−0.006	0.005
	(0.028)	(0.029)	(0.028)	(0.029)
TRADE	0.024	0.019	0.023	0.018
	(0.017)	(0.018)	(0.017)	(0.018)
FINANCE	−0.005	−0.005	−0.009	−0.010
	(0.010)	(0.010)	(0.010)	(0.010)
SERVICE	0.035***	0.026**	0.033***	0.023*
	(0.012)	(0.012)	(0.012)	(0.012)
GOVERNMENT	−0.036**	−0.043**	−0.038**	−0.045**
	(0.016)	(0.018)	(0.016)	(0.018)
LABOR_FORCE_CONCENTRATION	−0.008	−0.002	0.000	0.006
	(0.015)	(0.016)	(0.015)	(0.016)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	72,761	67,915	72,761	67,915
R^2	0.569	0.563	0.569	0.563

(continued on next page)

TABLE 12 (continued)
Addressing Additional Endogeneity Concerns

	$\ln(1+CIT/PAT)_{t+3}$	$\ln(1+CIT/PAT)_{t+4}$	$\ln(1+CIT/PAT)_{t+3}$	$\ln(1+CIT/PAT)_{t+4}$
	1	2	3	4
Panel B. Controlling for State-Specific Time Trends and Industry–Year Fixed Effects				
TAXDECR	0.094***	0.100***		
	(0.028)	(0.027)		
TAXINCR			−0.050**	−0.041**
			(0.021)	(0.020)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
State time trends	Yes	Yes	Yes	Yes
Industry × year FE	Yes	Yes	Yes	Yes
No. of obs.	72,822	67,965	72,822	67,965
R^2	0.604	0.602	0.604	0.602
Panel C. Falsification Test Using Neighboring States				
TAXDECR	0.135***	0.137***		
	(0.034)	(0.025)		
TAXDECR_IN_NEIGHBORING_STATES	−0.088***	−0.077***		
	(0.020)	(0.021)		
TAXINCR			−0.091***	−0.088***
			(0.027)	(0.028)
TAXINCR_IN_NEIGHBORING_STATES			0.047***	0.027**
			(0.019)	(0.019)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	73,065	68,203	73,065	68,203
R^2	0.567	0.560	0.567	0.560
Panel D. Regressions Using System GMM				
TAXDECR	0.137***	0.153***		
	(0.045)	(0.050)		
TAXINCR			−0.136***	−0.138***
			(0.046)	(0.050)
$\ln(1+CIT/PAT)_t$	1.015***	0.873***	0.989***	0.877***
	(0.115)	(0.126)	(0.114)	(0.129)
$\ln(1+CIT/PAT)_{t-1}$	−0.183	−0.115	−0.161	−0.124
	(0.127)	(0.146)	(0.127)	(0.151)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	71,099	66,317	71,099	66,317

locations, it may create a noncausal correlation between state-level tax changes and corporate innovation (Lerner and Seru (2015)). To address this concern, we first exclude firms from California or Massachusetts from our analysis and find similar results as reported in Table IA.1 of the Supplementary Material. To further address this concern, we follow the methodology of Cornaggia et al. (2015) to control for state-level labor-force concentration and state-level labor share, which is defined as the fraction of gross product in state i in year t that is from mining, construction, manufacturing, transportation, trade, finance, services, and government industries.

The above 14 state-level variables are included as additional controls in Panel A of Table 12. We find that tax cuts continue to have a significant positive effect on the quality of innovation. The magnitudes of the effects are also similar to the baseline case, suggesting that our prior results are not driven by these additional state-level variables. In Panel B of Table 12, we control for additional unobserved time-varying state characteristics through state-specific time trends. In addition, we also control for industry–year fixed effects to account for any unobserved time-varying industry characteristics (e.g., changes in growth opportunities). The main effects of the tax decreases still remain, suggesting that the documented relations are not driven by state-specific time trends and time-varying industry factors.

2. Falsification Test Using Neighboring States

To further address concerns of omitted variables, we conduct a falsification test based on Heider and Ljungqvist (2015) by comparing the effect of tax cuts on neighboring states and the firms' own states in Panel C of Table 12. The idea is that if local economic conditions are driving our results, these conditions likely affect both the state in question and its neighboring states. Even if the effect does not have the same magnitude, it should have the same sign. Thus, if tax changes in neighboring states have similar effects as tax changes in the firm's own state, then the results are likely due to common economic conditions rather than tax changes. It is worth noting that the test does not rely on firms on either side of the state border being randomly distributed. It takes as given that firms are already residing in the state of their choice for whatever reason and asks how a tax decrease affects otherwise similar firms in the neighboring states.

As shown in Panel C of Table 12, the coefficients on the tax-decrease indicator are significant and positive, as in the baseline case. At the same time, tax decreases in neighboring states have a negative and significant effect on the number of citations per patent. Because tax changes in neighboring states have opposite effects as tax changes in the firm's own state, the evidence is not consistent with unobserved region-specific economic conditions common to neighboring states driving both innovation and tax changes. Instead, the opposite impact of tax cuts in neighboring states is indicative of a competition (beggar-thy-neighbor) effect. Firms operating in a state that introduces a tax cut will see their pledgeable income increase. Consequently, they will be more likely to attract additional investment in the form of money, time, and effort from their stakeholders. Financiers are likely more willing to invest in firms with higher after-tax profits. Talented individuals are also more likely to move to or stay (if they were planning a move for other reasons) in firms operating in states with lower tax rates if their incentives are positively affected by after-tax profits. As a result, when the neighboring states of the focal state s introduce tax decreases, firms in the focal state s are likely to experience a reduction in innovative output due to relatively higher financing costs and a net outflow of talented workers. It is worth noting that although tax decreases in the firm's own state and the neighboring states have opposite effects, the two effects do not completely cancel out, so the overall positive effect of tax cuts still remains.

3. Other Alternative Explanations

In Panel D of Table 12, we examine whether our results are affected by controlling further for innovation dynamics. Including citations per patent at time t and $t-1$ in a regression with firm fixed effects, however, can introduce a dynamic-panel bias (Nickell (1981)). To address this potential issue, we follow prior studies (e.g., Faulkender, Flannery, Hankins, and Smith (2011), Brown and Martinsson (2016)) and use a generalized method of moments (GMM) to jointly estimate equation (1) in first-differences and in levels. We use lagged levels (at $t-3$ and $t-4$) of the right-hand-side variables as instruments for the regression in differences and use lagged differences (at $t-2$) of the right-hand-side variables as instruments for the regression in levels. The results show that the coefficients on the tax-decrease and tax-increase indicators continue to have the same sign and significance as before, suggesting that controlling for these dynamics does not affect our baseline estimates.

Another possible explanation suggests that our results are not due to firms creating more patents on their own but, rather, acquiring other firms with patents. In Table IA.6 of the Supplementary Material, we test this explanation in two ways. First, we control for the firms' merger and acquisition activities in the year in which innovation is recorded. Second, we run regressions only on observations of firms with no mergers or acquisitions. In both tests, the key coefficients on tax increases and decreases remain significant and similar to the baseline case, suggesting that our main results are not mainly driven by firms acquiring other firms with patents.

Another alternative explanation that we consider is that firms observe tax decreases in neighboring states and anticipate similar changes in their own states, thus withholding innovation until tax changes are implemented. Because the innovation lag is highly uncertain, it would require that managers possess great predictive power to time the tax change and the resulting innovation. The premise of this explanation is that firms can predict tax changes in their own states based on tax changes in neighboring states. We test this premise in Table IA.2 of the Supplementary Material. The results show that tax changes in state s are unrelated to tax changes in the neighboring states. This finding does not support the alternative explanation and further corroborates our hypothesis of a causal impact of tax changes on innovation.

C. Additional Robustness Tests on Identifying the Most Relevant State for Tax Purposes

In this subsection, we conduct additional robustness analysis to ensure that our results are not driven by the definition of the most relevant state. We start with the observation that many firms operate in multiple states. As described earlier, we use state count information from 10-K reports to identify the most relevant state for a firm in terms of the burden of corporate income taxes. Here, we examine the validity of this definition by relating the amount of total state taxes paid to tax changes in the most mentioned state. If the identified state is indeed important for tax purposes, then we should expect to see a significant negative relation between tax decreases in that state and the total state taxes paid and a positive relation between tax increases in that state and the total state taxes paid.

The results in Panel A of Table 13 confirm this prediction. The coefficient in column 1 suggests that on average, tax decreases reduce the total state taxes paid by the firms in our sample by 20.7%. Similarly, the coefficient in column 2 suggests that on average, tax increases raise total state taxes paid by 17.3% above the mean of the ratio of state taxes paid to pretax income (2.76%). By the same

TABLE 13
Additional Analysis of the Most Relevant State

Panel A of Table 13 estimates the ordinary least squares (OLS) model of state taxes/pretax income on TAXDECR and TAXINCR, which equal to 1 if there has been a significant tax decrease (increase) in the most (or least) mentioned state for firm *i*, and 0 otherwise. Panel B performs robustness checks for the most relevant state used to identify tax changes. The same set of controls from Table 3 is used. All regressions are estimated with time and firm fixed effects (FE), and the standard errors in parentheses are corrected for clustering at the firm level. The sample consists of firm-year observations from 1988 to 2006. *, **, and *** indicate significance at the 1%, 5%, and 10% level, respectively.

Panel A. Tax Changes and State Taxes Paid

	(State Taxes/Pretax Income) $_{t+1}$			
	1	2	3	4
TAXDECR (most mentioned state)	−0.570***			
	(0.180)			
TAXINCR (most mentioned state)		0.477***		
		(0.169)		
TAXDECR (least mentioned state)			0.064	
			(0.180)	
TAXINCR (least mentioned state)				−0.013
				(0.148)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. of obs.	63,058	63,058	63,058	63,058
R^2	0.259	0.259	0.259	0.259

Panel B. Robustness Checks of the Most Relevant State

	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$	$\ln(1+\text{CIT/PAT})_{t+3}$	$\ln(1+\text{CIT/PAT})_{t+4}$
TAXVAR	TAXDECR	TAXDECR	TAXINCR	TAXINCR
Time-varying most mentioned state	0.087***	0.078***	−0.063**	−0.070***
	(0.018)	(0.017)	(0.028)	(0.027)
No. of obs.	40,791	37,628	40,791	37,628
Top 3 most mentioned states	0.129***	0.121***	−0.067***	−0.061***
	(0.026)	(0.027)	(0.022)	(0.023)
No. of obs.	73,065	68,203	73,065	68,203
States with at least 30% counts	0.146***	0.150***	−0.076***	−0.084****
	(0.033)	(0.034)	(0.026)	(0.027)
No. of obs.	72,938	68,080	72,938	68,080
Firms with 1–3 equivalent states	0.235***	0.249***	−0.146***	−0.146***
	(0.050)	(0.049)	(0.039)	(0.041)
No. of obs.	31,302	29,000	31,302	29,000
Headquarters (HQ) state	0.102***	0.097***	−0.080***	−0.083***
	(0.032)	(0.033)	(0.027)	(0.028)
No. of obs.	63,741	59,087	63,741	59,087
State with most patents	0.136**	0.145***	−0.090**	−0.085*
	(0.041)	(0.038)	(0.037)	(0.036)
No. of obs.	37,699	35,618	37,699	35,618
State with most subsidiaries	0.339***	0.385***	−0.183***	−0.190***
	(0.056)	(0.052)	(0.044)	(0.047)
No. of obs.	53,477	50,611	53,477	50,611
Same HQ and most mentioned state	0.162***	0.138***	−0.103***	−0.110***
	(0.047)	(0.048)	(0.039)	(0.041)
No. of obs.	38,850	36,235	38,850	36,235

rationale, we should not expect to see a significant relation between total state taxes paid and tax changes in the least mentioned state if using state counts to identify the location of businesses is valid. We find results consistent with this prediction in columns 3 and 4 of Panel A, providing additional support for our identification of the most relevant state.

Furthermore, we perform several robustness checks for the identification of the most relevant state in Panel B of Table 13. In the main analysis, we use the most mentioned state over the 1988–2006 period so that there is one corresponding state per firm, and it does not vary over time. For robustness, we identify the most mentioned state for each firm-year and continue to find a similar and significant relation between tax cuts in the time-varying most mentioned state and the number of citations per patent, although the sample size is smaller. As another robustness check, instead of the single most mentioned state, we look at the top 3 most mentioned states and define the tax variable to be 1 if there is a significant tax change in any of the top 3 most mentioned states in which the firm operates. Alternatively, instead of using the single most mentioned state based on the 10-K reports, we use all states that are mentioned at least 30% of the time on average. As shown in Panel B, our main findings are robust to using multiple states, rather than the single most mentioned state. We also restrict the sample to firms with fewer than three equivalent states, where the number of equivalent states is calculated as 1 divided by the Herfindahl index of the state distribution for each firm. The rationale behind this is that if a firm operates only in a small number of states, the impact of tax changes will be more significant than if the firm's operations are spread out in many states. Consistent with this idea, we find that the coefficients are not only significant but also larger than those in the main analysis.

Finally, we use alternative definitions of the most relevant state based on the headquarters, the locations of patent grants, and subsidiary locations and find similar results.[18] As another robustness check, we also restrict the sample to firms that have the same headquarters as the most mentioned state. Together, the analyses in this section provide strong support for our identification of the most relevant state and confirm the robustness of our main findings.

D. Other Robustness Checks

We conduct a series of robustness checks in Table IA.1 of the Supplementary Material to document that our results are robust to subsample analysis, different clustering, and variable definitions. We perform several subsample analyses. First, we only include firms with the same time-varying most mentioned state during the entire sample period. Second, we exclude firms with nonpositive total state corporate income taxes paid (TXS). Third, we exclude noninnovative firms (i.e., firms with no patent during the entire sample period) and firms with no positive R&D expenditures during the entire sample period. Fourth, we exclude firms located in California or Massachusetts from our sample. Fifth, we end the sample in 2003 rather than 2006 to account for the increased patent-citation truncation bias during the 2003–2006 period.

In the main analysis, we cluster the standard errors by firm. For robustness, we also cluster the standard errors by year, by the state of location, or by both state of location and year. Next, instead of using the number of citations per patent

[18] Historical headquarters location comes from Compact Disclosure and parsed 10-K data from Bill McDonald's Web site. Patent location data come from the NBER, where we identify the most relevant state as the state where most of the firm's patents are assigned. The number of observations is smaller for this sample because patent location is only available for firms with at least one patent in a given year. Firms' subsidiaries information comes from Exhibit 21 of the 10-K reports collected by Dyreng and Lindsey (2009). Using this data, we identify the most relevant state as the state with the highest number of subsidiaries.

adjusted for truncation based on a quasi-structural model to estimate the citation lag, we use different variable definitions for our dependent variables, following Hall et al. (2001). First, we use the unadjusted number of citations per patent. Second, we use the fixed-effects methodology that controls for truncation and construct a measure of innovation that purges the citations-per-patent measure from time fixed effects and only compares patents applied for in the same year. Third, we construct another measure of innovation that purges the citations-per-patent measure from both time and technology-class fixed effects. It controls for the fact that different technology classes have different propensities to patent their innovations and to be cited subsequently. Our results are robust in all of these cases.

VI. Discussion of the Related Study by Mukherjee et al. (2017)

Our findings are different from a recent article by Mukherjee et al. (MSZ) (2017) that also studies the impact of corporate income taxes on innovation. The most important difference is that we document a significant positive effect of tax cuts on innovation, whereas they find an insignificant effect. Furthermore, unlike MSZ, we also provide evidence on several previously unexplored mechanisms that illuminate our understanding of why tax cuts are an important driver of corporate innovation. In this section, we discuss the differences between the articles and provide an explanation of why these differences may occur based on the research design, methodology, sample selection, and variable definitions.

Whereas we document a symmetric effect of tax increases and decreases on corporate innovation, MSZ (2017) find a significant effect only for tax increases. However, the asymmetry is hard to motivate and cannot be derived from the theoretical model. MSZ consider several reasons for the asymmetrical effect but do not find much support for them. They also hypothesize, but do not empirically test, that the asymmetrical effect may be due to labor-market frictions, which lead to asymmetric adjustment costs that make it easier to reduce the workforce following tax increases than to acquire new innovators following tax decreases. We test this hypothesis in the Supplementary Material by interacting their tax measures with wrongful discharge laws. The idea is that because wrongful discharge laws make it more difficult to fire employees, if their rationale is correct, the passage of these laws should attenuate the negative impact of tax increases (i.e., a positive interaction term), thus making the impact of tax changes more symmetrical. In Table IA.14 of the Supplementary Material, we create a composite strong-labor index based on the three types of wrongful discharge laws: the good-faith exception, the public policy exception, and the implied-contract exception. The results in Panel A show that there is a significant negative interaction between the tax-increase measure and the strong-labor index, which does not support their hypothesis of labor-market friction. Therefore, the asymmetric effect MSZ find is puzzling and hard to explain.

Another issue with the results of MSZ (2017) is that they find that the negative impact of tax increases on innovative output is mostly for years 1 and 2, and the effect appears as early as year 0 (i.e., the year of the tax increase). The quick response in innovation is puzzling because innovation is a long-term process, and innovative output can take several years to materialize (Griliches (1990), Hall et al. (2001), (2005)). Even more puzzling, MSZ also look at new-product announcements and find a significant negative effect of tax increases in year 1. Although there should be a lag between tax changes and changes in patent output, there should also be another lag between innovation and the launching of new products, so the effect in year 1 is too quick to rationalize.

The difference in our findings can be partly due to the fact that we use state mentions in 10-K filings to better define the most relevant state, whereas MSZ (2017) use headquarters state. For 36% of the firms in our sample, the most mentioned state is different from the headquarters state. Because the state of company headquarters is often not where most of the profits are generated, using the headquarters state can lead to some differences in results.

In addition, we focus on major tax changes that are not reversed within 3 years in order to identify more permanent tax signals that are likely to have an impact on a long-lasting process such as corporate innovation. In contrast, MSZ (2017) use all tax changes, many of which are small and transitory. Their approach can be problematic because it is unlikely that firms will react to small and transitory changes, and including them increases the likelihood that the captured effects are noisy or spurious. Moreover, many small changes occur around the same time, making it difficult to assess their impact, especially with time lags between tax changes and innovation. This problem is especially exacerbated when tax increases and decreases occur within a short period. For example, Connecticut has a tax increase in 1990 and a tax decrease in 1992. So, the change in innovation in 1993 would be year $t+3$ for the tax increase and also year $t+1$ for the tax decrease, which is very problematic because tax increases and decreases are predicted to have opposing effects on innovation. This issue is not isolated; it happens in 30 of the 85 tax changes that MSZ examine.

Furthermore, we use a DID methodology to capture the effect of tax changes on innovation, following many prior studies in the innovation literature (e.g., Bertrand and Mullainathan (2003), Atanassov (2013), Acharya et al. (2014), and Cornaggia et al. (2015)). In contrast, MSZ (2017) use a first-difference methodology. In Table IA.15 of the Supplementary Material, we use a simple example to compare the two approaches in the context of innovation. Although the plots clearly show that tax decreases have a positive impact on patent count, the key coefficients in MSZ's model are all insignificant. This suggests that unlike the fixed-effects methodology, the first-difference methodology used by MSZ has a difficult time correctly capturing changes in innovation outputs that occur with uncertain lags. Because an uncertain and poorly defined lag is a key characteristic of innovative output (Griliches (1990)), using the first-difference methodology in this context is problematic and could be the reason why they do not find a significant effect of tax cuts on innovation.

Finally, to further explore these issues in their study, we attempt to replicate the main results of MSZ (2017) in Table IA.13 of the Supplementary Material using their tax variables, model specifications (i.e., first differences), and sample construction. We find that tax increases are negatively related to the number of patents and that tax decreases are unrelated to the number of patents,

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consistent with their study. However, when an alternative state definition based on the most mentioned state is used, neither tax increases nor decreases are significantly related to the number of patents. Moreover, the relation between tax increases and innovation quality is not robust across different citations-per-patent measures. These results suggest that the documented effects in MSZ may be noisy and less robust, likely due to the issues mentioned previously.

VII. Conclusion

This article presents new evidence on the impact of corporate income taxes on the quantity and quality of innovation. We are the first to document that significant tax cuts lead to higher innovative output. Exploring the channels, we find that tax cuts have a larger impact on innovation for firms that are more financially constrained, have smaller collateral, have weaker corporate governance, and avoid taxes more. Our results are confirmed after a battery of additional endogeneity checks and robustness tests. These findings suggest that by affecting firms' pledgeable income, corporate income tax policies can significantly affect firms' incentives to innovate and therefore have strong implications on long-term firm performance and economic growth. Our findings also have significant policy implications related to corporate tax cuts at both the state and federal levels.

Appendix A. Theoretical Model and Hypothesis Development

In Appendix A, we present a simple model based on Tirole (2006) to formally explain how taxes affect the incentives of entrepreneurs to innovate rather than engage in routine or nonproductive activities and the incentives of financiers to provide financing based on whether entrepreneurs behave (innovate) or misbehave (pursue routine projects or shirk). Here, we assume that "entrepreneur" is a general name for firm stakeholders (e.g., managers and employees) who take part in the innovative process, whereas "financier" refers to shareholders or creditors that decide whether or not to finance the innovative projects of the firm.

We start by presenting the baseline model, in which entrepreneurs enjoy private benefits of control if they shirk, and there are no taxes. We then introduce taxes and show how they affect the incentives of entrepreneurs. We also show that the impact of tax cuts is stronger for firms with greater private benefits of control or with weaker balance sheets (more financially constrained). The novelty of this model, compared with the previous literature that studies the effect of taxes on investment (Hall and Jorgenson (1967), Auerbach and Hassett (1992), Cummins et al. (1996), Hines and Rice (1994), Hassett and Hubbard (2002), and Djankov et al. (2010)), is that we show that private benefits of control and differential effort are essential for understanding the impact of taxes on the incentives to innovate. The model could, of course, be generalized not only to innovation but to other types of inputs and outputs of the production process. This fact does not diminish the conclusions regarding innovation. Furthermore, innovative projects are especially prone to agency and asymmetric-information problems, which makes this model particularly relevant for these types of projects.[19]

[19]Because we follow very closely the base model presented by Tirole (2006), we do not go over all the details and justify all the assumptions. For more thorough explanations, the reader should consult the original text. Our contribution here is to extend Tirole's model by introducing taxes and showing

1. The Case of No Income Taxes

For continuity, we first present the baseline model without taxes. We assume that there is an entrepreneur who has a choice between an innovative, risky project and a routine, risk-free project. The entrepreneur provides initial resources in the form of cash and other tangible (property, plant, equipment) and intangible (patents, trademarks, know-how, trade secrets) assets in the amount of A, and the innovative project requires a total investment in the amount of I. Therefore, the entrepreneur needs additional financing, which does not have to be only monetary, equal to $I-A$. This is a fixed-investment model that assumes rapid decreasing returns after the project has reached its investment level I.[20]

We assume that there is a principal–agent problem between the firm's financiers and the entrepreneur (managers and creative employees in publicly traded firms). In this model, the problem is depicted by the size of the private benefits of control B. Larger values of B imply greater private benefits of control. They can take the form of perk consumption (Yermack (2006)), theft, or simply shirking and enjoying the quiet life (Bertrand and Mullainathan (2003)). In the case of innovation, perk consumption could involve not innovating at all, pursuing routine projects, or creating low-impact patents. We assume that the size of private benefits is determined by the strength of corporate governance. Ceteris paribus, firms with stronger governance will have smaller private benefits of control B.

This is a 2-period model. In the first period, the entrepreneur invests in the project if he or she is able to obtain the additional financing in the amount of $I-A$. In the second period, the return $R>0$ is realized if the project is successful, and it is shared between the entrepreneur, in the amount of R_e, and the financiers, in the amount of R_f, where $R_e+R_f=R$. If the project is not successful, the return is equal to 0. For simplicity, the model assumes that the risk-free discount rate is equal to 0, and the return, the investment, the cash, and the private benefits of the routine project are normalized to 0. More generally, all the variables (A, I, B, R, etc.) can be considered as the difference between the innovative project and the routine project. In the first period, the entrepreneur decides whether to behave (work hard, stay focused, be creative, not steal, etc.) or misbehave (shirk, enjoy the quiet life, pursue routine projects, steal, etc.). If the entrepreneur behaves, the probability of success is P_H, and if he or she misbehaves, the probability of success is P_L, where $P_H>P_L$. To keep the analysis interesting, the model assumes that if the entrepreneur behaves, the project is profitable, and if he or she misbehaves, the project is not profitable. That is, $P_H R-I>0$ and $P_L R-I+B<0$. Therefore, financiers will not invest in the project if they expect that the entrepreneur will misbehave. The entrepreneur and financiers are risk neutral, and the financial markets are competitive, and therefore the financiers make 0 profit in equilibrium.

The incentive compatibility constraint (IC) for the entrepreneur is $P_H R_e \geq P_L R_e + B$. Rearranging, we get $R_e \geq B/\Delta P$, where $\Delta P = P_H - P_L$. This inequality tells us that the financiers need to leave at least $B/\Delta P$ to the entrepreneur to incentivize him or her to behave. The participation constraint for the financiers is $P_H R_f = I-A$. The participation constraint is satisfied with an equality due to the competitive nature of the financial markets. It follows that the return to the financiers is $R_f=(I-A)/P_H$. Because $R_e+R_f=R$, we can substitute in the IC constraint and obtain $R-(I-A)/P_H \geq B/\Delta P$. Transforming further, we get $P_H(R-B/\Delta P) \geq I-A$. This inequality says that the expected pledgeable income has to be greater than the investment by the financiers for the entrepreneur to have an incentive to behave and pursue the innovative project and

that changes in tax rates affect the likelihood of pursuing innovative projects and that the likelihood depends on financial constraints.

[20]The results also hold in the variable investment model that assumes constant returns to scale. We assume fixed investment here to keep the model as simple as possible.

therefore to receive that additional financing to complete the project. Rearranging, the result is that if $A \geq \bar{A} = P_H B/\Delta P - (P_H R - I)$, the entrepreneur will behave, receive the additional financing, and complete the innovative project. Therefore, $\bar{A}$ is the minimum net worth (initial resources) that the entrepreneur needs to have to obtain the additional financing.

2. The Case of Income Taxes

Now we introduce income taxes and compare the outcome to the outcome without taxes. We investigate whether income tax rates can affect the incentives of the entrepreneur to behave and, hence, whether he or she receives additional financing and undertakes the innovative project. We introduce two simple assumptions.

Assumption 1. An amount equal to TR is collected by the government.

Assumption 2. All investment is tax deductible.

The consequence from these assumptions is that the total investment requirement is only $I(1-T)$, and the additional investment needed by the entrepreneur is $I(1-T)-A$. That is the case because, effectively, the firm will obtain a tax credit in the amount of TI after the project is completed, and the discount rate is normalized to 0.[21] The assumption that all investment is tax deductible is somewhat stringent. If part of the investment is not tax deductible, our results that follow would be even stronger and in the same direction. Therefore, we adopt the second assumption to be more conservative because most of the investment in the innovative project is in the form of R&D expenditures, which are usually tax deductible. In this sense, our model differs from other models that may consider different types of investments. This assumption is, however, without loss of generality.[22]

The IC constraint for the entrepreneur with taxes is then $R_e \geq B/\Delta P$. The participation constraint for the financiers is $P_H R_f = I(1-T)-A$. It follows that the return to the financiers is $R_f = (I(1-T)-A)/P_H$. In the case of taxes, R_f and R_e are the after-tax returns to the financiers and the entrepreneur. Therefore, $R_f + R_e = R(1-T)$, and we can substitute in the IC constraint and obtain:

$$P_H\left(R(1-T) - \frac{B}{\Delta P}\right) \quad \geq \quad I(1-T) - A.$$

The minimum level of assets that the entrepreneur must have to obtain financing in the presence of taxes is then:

$$\bar{A}_T \quad = \quad \frac{P_H B}{\Delta P} - (1-T)(P_H R - I).$$

If we take the difference between the minimum assets required to obtain additional investment with and without taxes, we get:

$$\begin{aligned} \bar{A}_T - \bar{A} \quad &= \quad \frac{P_H B}{\Delta P} - (1-T)(P_H R - I) - \frac{P_H B}{\Delta P} + (P_H R - I) \\ &= \quad T(P_H R - I) > 0, \end{aligned}$$

if the firm has a positive-NPV project and if $T > 0$. Therefore, firms with positive-NPV projects that have assets A, such that $\bar{A}_T > A > \bar{A}$, will not have the incentives to behave

[21] This is without loss of generality.

[22] The additional financing can be in the form of extra incentive compensation to top managers and not necessarily for R&D expenditures. In the Supplementary Material, we investigate this prediction and find supportive evidence that stock-option-based compensation to top-level executives decreases (increases) after a significant tax increase (decrease).

and therefore would not be able to obtain additional financing because of taxes, whereas they would have undertaken the project if there were no taxes. The government in this case acts as an additional financier. Because of the higher cut demanded, there is not enough income left to the entrepreneur to incentivize him or her to behave and pursue the innovative project.

More generally, differentiating $\bar{A}_T$ with respect to T, we obtain:

$$\frac{\partial \bar{A}_T}{\partial T} \quad = \quad P_H R - I \quad > \quad 0.$$

That is, ceteris paribus (for a given distribution of A, R, I, P_H, P_L, and B), a tax cut will lower the necessary additional financing for innovative projects, and therefore it will make it easier to create more innovations. In other words, lowering the tax rate increases the pledgeable income and makes it more likely that the entrepreneur works and innovates rather than shirks and undertakes the routine project.

Hypothesis 1. Tax cuts increase firms' pledgeable income and lead to more innovation.

3. Financial Constraints, Tangible Assets, and Patent Stock

It is easy to extend the previous analysis to show that firms that are more financially constrained will benefit more from lower tax rates. In this simple model, we measure financial constraints by the availability of assets in hand that includes cash A. We can see that a firm that has a level of cash A_c, where $\bar{A}_T \geq A_c \geq \bar{A}$, will not obtain additional financing for its innovative project, whereas a firm with cash equal to $A_{nc} \geq \bar{A}_T$ will obtain additional financing. Under the no-tax case, both firms will obtain additional financing and innovate. Therefore, the financially constrained firm will benefit more from a reduction in tax rates that will bring $\bar{A}_T$ below A_c and make additional investment in the innovative project possible.

Hypothesis 2. Financially constrained firms will benefit more from a reduction in tax rates and will be hurt more by an increase in tax rates.

Although A mostly represents cash, it can also be a measure of other tangible assets or patent stock that the entrepreneur or the firm will bring to the innovative project. We would therefore expect that firms with fewer tangible assets (property, plant, and equipment) or fewer assets that can be collateralized (e.g., previous patent stock) (Hochberg et al. (2015)) will benefit more from tax decreases.

Hypothesis 3. Firms with fewer tangible assets or a smaller previous patent stock will benefit more from a reduction in tax rates.

4. Private Benefits of Control and Corporate Governance

Finally, the size of private benefits may also affect the relation between tax cuts and innovation. It is obvious that if private benefits of control are absent, and the entrepreneur always exerts high effort (no agency problems), positive-NPV projects will always be financed with or without taxes. To derive a prediction for the effect of private benefits, we start with the key inequality for the case of no income taxes that $P_H(R - B/\Delta P) \geq I - A$. Rearranging, the result is that if $B \leq \bar{B} = \Delta P(R - I/P_H) + (\Delta P/P_H)A$, the entrepreneur will receive the additional investment. Therefore, $\bar{B}$ is the maximum size of private benefits that the entrepreneur can have to obtain the additional investment.

The analogous inequality for the case with income taxes is $P_H(R(1-T) - (B/\Delta P)) \geq I(1-T) - A$. Rearranging, the maximum size of private benefits that the entrepreneur can have to obtain additional investment is $\bar{B}_T = \Delta P(1-T)(R - (I/P_H)) + (\Delta P/P_H)A$. If we take the difference between the maximum size of private benefits allowed to obtain additional investment with and without taxes, we get $\bar{B}_T - \bar{B} = \Delta P(1-T)(R-(I/P_H)) + (\Delta P/P_H)A - \Delta P(R-(I/P_H)) - (\Delta P/P_H)A = -T\Delta P(R-(I/P_H)) < 0$ if the firm has a positive-NPV project and if $T>0$. Therefore, firms with positive-NPV projects that have private benefits B^H, where $\bar{B}_T < B^H < \bar{B}$, will not obtain additional financing when there are corporate income taxes, whereas a firm with $B^L < \bar{B}_T$ will. Under the no-tax case, both firms will obtain additional financing and innovate.

More generally, differentiating $\bar{B}_T$ with respect to T, we obtain $\partial\bar{B}_T/\partial T = -\Delta P(R-(I/P_H)) < 0$, which indicates that $\bar{B}_T$ increases with decreasing tax rates. Therefore, the firm with more private benefits (weaker governance) will benefit more from a reduction in tax rates that will bring $\bar{B}_T$ above B^H and make additional investment in the innovative project possible. Thus, we have the following prediction:

Hypothesis 4. Firms with greater private benefits (weaker corporate governance) will benefit more from a reduction in tax rates.

In the empirical analysis, we test these 4 hypotheses and provide a detailed analysis of the impact of tax cuts on innovation.

Appendix B. Definitions of Main Variables

PATENT$_{it}$: Count of the number of patents in application year t by firm i. *Source:* NBER patent data.

CIT/PAT$_{it}$: The number of citations per patent applied for in year t by firm i adjusted for truncation using a quasi-structural model to estimate the citation lag, where each patent citation is multiplied by an index created by econometrically estimating the distribution of the citation lag (the time from the application of the patent until a citation is received). *Source:* NBER patent data.

TAXDECR$_{st}$: An indicator variable equal to 1 if there has been a significant tax decrease of at least 100 bps in the largest state of business of firm i in year t, and 0 otherwise. The tax variable equals 1 in the year of the change and all subsequent years unless the tax rate is reverted back to the level before the change.

TAXINCR$_{st}$: An indicator variable equal to 1 if there has been a significant tax increase of at least 100 bps in the largest state of business of firm i in year t, and 0 otherwise. The tax variable equals 1 in the year of the change and all subsequent years unless the tax rate is reverted back to the level before the change.

TAXCHG$_{st}$: An indicator variable equal to 1 if there has been a significant tax increase of at least 100 bps in the largest state of business of firm i in year t, equal to -1 if there has been a significant tax decrease of at least 100 bps in the largest state of business of firm i in year t, and 0 otherwise. The tax variable equals 1 or -1 in the year of the change and all subsequent years unless the tax rate is reverted back to the level before the change.

ln(SALES)$_{it}$: Natural logarithm of sales (SALE, in $millions) of firm i in year t. *Source:* Compustat.

RD/SALES$_{it}$: R&D expenditure (XRD) of firm i in year t divided by sales (SALE). *Source:* Compustat.

LEVERAGE$_{it}$: Total debt of firm i in year t divided by total assets (AT), where total debt = short-term debt (DLC) + long-term debt (DLTT). *Source:* Compustat.

PROFITABILITY$_{it}$: EBIDTA of firm i in year t divided by total assets. *Source:* Compustat.

TANGIBILITY$_{it}$: Net property, plant, and equipment (PPENT) of firm i in year t divided by total assets. *Source:* Compustat.

$\ln(K/L)_{it}$: Natural logarithm of net property, plant, and equipment (PPENT) of firm i in year t divided by the number of employees (EMP). *Source:* Compustat.

RATING$_{it}$: An indicator that equals 1 if the firm-year has a debt rating from S&P, and 0 otherwise. *Source:* Compustat.

ln(AGE)$_{it}$: Natural logarithm of the age of firm i in year t based on the years in the Compustat sample. *Source:* Compustat.

HERFINDAHL$_{it}$: Herfindahl index of firm i in year t constructed based on sales at both the 4-digit SIC and, for robustness, for the Fama and French (1997) 48 industries. *Source:* Compustat; Kenneth French's Web site.

ln(REALGSP)$_{st}$: Natural logarithm of state-level real GSP per capita in state s in year t. *Source:* Cleveland Federal Reserve and the Bureau of Economic Analysis.

UNEMPRATE$_{st}$: State-level unemployment rate in state s in year t. *Source:* Cleveland Federal Reserve.

GSPGROW$_{st}$: The ratio of state s's GSP in year t divided by its GSP in $t-1$, and minus 1. *Source:* Cleveland Federal Reserve and the Bureau of Economic Analysis.

GSPGROWLAG$_{st}$: The ratio of state s's GSP in year $t-1$ divided by its GSP in $t-2$, and minus 1. *Source:* Cleveland Federal Reserve and the Bureau of Economic Analysis.

TAXES/GSP$_{st}$: Total state tax revenue divided by GSP in state s and year t. *Source:* Cleveland Federal Reserve and the Bureau of Economic Analysis.

ln(POP)$_{st}$: Natural logarithm of the state population in state s and year t. *Source:* U.S. Census Bureau.

WWFINCON$_{it}$: An indicator variable equal to 1 if the firm is in the top tercile of the yearly WW (2006) index, and 0 otherwise. The WW index is constructed following Whited and Wu (2006) as

$$\begin{aligned}&-0.091 \times \frac{ib_t + dp_t}{at_t} - 0.062 \times I(dvc_t + dvp_t > 0) + 0.021\\&\times \frac{dltt_t}{at_t} - 0.044 \times \ln(at_t) + 0.102 \times \text{SALES\_GROWTH}_{3\text{SIC}}\\&- 0.035 \times \text{SALES\_GROWTH},\end{aligned}$$

where SALES_GROWTH is the annual percentage increase in sales, and SALES_GROWTH$_{3\text{SIC}}$ is the average industry sales growth for each 3-digit SIC industry and year. *Source:* Compustat.

KZFINCON$_{it}$: An indicator variable equal to 1 if the firm is in the top tercile of the yearly Kaplan and Zingales (1997) (KZ) index, and 0 otherwise. The KZ index is constructed as

$$\begin{aligned}&-1.0019 \times \frac{ib_t + dp_t}{ppent_{t-1}} + 0.2826 \times \frac{at_t + prccf_t csho_t - ceq_t - txdb_t}{at_t}\\&+ 3.1391 \times \frac{dltt_t + dlc_t}{dltt_t + dlc_t + seq_t} - 39.3678 \times \frac{dvc_t + dvp_t}{ppent_{t-1}}\\&- 1.3147 \times \frac{che_t}{ppent_{t-1}}.\end{aligned}$$

Source: Compustat.

$HPFINCON_{it}$: An indicator variable equal to 1 if the firm is in the top tercile of the yearly Hadlock and Pierce (2010) (HP) index, and 0 otherwise. The HP index is constructed as $-0.737 \times \text{SIZE} + 0.043 \times \text{SIZE}^2 - 0.040 \times \text{AGE}$, where SIZE is the natural logarithm of inflation-adjusted total assets, capped at the natural logarithm of 4.5 billion, and AGE is the number of years the firm is listed with a nonmissing stock price on Compustat, capped at 37 years. *Source:* Compustat.

$INTANGIBLE_{it}$: An indicator variable equal to 1 if the firm is in the lowest tercile of the yearly tangibility measure (PPENT/AT), and 0 otherwise. *Source:* Compustat.

$PATENT\_STOCK_{it}$: Total number of patents the firm has created in the last 20 years from year $t-19$ to year t, divided by total assets in year t. *Source:* NBER patent data.

$ANTITAKEOVER\_INDEX_{it}$: The firm-level takeover index developed by Cain et al. (2017), which is constructed based on the passage of 13 different types of state takeover laws, 1 federal statute, and 3 state standards of review. The original takeover index is multiplied by -1, so higher values indicate a lower hostile-takeover hazard. *Source:* Steve McKeon's Web site.

$TAXAVOID_{it}$: An indicator variable equal to 1 if the firm is in the bottom tercile of the yearly industry- and size-adjusted cash effective tax rate (ETR), and 0 otherwise. Industry- and size-adjusted ETR is calculated by subtracting the same year's 3-year ETR for the portfolio of firms in the same quintile of total assets and the same Fama–French 48 industry from the firm's ETR. ETR is the ratio of the 3-year sum (from year $t-2$ to t) of cash taxes paid (TXPD) divided by the 3-year sum of pretax income (PI) less special items (SPI). *Source:* Compustat.

$STATE\_TAXES/PRETAX\_INCOME_{it}$: State taxes (TXS) of firm i in year t divided by pretax income (PIDOM, or PI if missing). *Source:* Compustat.

Supplementary Material

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