Dynamics of Financing Frictions for Investment in R&D*

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[PRELIMINARY DRAFT]

Abstract

We analyze the role of financing frictions for investment in R&D and innovation by building and estimating a structural investment model for privately-held, R&D-intensive companies – a group for which reliable estimates of financing frictions have not been available in earlier papers. We use confidential administrative data from the UK to study the effect of a special policy that aims to address financing frictions and stimulate innovation. Profitable firms are offered tax super-deductions for R&D, while loss-makers are given a choice between taking a cash injection from the government immediately or when they become profitable in the future. Claiming the cash immediately comes at a cost; the rate at which the government pays cash to loss-making firms is significantly lower than a future deduction. Firms' choices reveal financing frictions and unobserved productivity. We find that privately-held innovative firms face much higher costs of external finance than public firms and there are vast heterogeneities across different sub-groups of firms in their exposure and responses.

Keywords: financing frictions, uncertainty, investment, R&D, structural estimation

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1 Introduction

Companies may forego potentially profitable investment opportunities because of financing frictions. It is often difficult to separately identify the effect of financing frictions from the effect of adverse shocks in determining the cause of changes in investment – both at the company level and at the aggregate level. In this paper, we distinguish between the impact of financing frictions and negative shocks in the way they affect firm-level investment in research and development (R&D). The existing literature on quantifying the impact of financing frictions on investment inevitably focuses on large, listed companies, because there is simply not enough data on external financing and investment choices of unlisted enterprises.[1] We use confidential tax returns data from the UK, matched with company accounts and patents to address some of the data challenges. The UK policy setting is useful for identifying the role of financing frictions in investment in R&D and innovation.

Evidence from reduced-form approaches points towards a strong link between the availability of external financing for investment in innovation and growth (Brown, Fazzari and Petersen, 2009; Dechezlepretre et al., 2016; Guceri and Liu, 2019; Chen et al., 2017). High-tech firms increasingly remain private. In this paper, we develop a framework to quantify the extent of financing frictions for private companies using the variation in firms' responses to different tax policy instruments. We flexibly model the dynamic choice of value-maximizing firms that face costs of external financing. In the model, firms adapt their choice of R&D investment according to the technology shocks and external financing costs that they face in each period. We model the tax system surrounding the firms' decision-making process by incorporating R&D tax incentives available to the firms, and their ability to carry their losses forward to offset future taxable profit.

The UK policy has features that are particularly useful for the empirical strategy of this paper. R&D-performing companies in a tax loss position have the option of taking a small amount of cash from the government immediately, or waiting and taking a larger amount (as a tax deductible) in the future. The R&D tax relief allows firms to deduct more than 100 percent of their qualifying R&D spending from taxable income. Because the value of the immediate cash refund is lower, a firm that chooses this option must either be facing a high cost of external finance, or it must not be expecting to move to profitable position in the near future. We model the choices of these firms, allowing for differences across firms in permanent unobserved productivity and shocks experienced over time. Firms' choices include the amount of investment in R&D, and if the firm

[1] With the exception of Nikolov, Schmid and Steri (2019), which we discuss later.

is in a tax loss position, whether to take the immediate cashback or to carry forward and claim the cash against future profit. Fluctuations in profit, output and inputs are informative about the nature of shocks and the production function parameters, while the choices of cash-now versus cash-later by firms and other information on financing reveal the cost of external finance. There are changes in R&D deduction rates and availability of cash across different groups of firms over time. Such policy variation is not required for identification of the financing friction but it is a useful feature of the setting for examining patterns of investment in R&D, productivity and innovative output (i.e. patents) in a rich dataset.[2]

The findings of this paper relate to three strands of literature. First, the available policy setting in this paper allows for a novel approach for the measurement and effects of financing frictions. There is little publicly-available data on firms that are particularly prone to experiencing a high cost of external finance. The limited data availability then creates problems for applying even the standard reduced-form regression analyses of the effect of cash flows on investment rates, controlling for a firm's market-to-book ratio as proposed by Fazzari, Hubbard and Petersen (1988). Even for publicly-traded firms for which more data is available relative to unlisted firms, there is evidence that such reduced form approaches do not accurately reflect the heterogeneities across firms and therefore misrepresent the extent of financing constraints (Hennessy and Whited, 2007; Farre-Mensa and Ljungqvist, 2016). There is some evidence that smaller firms are more financially constrained than larger firms, but again, within a sample of publicly-traded companies, the extent of financing frictions for smaller and privately-held companies is often overlooked (Nikolov, Schmid and Steri, 2019). Both theoretically and empirically, there is evidence that financing frictions explain a large part of firm responses to investment incentives, but the causal link is difficult to establish (Cooper and Ejarque, 2003; Hennessy and Whited, 2007; Edgerton, 2010; Strebulaev and Whited, 2012; Devereux and Liu, 2016).

Second, recently the literature on the effectiveness of investment tax incentives has developed rapidly thanks to the broader availability of micro-level administrative data. Recent estimates based on quasi-experiments have guided our understanding of the impact of tax incentives on firms' investment in both physical capital and R&D, as well as other outcomes such as patent counts and total factor productivity (Rao, 2016; Guceri, 2017; Agrawal, Rosell and Simcoe, 2020; Guceri and Liu, 2019; Dechezlepretre et al., 2016; Chen et al., 2017). Some of these studies found stronger responses to tax incentives by younger firms and interpreted this finding as indicative of the importance of cash

[2] Work on patent data is ongoing and hence not presented in this draft.

flow constraints, but the precise nature and extent of financing frictions for innovative firms have largely remained unexplored. This fundamental question is fundamentally linked to optimal R&D policy design, as explored theoretically in Akcigit, Hanley and Stantcheva (2016).

Finally, loss-making companies constitute a large share of businesses in developed economies (Altshuler et al., 2009). Governments that choose to offer special tax incentives to stimulate investment have to consider the implications on firms with tax losses. Theoretically, asymmetries in the tax system result in different investment outcomes for firms with different profit-or-loss statuses (Devereux, Keen and Schiantarelli, 1994; Bond and Devereux, 1995; Edgerton, 2010), as asymmetric treatment of losses within the tax system renders investment incentives less effective (Auerbach, 1986; Mayer, 1986; Devereux, Keen and Schiantarelli, 1994; Edgerton, 2010; Zwick and Mahon, 2017; Altshuler and Auerbach, 1990; Auerbach and Poterba, 1987). Is a refund option a viable policy alternative to a system that is limited to carrying the losses back or forward in time? The present paper finds that a well-administered cash refund is likely to alleviate some complications arising from financing frictions, at least for innovative companies.

In this paper, we make two novel contributions. First, we quantify the extent of financing constraints for privately-held, innovative companies. This is made possible thanks to the detailed administrative population data and a useful quasi-experiment based on the UK's R&D policy framework. Second, we propose a fiscal policy-focused framework to estimate the dynamics of financing constraints for the population of firms in a large and innovative economy. The use of this framework is not confined to the availability of the specific policy setting in the UK. Alternative policy settings which allow similar approaches include any investment tax credits and net operating loss carryforwards and carrybacks.

In the next section, we describe the specific institutional environment that enables the counterfactual analyses that we carry out later in the paper. Section 2.2 then presents the dataset. Section 3 sets out the model and Section 4 discusses the structural estimation strategy, presents the results, and then provides supporting evidence using a reduced-form approach. Section 5 shows counterfactual experiments. The tentative Section 6 lists the next steps. Section 8 concludes.

2 Background

2.1 The policy experiments

During the period 2000-2008, the R&D tax deduction rates were 150 percent for small and medium-sized enterprises (SMEs) and 125 percent for large companies. For example, each profitable SME with qualifying R&D spending of £100 could deduct £150 from its taxable profit and each profitable large firm with the same R&D spending could deduct £125 from its taxable profit. Both SMEs and large companies were allowed to carry forward the losses arising in each period, including the loss arising due to the enhanced deduction. Loss-making SMEs also had the option of a cash refund. Each loss-making SME with £100 of qualifying R&D spending could either calculate its current period loss using the enhanced deduction, and carry forward the loss amount, with a nominal value of the future deduction of £$150 \times \tau$ (where τ is the corporation tax rate) or claim a maximum immediate cash refund from the government of £24. Consider a company that is in a loss position in 2006, and then switches to profit in 2007. The undiscounted gain from carrying forward the loss to claim against future tax is $(1 + d) \times \tau$, which is $1.5 \times 0.3 = 0.45$ for a company that pays corporation tax at the main rate of 30%.[3]

Importantly, firms that chose the immediate cash option could not receive the equivalent of the full tax gain – the nominal value of the immediate cash benefit was lower than the tax gain for a profitable firm. On the other hand, if the firms waited and carried the loss forward to set off against future profits, they could use the full amount in terms of a reduction in tax liability. Therefore, two main reasons may drive companies to choose the cash option. First, the company may not expect to switch to profit in the near future due to a recent adverse shock, and second, the company faces an external financing friction which is preventing it from undertaking a profitable investment opportunity. We henceforth refer to the choice between taking a cash refund immediately and carrying the loss forward to receive a higher future cash flow as the 'cash-now' versus the 'cash-later' choice.

Figure 1 summarizes the cash flow benefits of choosing cash-now or cash-later, under different policy regimes and a no discounting assumption.

Two reforms took place in 2008. First, the deduction rates increased for both SMEs and for large companies (Figure 2a). *Ceteris paribus*, the increase in the SME deduction rate from 150% to 175% reduced the user cost of R&D capital by 14 percent. The minor increase in deduction rate for large companies from 125% to 130% did not translate to a substantial change in the user cost of R&D capital because of a two-percentage-point

[3]This rate is $1.5 \times 0.2 = 0.3$ for taxpayers at the small profits rate.

Figure 1. Illustration of the cash flow benefit under different policy options without discounting

Gain from cash today (2006)	Gain from carry forward to claim against tax in 2007
£24	150 × 0.3 = 45 for main rate taxpayers 150 × 0.2 = 30 for taxpayers at the lower rate
Gain from cash today (2010)	**Gain from carry forward to claim against tax in 2010**
£24.5	175 × 0.26 = 45.5 for main rate taxpayers 175 × 0.21 = 36.75 for taxpayers at the lower rate

Note: In the absence of discounting, the benefit to firms of each of the cash-now and cash-later options are demonstrated in this figure. In 2006, firms with large profits (above £1.5 million) faced a 30 percent marginal tax rate, while the firms with smaller profits (below £ 300,000) faced a 20 percent marginal tax rate. There were also intermediary marginal tax rate brackets for amounts that fell between these two thresholds.

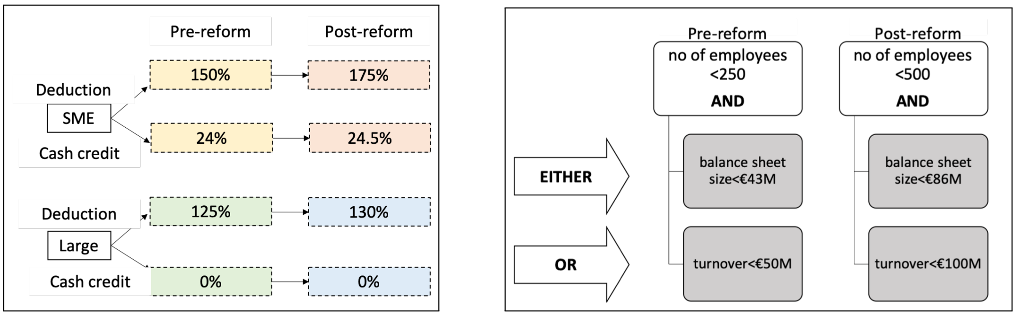
reduction in tax rates in the same year. Medium-sized companies that have between 250 and 500 employees experienced the largest reduction in the tax component of their user cost of capital at 24%, as their status switched from 'large' to 'SME' *only for purposes related to the tax treatment of investment in R&D*. The same group also became eligible to receive the cash option when it was in a loss position. Figure 2b shows further detail on the requirements to benefit from the more generous SME scheme before and after the reform.

The cash-now option was available for three out of the six policy regimes generated by this institutional setting. We summarize these six policy regimes along with the availability of the cash option in Table 1. The medium-sized group lends itself to being a suitable treatment group whose behavior can be compared with: (1) small companies, whose immediate cash option stayed intact before and after the reform, but whose user cost of capital dropped for profitable firms (or for loss-making firms that do not choose the cash option), albeit at a lower rate than for medium-sized companies, and (2) large companies, who never had the immediate cash option either before or after the reform, and whose user cost of capital also remained stable.

The data period for this paper saw two important reforms in the tax treatment of investment in R&D. These institutional changes in the UK affected small, medium-sized and large firms differently, generating six regimes with cross-sectional and time-series variation in the cost of capital and the availability of cash for investment.[5]

[5] In this section, we summarize the aspects of the policy setting that are relevant for the empirical strategy of this paper. In Appendix A, we detail some additional features of the policy environment.

Figure 2. Institutional changes during the data period



(a) Changes in deduction rates (b) Change in the SME definition

Note: The left panel of this figure shows the four main policy regimes that are available in our data period. In both the pre-reform and the post-reform periods, the SME scheme has higher deduction rates than the large company scheme, but the available deduction increases more for SMEs than for large companies in the post-reform period. The large company scheme does not have a cash refund component for loss-making companies.[4] The legislation provides cash refund rates in terms of the way in which they multiply the super-deducted R&D. In the pre-reform period, this means that the cash refund rate, as quoted in the policy, is 16 percent: For a company that invests £1 and is in loss position in the pre-reform period, the gain from claiming cash immediately is $(1 + d) \times c$, which is $1.5 \times 0.16 = 0.24$ in 2006.

Table 1. Availability of the immediate cash option for different size groups when loss-making

	Pre-reform	Post-reform
Small	**Yes**	**Yes**
Medium	No	**Yes**
Large	No	No

2.1.1 2013 R&D Expenditure Credit Expansion to Large Companies

A further experiment was implemented in April 2014 which expanded the cash-now option into large firms. We plan on using our estimated model to predict the outcome of this expansion on R&D investment by large firms.

2.2 Data and trends in cash claims

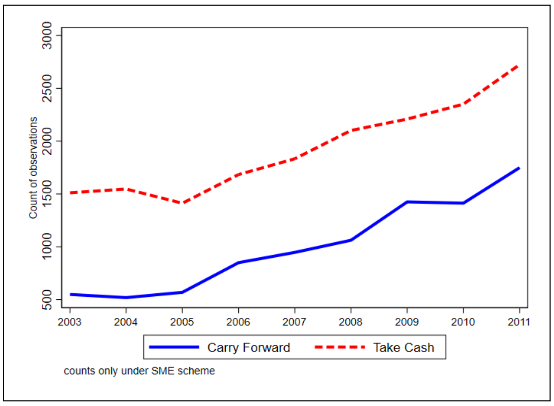
For the empirical analysis in this paper, we use the population of corporation tax returns from the UK's revenue authority (HMRC), matched with balance sheet and income statement information from Bureau van Dijk's Financial-Analysis-Made-Easy (FAME) database.[6] Tax returns contain detailed information on companies – including revenues,

[6]Work on Bureau van Dijk's ORBIS Global Company-Level Intellectual Property Database is currently underway.

trading profit (or loss), deductions for different types of investment and allowances, total R&D spending that qualifies for the deduction, losses carried forward and taxable income. The dataset contains information on about 1.5 million companies each year over the nine-year period (2003-2011) used in this study. If a company reports a trading loss, then the company's choice of cash-now or cash-later is also reported.[7] Variables related to external financing are from the FAME database.

Figure 3 shows that there is variation in the cash refund choice of eligible loss-making companies. The two lines which trace the behaviour of loss-makers generally follow a parallel trend, with the number of firms choosing the immediate cash option being larger by more than double the 'cash later' claims each period. The total number of claims by loss-making companies increase steadily over time, starting in 2002 at around 2000 claims and increasing to more than 4,500 claims in total.

Figure 3. Number of deduction and cash claims by loss-making SMEs



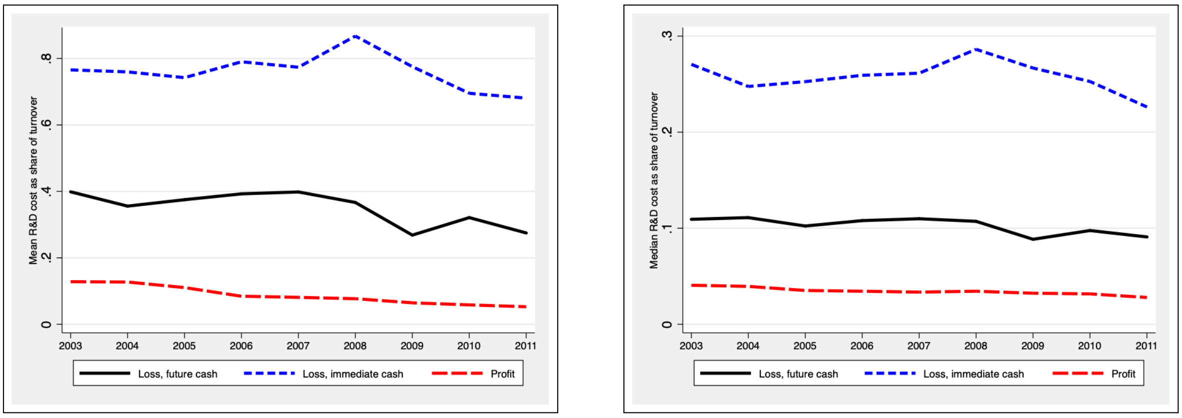
Note: This figure shows the total number of claims by small and medium-sized enterprises that reported both positive qualifying R&D and a trading loss, rendering them eligible for choosing between the immediate cash refund (cash-now) option and the more generous carry-forward (cash-later) option. The straight blue line shows the count of firms that chose to wait and carry the loss forward. The red dashed line shows the count of firms that chose to receive cash immediately.

Companies that choose the cash-now option differ in characteristics from firms that choose the cash-later option, which also differ from companies that report profits and therefore receive the cash flow boost in form of an immediate tax deduction. Cash-takers typically spend more on average in R&D (as a proportion of their size) and incur larger losses, relative to their counterparts which choose to carry their losses forward. This pattern is in line with more R&D-intensive firms typically facing higher financing

[7]If a company chooses the cash-now option, it has to claim the full amount this way, except in cases where the company is profitable before applying the R&D super-deduction, which naturally means that the company receives a reduction in tax liability up to the point at which this liability hits the zero lower bound, and after which point the company can choose between cash-now and cash-later.

constraints, partly because the output of innovative discovery does not have a market yet and entail a larger return uncertainty for potential providers of finance, and partly because the successful R&D accumulates into knowledge capital, or an intangible asset, rather than physical assets that are more preferable for use as collateral. Figure 4 shows mean and median R&D intensity measured by investment in R&D as a share of annual turnover, split by profitable, loss-making with a preference for immediate cash, and loss-making with a preference for future cash. The left hand panel shows the means and the right hand panel shows the medians of this variable. Among the three groups, average R&D intensity is the highest for loss-making companies that choose the immediate cash option, followed by loss-making companies that opt to delay their cash receipt. Profitable firms report the lowest average R&D intensity. The difference between Figures 4a and 4b reveals that there are vast heterogeneities in R&D intensity across firms within each group.

Figure 4. R&D intensity by profitable and loss-making categories



(a) R&D intensity, mean

(b) R&D intensity, median

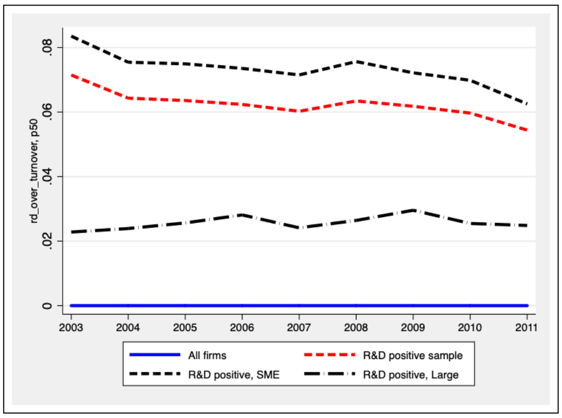
Note: The left panel of this figure shows the mean R&D intensity measured by R&D spending as a share of turnover. The right panel again shows the trend in the median of the same R&D intensity measure. In each subfigure, the straight black line captures the R&D intensity trend for loss-making firms that choose to take cash in a later year, blue dashed line captures the R&D intensity trend for loss-making firms that choose immediate cash and the red long-dashed line captures the R&D intensity trend for profitable firms.

2.3 Patterns of innovation and financing constraints for high-tech companies

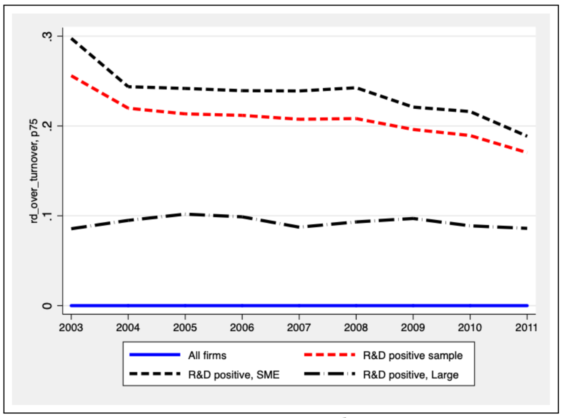
Innovative firms have distinct characteristics in comparison to the overall population of firms. [add here discussion on characteristics presented in Figure 5 below.]

[To be added:] Patenting performance from ORBIS IP data + some information from

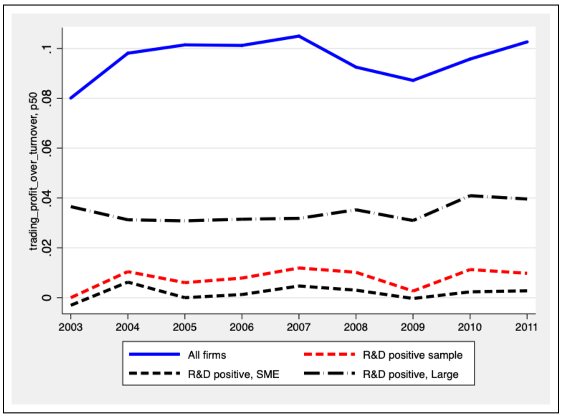
Figure 5. Comparison between the population of UK corporations and the R&D-positive sample



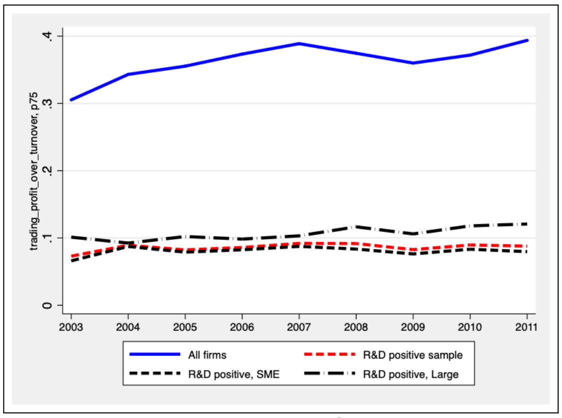
(a) R&D intensity, median



(b) R&D intensity, 75^{th} percentile



(c) Profit margin, median



(d) Profit margin, 75^{th} percentile

Note: here

BERD publicly-available files on the importance of SMEs vs. large firms in R&D.

High tech firms are predominantly reliant on external finance, and the external financing that they raise is mostly in form of equity rather than debt. This is because innovative firms typically do not have physical assets to pledge as collateral. Among the population of UK corporations, close to half of R&D-positive firms raise external financing in a typical year, whereas this proportion is less than 20 percent for zero-R&D firms.[8] In addition, the shares of firms that choose debt financing is negligible, verifying some of the stylized facts outlined earlier in Brown, Fazzari and Petersen (2009).

[8] For example, in year 2011, a representative year in the dataset, the share of firms that raised external financing is 47 percent for the R&D-positive subsample, and 17 percent for the zero-R&D subsample. Among the positive-R&D firms, this ratio was 48 percent for SMEs and 42 percent for large companies.

3 A model of uncertainty, financing frictions and investment in R&D

3.1 A simple two-period model

Some of the intuition for the dynamic model that we present later in this chapter can be demonstrated in two periods ($t \in \{0, 1\}$). To fix ideas, let us assume the simplest possible two-period investment model without depreciation and any discounting. Firms start with zero capital stock and invest in knowledge capital at $t = 0$. For tax purposes, the government allows a super-deduction of the cost of purchasing knowledge capital at rate q. This means that every dollar of investment will be counted as $(1 + q)$ for tax deduction purposes if the company is profitable. At $t = 0$, the firm has no profit or production, and in this period, the firm makes all its decisions about investment and financing of that investment. To finance the initial investment K, firms can take cash from the government at rate ϕ and raise the remaining amount by issuing external equity (X) also in period $t = 0$. Alternatively, they may choose to set off this amount against the profit arising in period $t = 1$ to save on their tax payments. In this case, the firm would have to raise a larger amount of external equity, which entails with it a search cost for the firm, represented by $\Lambda(X)$.

$$\Lambda : \forall X \leq 0, \Lambda(X) = 0; \forall X > 0, \Lambda(X) > 0, \Lambda'(X) > 0 \tag{1}$$

The sources and uses of funds identity captures the total external equity raised and any cash available from the government. We define the firm's binary choice for the immediate cash refund option from the government as $D = 1$ (and $D = 0$ if the firm chooses to carry this super-deduction forward to claim against $t = 1$ profit). At the refund rate of ϕq, the sources and uses of funds identity is:

$$K = X + \phi q K D \tag{2}$$

Rearranging 2, and assuming a linear functional form for $\Lambda(X)$, we get:

$$\begin{aligned} \Lambda(X) &= \lambda X && (3) \\ &= \lambda K(1 - \phi q D) && (4) \end{aligned}$$

In period 1, the firm observes the period shock A_1 and starts production. In period

0, the firm maximizes its net-of-tax cash flow. The firm maximizes its total payoff π:

$$\max_{K,D} \Big(\mathbb{E}_0[A_1] f(K) - K \Big)(1-\tau) + (1-D)qK\tau + \phi qKD - \lambda K(1-\phi qD) \tag{5}$$

This formulation considers the company paying taxes at rate τ, with $\tau > \phi$ if it is profitable, and $\tau = 0$ if it is in a loss position in the final period $t = 1$.

For simplicity, assume $f(K) = K^\alpha$. It follows immediately that *ex post*, the company makes a loss if $K > A_1^{\frac{1}{1-\alpha}}$. If the firm expects a loss, it should not invest and therefore it should not raise any external equity. Consider the cases in which the firm expects to make a profit at $t = 1$.

$$\begin{aligned}
&\text{For } D = 0: \\
&\qquad \pi_0 = (\mathbb{E}_0[A_1]K^\alpha)(1-\tau) + K(q\tau - 1 + \tau - \lambda) \\
&\text{For } D = 1: \\
&\qquad \pi_1 = (\mathbb{E}_0[A_1]K^\alpha)(1-\tau) + K(q\phi - 1 + \tau - \lambda(1-\phi q))
\end{aligned}$$

The firm will choose $D = 1$ if the external financing cost is sufficiently large. In this simple version of the model, the threshold is:

$$\lambda \geq \frac{\tau}{\phi} - 1$$

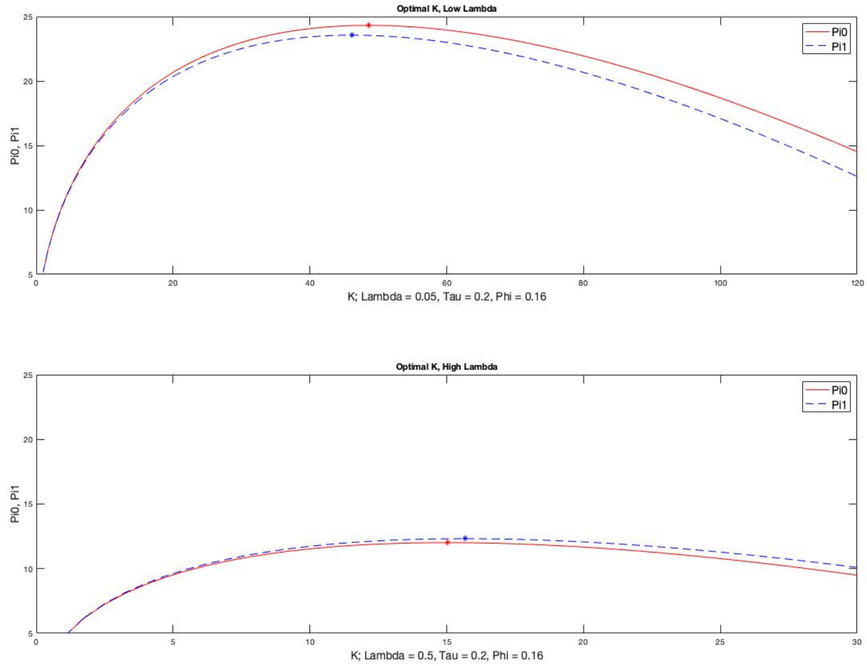
The firm would be indifferent between the choice of cash and external finances if equality holds in the previous threshold. This is because the cost of equity is exactly the same as the forgone tax benefit from taking the cash. To demonstrate the implication of this result, consider the small profit tax rate of $\tau = 0.2$ and the cash refund rate of $\phi = 0.16$. In this policy environment, an external financing cost of 25 percent is sufficient to induce firms to accept immediate cash from the government.

Solving for the amount of investment in knowledge capital, we obtain the user cost of capital conditional on the choice of D, and as a function of the cost of external finance:

$$\begin{aligned}
&\text{For } D = 0: \\
&\qquad F'(K_0) = \frac{1 - \tau - \phi q + \lambda - \lambda\phi q}{1-\tau} \\
&\text{For } D = 1: \\
&\qquad F'(K_1) = \frac{1 - \tau - \tau q + \lambda}{1-\tau}
\end{aligned}$$

For high values of λ, specifically, $\lambda \geq \frac{\tau}{\phi} - 1$, the company is able to accumulate a higher

Figure 6. Capital accumulation and payoffs under different cash choices



Note: This figure shows the payoff function at different levels of investment, conditional on $D = 0$ and $D = 1$. In each graph, the red straight line represents the profit of firm with $D = 0$ and the blue dashed line represents the profit of firm with $D = 1$. The asterisk (*) on each plot corresponds to the profit at the optimal level of capital stock. The top panel shows the case with $\lambda < \frac{\tau}{\phi} - 1$ and the bottom panel shows the case with $\lambda > \frac{\tau}{\phi} - 1$.

level of capital $K_1^* \geq K_0^*$, and it chooses $D = 1$. Conversely, for low values of λ, the firm chooses $D = 0$ and accumulates $K_0^* \geq K_1^*$. Figure 6 demonstrates these conditions graphically.

3.2 The dynamic investment model

3.2.1 A world without taxes or external finance

In this, section, we build on the neoclassical model (Jorgenson, 1963; Hall and Jorgenson, 1967) in which firms maximise the net present value of all expected future cash flows. In the simplest version of the model, investment is fully financed by internal funds and there are no taxes or financing frictions. Profits arise from the production and sale of an innovative output. Each firm i uses 'knowledge capital' k as input to produce according to the production function:

$$Y_t = A_t f(K_t)$$

with $f(K_t) = K_t^\alpha$ and $\alpha \in (0,1)$. For firm i, A_{it} summarizes the productivity and demand terms[9], and it combines the firm-specific permanent productivity a_i and the AR(1) shock ε_{it}. The firm-specific productivity A_{it} can be decomposed as follows:

$$A_{it} = \exp(a_i + \varepsilon_{it}) \tag{6}$$

$$\varepsilon_{it} = \rho\varepsilon_{it-1} + \nu_{it} \tag{7}$$

$$0 < \rho < 1, \qquad \nu_{it} \sim \mathcal{N}(0, \sigma_\nu^2) \tag{8}$$

The timing and irreversibility of investment are key for determining period profit-or-loss positions of firms. In the case of investment in R&D, investment in knowledge capital is likely to be firm-specific and cannot be disposed of.[10]

$$K_{it+1} = (1-\delta)K_{it} + R_{it}, \;\; R_{it} \geq 0 \tag{9}$$

Depreciation rate δ in the context of knowledge capital refers to the obsolescence rate of the underlying know-how. Other factors of production, such as physical capital and labor are maximized out of the problem.

Equation 10 presents the period cash flow of the company, which is composed of its revenue, net of the cost of its investment in period t and a fixed production cost $\underline{G} \geq 0$. $\underline{G}$ represents a production friction which facilitates firm exits if the current expected liquid funds cannot meet this production cost.[11]

$$\Omega(K_{it}, R_{it}, a_i) = p_t^Y K_{it}^\alpha \exp(a_i + \varepsilon_{it}) - \underline{G} - p_t^K R_{it} \tag{10}$$

This formulation suggests that the firms can over-invest to the extent that they are optimistic about the future, based on the persistence of the shocks that they experience. Firms face competitive prices in both their input and output markets; we normalise the price of output p_t^Y and price of the investment good p_t^K to unity.[12]

[9]See, for example, Bloom (2009) for a production system of this kind with isoelastic demand.

[10]We take the findings of the literature on non-convex adjustment costs to be given for our modeling purposes. Some prominent examples include Abel and Eberly (1999); Cooper and Haltiwanger (2006); Jiang, Suarez Serrato and Xu (2019); Winberry (2020). Similarly to investment in physical capital, investment in R&D is lumpy. The irreversibility of investment in knowledge capital generates an analogous lumpiness in R&D spending at the firm level as predicted by the existing literature.

[11]Estimates presented later in this draft assume $\underline{G} = 0$

[12]This simplification, common in corporate finance models of financing frictions as reviewed in Strebulaev and Whited (2012), abstracts away from some of the considerations explored in Caballero (1991) and Bond, Soderbom and Wu (2008), in relation to imperfect competition in input and output markets.

Each firm maximizes:

$$V(K_{it}, \varepsilon_{it}) = \max_{K_{it+1} \geq 0} \Omega(K_{it}, R_{it}) + \beta \mathbb{E}_{it} V(K_{it+1}, \varepsilon_{it+1}) \tag{11}$$

3.2.2 The tax system

Having laid out the backbone of this capital accumulation model in the previous section, we now introduce the tax system, including a tax on corporate profits and an incentive that allows a more-than-100% deduction of a certain investment category, which, in this case, is R&D. All the characteristics of the model in Section 3.2.1 still hold. For ease of notation, we now use the normalised prices. In addition, firms pay taxes on their profit at rate τ. The government allows R&D to be super-deducted at rate q (the additional deduction allowed on top of 100 percent expensing). Profit-making firms use the deduction to reduce their tax liability as incurred at period t. Loss-making firms may have two options, depending on their eligibility based on size (SME scheme allows cash refunds and the large company scheme does not):

1. Take cash from the government at rate $\phi \in [0, 1]$, where $\phi = 1$ corresponds to a full refund. The policy context that we study here does not allow a full refund, and we consider $\phi < 1$.

2. Carry the deduction forward to reduce future tax liability as soon as the firm enters a profitable position.

Define, for any period:

$$D_{it} = \begin{cases} 1, & \text{if the firm takes cash} \\ 0, & \text{otherwise} \end{cases}$$

The firm's optimisation problem now becomes:

$$V(K_{it}, H_{it}, \varepsilon_{it}) = \max_{K_{it+1}, D_{it}} \Pi(K_{it}, R_{it}, H_{it}, \varepsilon_{it}) + \beta \mathbb{E}_t V(K_{it+1}, H_{it+1}, \varepsilon_{it+1})$$

where H_t is the total accumulated losses brought to period t. The ability to carry losses forward is in line with the treatment of tax losses in the UK and the US.[13]

The firm's pre-tax cash flow Ω_t remains unchanged. Investment in R&D (R_t) can be deducted at the super-deduction rate of $1 + q$. Because Ω_t already incorporates a 100% deduction of the period's spending on R&D, the additional deduction amounts to

[13] In the UK, firms can carry losses forward indefinitely, while the US tax law allows firms to use their losses within 20 years after incurring the loss.

$q \times R_t$. We summarize the policy-induced firm constraints precisely in the following three equations. We define the net cash flow of company i in period t, after the realization of ε_t as follows:

$$\Pi_{it} = \begin{cases} \Omega_{it} - \tau[\Omega_{it} - qR_{it} - M_{it}] & \text{if } \Omega_{it} - qR_{it} \geq 0 \\ \Omega_{it} + D_{it}\phi q R_{it} & \text{if } \Omega_{it} - qR_{it} < 0 \end{cases} \tag{12}$$

Equation 12 reflects that each company i can deduct a stock M_{it} of losses that it had accumulated in preceding periods up to t. The company has to set $D_{it} = 0$ if it is in a profitable position after having deducted its R&D spending at the super-deduction rate q, or gets a choice about whether to take the cash now with a haircut ($D_{it} = 1$), or to carry forward the loss ($D_{it} = 1$) to offset against future profit. The remaining laws of motion that we present in Equations 13 and 14 are similarly piecewise in post-R&D profit. The stock of accumulated carry forwards is defined as follows:

$$H_{it+1} = \begin{cases} H_{it} - M_{it} & \text{if } \Omega_t - qR_{it} \geq 0 \\ H_{it} + (1 - D_{it})[qR_{it} - \Omega_{it}] & \text{if } \Omega_{it} - qR_{it} < 0 \end{cases} \tag{13}$$

In each period t, the existing stock of losses is drawn down by an amount M_{it}, which is capped at the current post-R&D profit. If the firm makes a post-R&D loss, its accumulation of losses depends on the cash-now vs cash-later choice represented by D_{it}. The current post-R&D loss only gets added to the existing loss stock of H_{it} if the carry-forward option through $D_{it} = 1$ is chosen. Finally, the current period amount carried forward and claimed against current profit is:

$$M_{it} = \begin{cases} \min\{H_{it}, \Omega_{it} - qR_{it}\} & \text{if } \Omega_{it} - qR_{it} \geq 0 \\ 0 & \text{if } \Omega_{it} - qR_{it} < 0 \end{cases} \tag{14}$$

3.2.3 Costly external finance

In this section, suppose now that the firm does not have access to a source of internal funding and has the option to use external financing. External financing is costly. It has been well-established in prior studies that such costs may arise from asymmetric information between the firm and the potential external funders (Stiglitz and Weiss, 1981; Myers and Majluf, 1984; Whited, 2006; Nikolov, Schmid and Steri, 2019, 2020).

Small- and medium-sized, innovative, and privately-held companies are typically equity-financed. For unlisted companies, the financing cost cannot be concretely pinned down as in the case of flotation costs of publicly-held companies. In this context, the external financing cost can be interpreted as all informational costs arising from the search costs and funding premia associated with early-stage financing. Equity injections entail an 'information cost', with a fixed and a variable component. Equity needs of the company are determined by its optimal investment choice and the funds available through profits or the cash option arising in case of losses.[14]

Risk-neutral shareholders directly benefit from their share of dividends, which is any positive cash flows arising in period t invested in R&D each period. We consider an equity-only external finance option, allowing the firms to finance investment through external equity or a cash refund from the tax authority.

Timeline: Each firm i, during period t:

1. decides on whether to be active or inactive in period t,
2. makes an investment decision R_{it} that will affect the knowledge stock in the subsequent period, K_{it+1}, with a promise to finance this investment after observing the shock.
3. decides on how to finance R_{it}; this may be through: (i) current profit, (ii) external equity, or (iii) cash received from the tax authority based on the firm's R&D spending R_{it} (or a combination of these sources),
4. chooses the best action D_{it}, deciding whether it will take cash-now or cash-later.[15]
5. produces output, using K_{it} as input, experiences a shock ε_t, incurs a profit or a loss;
6. if in a profitable position, distributes dividends.

Financing: Firms can use period profits (Π_{it}), government cash refund option ($\phi q R_{it}$) if in loss, or external equity (X_{it}) to fund investment. The sources and uses of funds in period t can be summarized as follows:

$$\Pi_{it} = -X_{it} \tag{15}$$

[14]We assume away issues arising from the dilution of existing shares that are discussed in Warusawitharana and Whited (2015). There are two reasons for this: this is a model of neoclassical firm behaviour where the firm's manager incentive overlap exactly with shareholders. The second reason is one can think of lambda as incorporating any dilution costs.

[15]The cash flow benefit of the cash-now option represented by $D_{it} = 1$ depends only on R_{it}. The firm knows *ex ante* the value of cash-now and cash-later in period t, regardless of the size of loss. For any given R_{it}, the firm can straightforwardly calculate the implied cash flow benefit if it chooses the cash-now option, through the formula: $\phi q R_{it}$ (as laid out in Equation 12).

Both equity payouts and new equity issuance are captured by X_{it}; with $X_{it} > 0$ indicating new equity issuance and $X_{it} \leq 0$ indicating payouts.

Define dividend distributions, Div_{it}, as the equity payout net of the cost of external equity (Nikolov, Schmid and Steri, 2019):

$$Div_{it} = -X_{it} - \lambda \cdot X_{it} \cdot \mathbb{1}(X_{it} > 0) \tag{16}$$

Valuation: The firm's optimization problem can now be summarized as maximizing shareholder value, which is quantified by the present discounted value of all future dividend distributions.

$$V(K_{it}, H_{it}, \varepsilon_{it}) = \max_{K_{it+1}, D_{it}, Div_{it}} \left\{ Div_{it} + \beta \mathbb{E}_t V(K_{it+1}, H_{it+1}, \varepsilon_{it+1}) \right\} \tag{17}$$

This value maximization is subject to the constraints laid out in Equations 9, 12, 13, 14, 15, 16. Equation 9 includes the nonnegativity constraints for R_{it}, in other words, the full irreversibility of knowledge capital. In addition, $H_{it} \geq 0$.

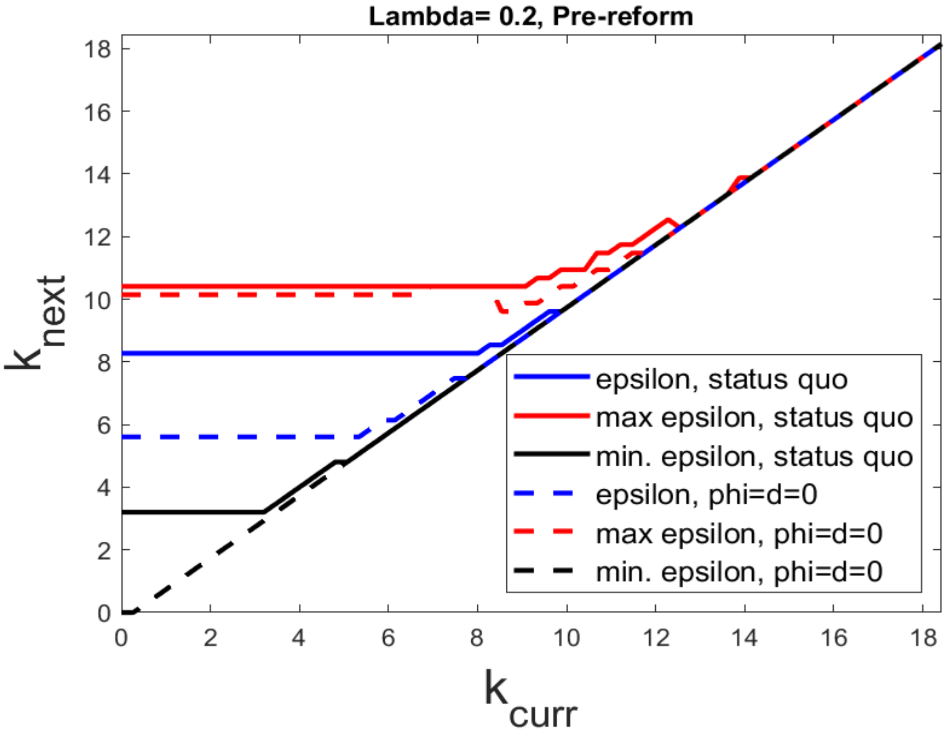
3.3 Comparative statics and interpretation for the infinite-horizon model

[in progress]

3.4 Numerical Comparative Statics

We solve the model numerically. Figure 7 presents the optimal K_{t+1} decisions under different super-deduction and cash-option rates in the pre-2008 reform period. The irreversibility of investment assumption implies that the larger firms have no interest in accumulating capital next period. Smaller more productive firms accumulate more capital next period compared to firms that receive smaller productivity shocks. Small firms accumulate more capital next period when the government provides tax credit incentives.

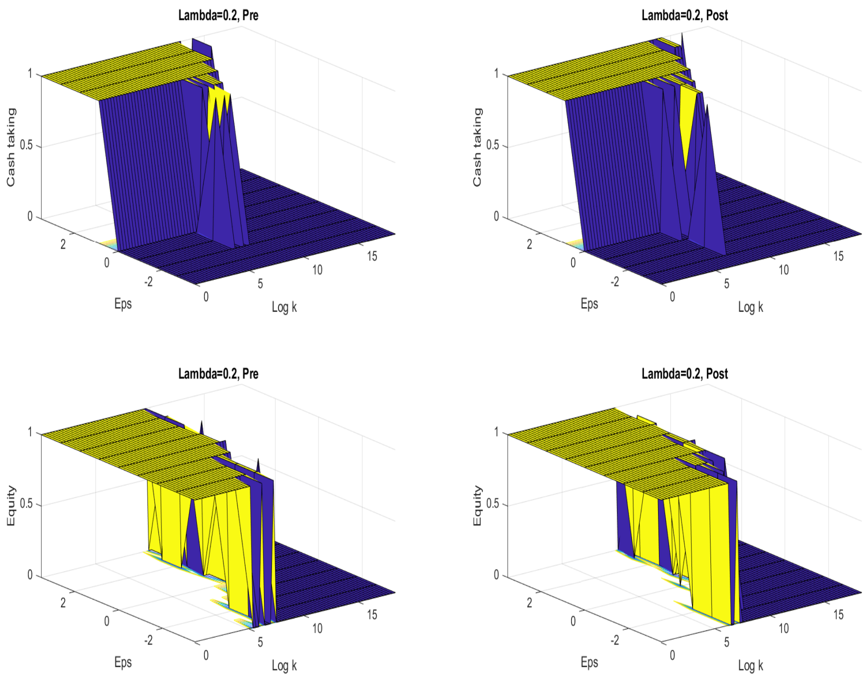
Figure 7. Capital accumulation with and without incentives.



Note: This figure shows the decision function for K_{t+1} at different levels of productivity (ϵ). The dashed lines represent the solution assuming that there is no additional R&D incentive. The solid lines represent the solution function assuming the pre-reform cash option and super-deduction rates.

Figure 8 presents the optimal cash-taking and equity decision pre- and post-reform in 2008. Before the reform, high productivity firms take cash even if those firms are not taking equity, indicating severe financing frictions for these types of firms. Low productivity firms take equity even if they are not taking cash, partially indicating the reduced financing needs of this type of firm. After the reform, more firms take the cash-now option, whereas the effect on equity taking is ambiguous.

Figure 8. Cash- and Equity-taking decisions before and after the 2008 reform.



Note: This figure shows the decision function for D_{t+1} and $\mathbb{1}(Div_t < 0)$ at different levels of productivity (ϵ) and capital stock. Yellow indicates cash-taking for the top panel and equity-taking for the bottom panel. Blue indicates not cash-taking and not equity taking.

4 Empirical approach and findings

The model set out in the previous section does not have a closed form solution – we use numerical methods to solve the firms' maximization problem. We estimate the model parameters using structural approaches, namely, generalized method of moments (GMM) and method of simulated moments (MSM) and complement the structural analysis with a reduced form difference-in-difference (diff-in-diff) framework. First, we discuss the sources of identifying variation, then present the structural approach and the findings. Finally, we provide a reduced form difference-in-difference framework that supports the structural findings. For each company i, we allow for unobserved permanent heterogeneity in productivity a_i, which has the following characteristics: $a_i \sim \mathcal{N}(\mu_a, \sigma_a)$, where μ_a and σ_a can be estimated alongside the other model parameters that emerge from the model in Section 3.

In estimation, we distinguish between two sets of parameters: (1) production function-related parameters; productivity of knowledge capital α_k, time-invariant productivity parameters μ_a and σ_a, the persistence ρ and standard deviation σ of the productivity shock, and (2) financing friction parameter $\Lambda(X_{it)} = \lambda X_{it}$. [Note: estimates presented in this version of the paper refer to permanent unobserved heterogeneity in λ, distinguishing between firms that permanently face λ^{High} and λ^{Low}. Estimates that follow the model that we laid out in the previous sections are in progress.]

4.1 Structural estimation

Identification of production function-related parameters is straightforward thanks to tax-induced exogenous variation in the user cost of capital that we discuss in Section 2. Equation 10 implies the following production function (in logs):

$$y_{it} = a_i + \alpha_k k_{it} + \varepsilon_{it} \tag{18}$$

Quasi-differencing the production function demonstrates that under Blundell and Bond's 2000 orthogonality conditions, own lags of knowledge capital can provide valid instruments and system GMM can be used for estimating the key parameters α_k, ρ, σ, μ_a and σ_a. In Equation 19, treating a_i as a random effect, we can decompose the variance of the error term into σ and σ_a.

$$y_{it} = \rho y_{it-1} + \alpha_k k_{it} - \alpha_k \rho k_{it-1} + a_i(1-\rho) + \nu_{it} \tag{19}$$

To estimate the financing constraint parameters, we use indirect inference (Gourieroux, Monfort and Renault, 1993; Smith, 1993; Gallant and Tauchen, 1996). For each company i in period t at state K_{it}, H_{it}, S_{it} and draw ε_{it}, and characteristics a_i and λ_{it}, we simulate, based on the Markov transition matrix, the choice of next-period capital and if the company is loss-making, whether to take cash immediately from the government or postpone to a future period. In the current set of estimates, we simulate 10,000 firms over the observed time period, including the policy changes applied in the equivalent periods as in real data. We obtain the stationary distribution using Page et al.'s 1998 PageRank algorithm. For the initial conditions, we do not apply any preferential policy for investment in R&D, which was the institutional setting before the introduction of the first R&D relief in the year 2000. We then apply the first special R&D regime, which empirically corresponds to the pre-reform period in the institutional setup that we summarized in Figure 2 and Table 1. Applying the policy changes induced by the reform then generates the post-reform set of three policy regimes, rendering a total of six policy regimes, from which we extract moments. Companies may move between regimes – for example, if a small company grows beyond the turnover size threshold for eligibility to the SME scheme, the policy environment that applies to that firm changes.

We obtain simulated moments for each size category, namely, 'small', 'medium' and 'large', and akin to a diff-in-diff strategy, use the difference between pre- and post-reform moments to match with their empirical counterparts. The MSM estimator is then:

$$\hat{\Theta} = \underset{\Theta}{argmin} \{[m_S - m_E]' W_n [m_S - m_E]\}$$

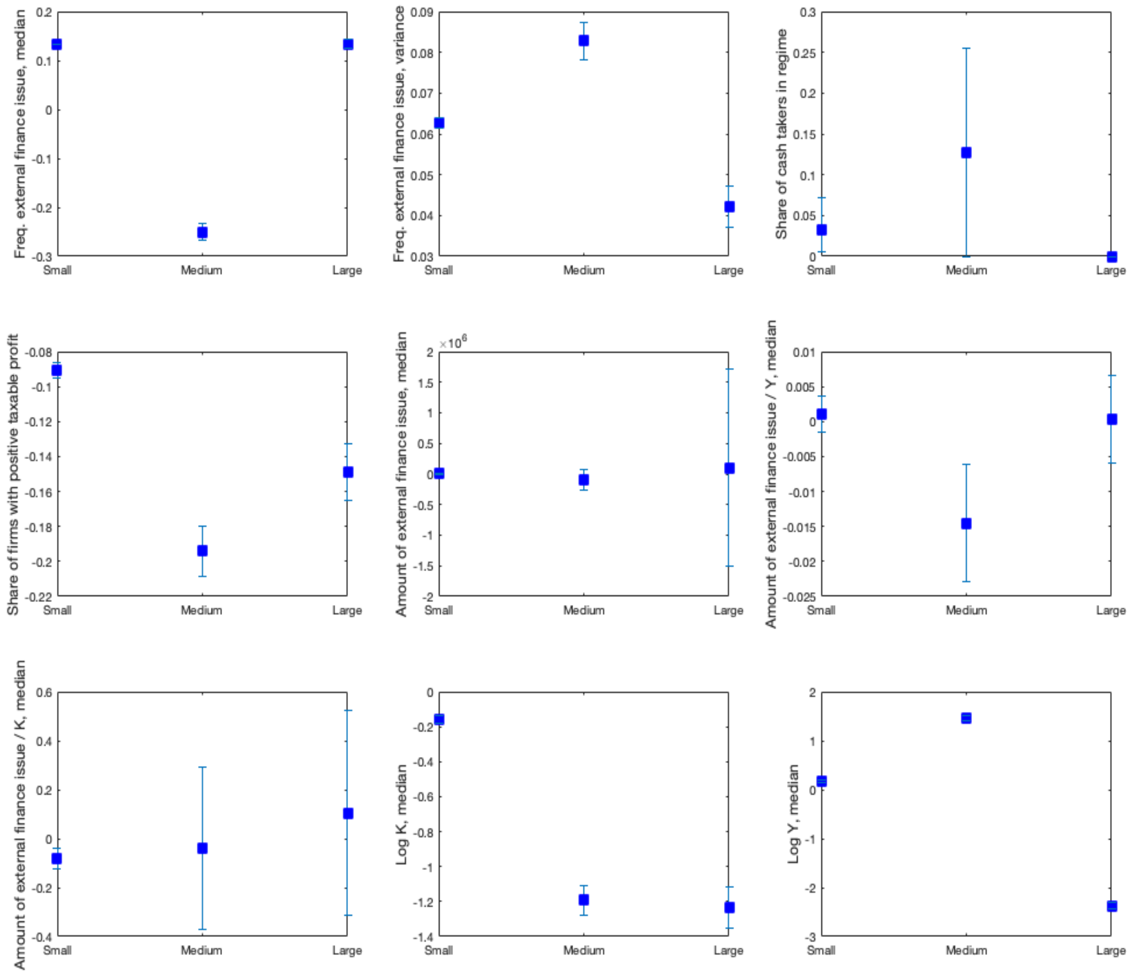
where m_S is the vector of simulated moments, m_E is the vector of empirical moments and W_n is the weight matrix. We use the diagonal elements of the bootstrapped variance-covariance matrix of moments to construct the weight matrix. We present the target moments m_E in Figure 9. We obtain the MSM estimates using a combination of quasi-MCMC [estimation in progress] (Chernozhukov and Hong, 2003) and the simplex method (Nelder and Mead, 1965). We construct standard errors using the standard GMM gradient formula. Some parameters in the model hinge on standard measures for which plausible assumptions or reliable estimates are available in the existing literature. We use existing findings for the depreciation rate δ and the discount factor β. Hall, Mairesse and Mohnen (2010)'s review paper reports depreciation rate estimates in relation to the findings of Bosworth (1978) and Griliches (1979), which is 15 percent. The discount factor $\beta = \frac{1}{1+r}$ is based on the risk-free interest rate r which can be inferred from the market rates of interest during the period of analysis. We use $\beta = 0.95$, which approximately assumes a 5 percent interest rate.

4.2 Simulation Results

In this section, we present the simulated fractions of firms taking cash and equity under parameter values before the reform. Figure 11 shows that under a higher cost of equity, firms are more willing to take the cash-now option of the government, while the fraction of firms taking equity remains largely constant. This indicates that when the cost of equity is higher, some fraction of firms reduce their overall cost of equity by on the margin taking cash on the intensive margin.

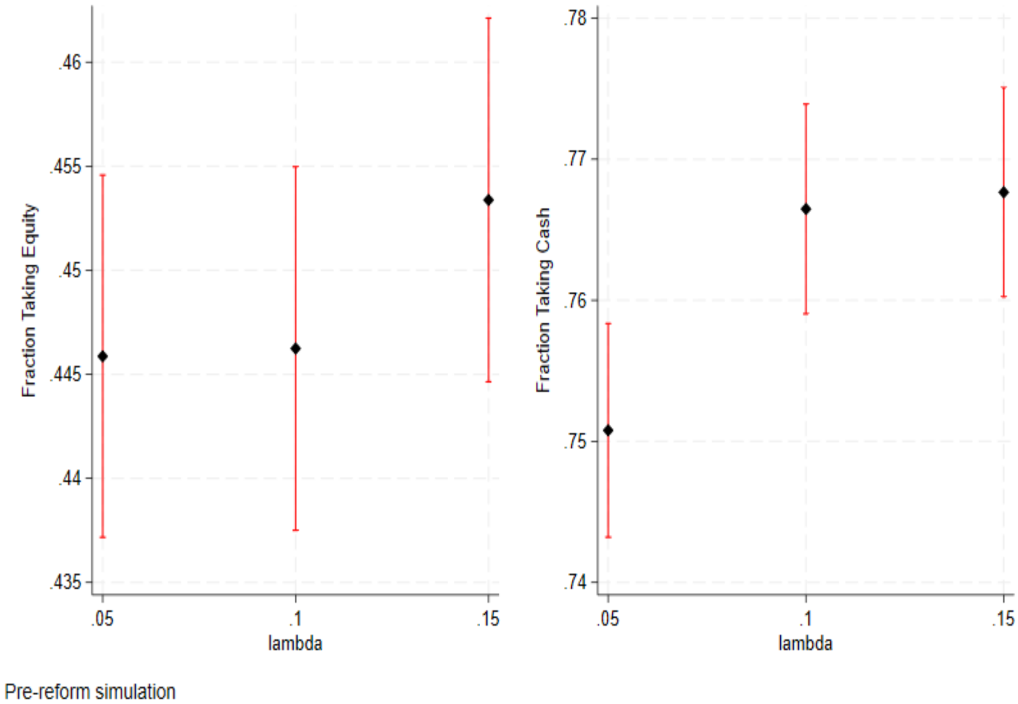
Figure 9. Empirical moments: Δ(Post-Reform – Pre-Reform)

[to be complemented with simulated counterparts]



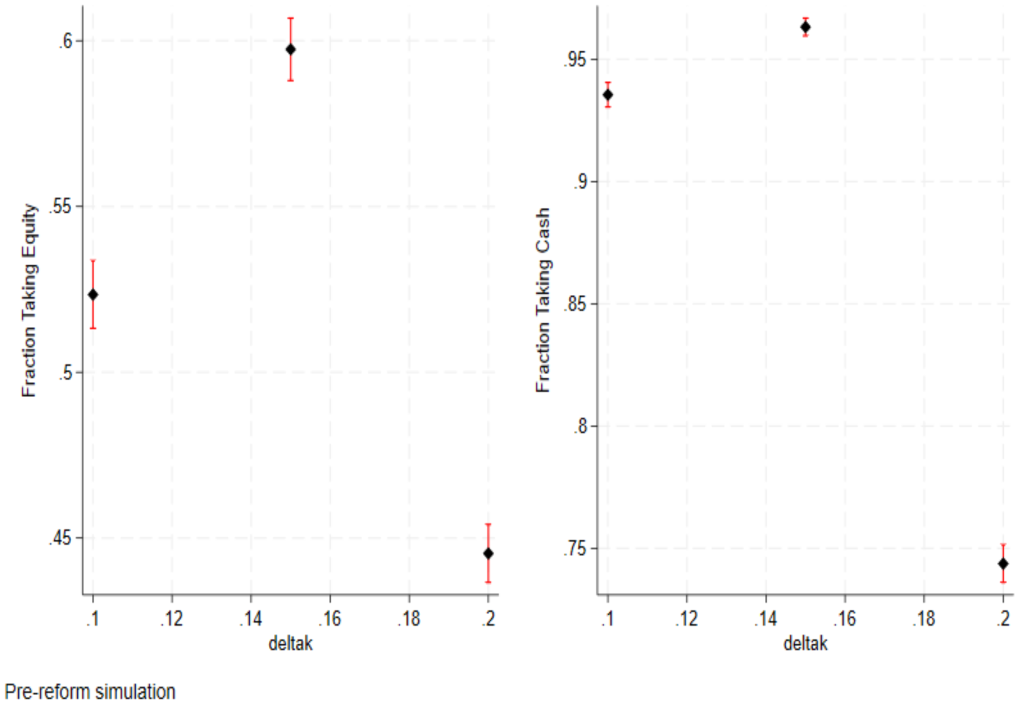
Note: All moments are reported in terms of the difference between the pre- and post-reform quantities.

Figure 10. Fraction of Cash-taking and equity-taking before the reform for a simulated sample of firms under different cost of equity assumptions.



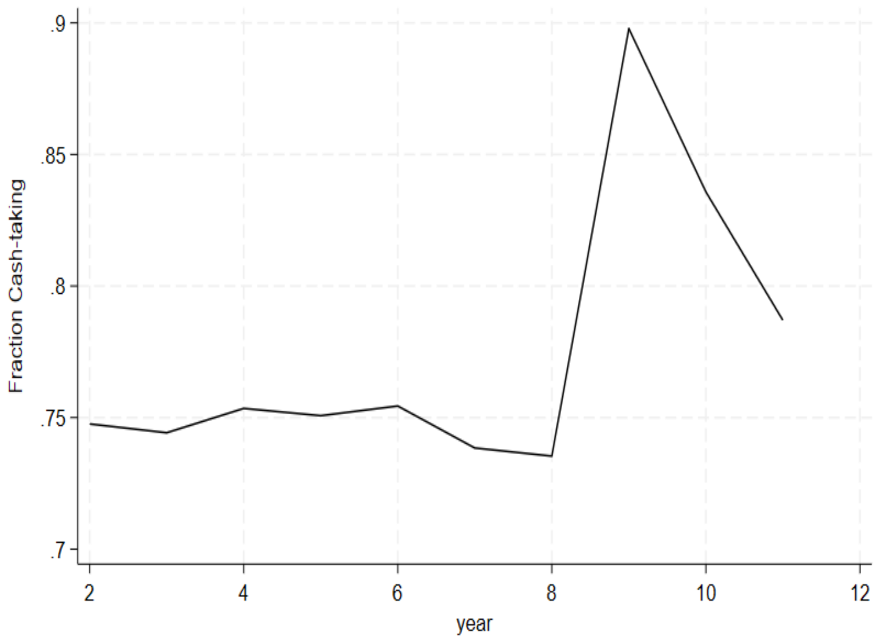
Note: This figure shows the fraction of firms taking equity and cash under different cost of equity assumptions for a simulated panel of 2000 firms before the 2008 reform.

Figure 11. Fraction of Cash-taking and equity-taking before the reform for a simulated sample of firms under different depreciation rates of capital.



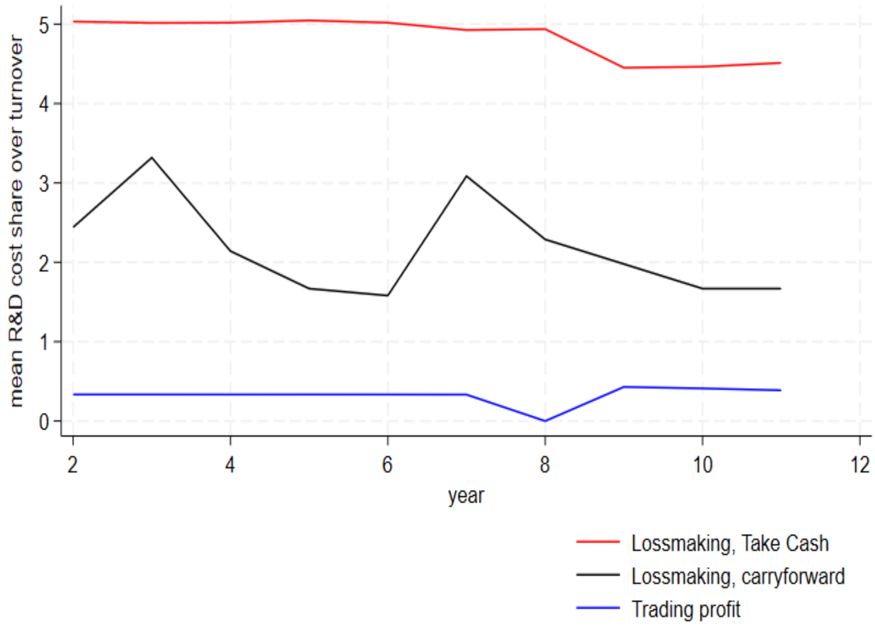
Note: This figure shows the fraction of firms taking equity and cash under different depreciation rates of capital for a simulated panel of 2000 firms before the 2008 reform.

Figure 12. Fraction of Cash-taking over time.



Note: This figure shows the fraction of simulated firms taking the cash-now option over time in a panel of 2000 firms.

Figure 13. Average R&D investment over time.



Note: This figure shows the average R&D investment relative to turnover over time in a simulated panel of 2000 firms. The reform corresponding to the 2008 policy reform happens in period 9.

4.3 Results

Table 2. Estimates of production function-related parameters

	(1) OLS	(2) WG	(3) DIF-GMM	(4) SYS-GMM
y_{it-1}	0.972***	0.391***	0.256***	0.670***
	(0.002)	(0.015)	(0.027)	(0.023)
k_{it-1}	-0.145***	-0.040***	-0.189***	-0.611***
	(0.007)	(0.008)	(0.059)	(0.032)
k_{it}	0.164***	0.154***	0.461***	0.694***
	(0.007)	(0.009)	(0.098)	(0.034)
N	62172	62172	62172	62172

Note: This table presents ordinary least squares, within-groups, differenced GMM and system GMM estimates in Columns (1) to (4), respectively, of the production function in Equation 19.

In Table 2, we present the results from the estimation of Equation 19 using ordinary least squares (OLS), within-groups estimator (WG), differenced GMM (Arellano and Bond, 1991) and system GMM (Blundell and Bond, 1998). The system GMM estimate for the coefficient on the lagged dependent variable falls between the upper bound OLS estimate and the lower bound WG estimate, which is reassuring. The estimated coefficient on k_{it} yields $\hat{\alpha}_k$ of 0.694, which is in a similar ballpark with existing estimates in the literature on R&D and productivity. The estimated coefficients on k_{it} and k_{it-1} together imply a long-run coefficient on knowledge capital of 0.25 (*s.e: 0.001*). Estimates of average productivity (μ_a) and the two variances σ^2 and σ_a^2 are obtained from the random effects estimation of regressing the residuals on a constant. We present these estimates in Table 3.

Table 3. Summary of results: policy, assumed and estimated parameters

		Policy Parameters
d:	Deduction Rate	$d0 = 0$; $d1 = 0.5$; $d2 = 0.25$; $d3 = 0.75$; $d4 = 0.3$
τ:	Tax Rate	0.2 (for small profits)
ϕ:	Cash refund Rate	$\phi_0 = 0$; $\phi_1 = 0.24$; $\phi_2 = 0$; $\phi_3 = 0.245$; $\phi_4 = 0$;
		Assumed Parameters
δ:	Depreciation Rate	0.15 (Hall, Mairesse, Mohnen, 2010)
β:	Discount Factor	0.95 (based on $r_f = 0.05$)
		Estimated Parameters by GMM
$\hat{\rho}$:	Persistence of the shock term	0.670***
$\hat{\sigma}$:	Standard deviation of the shock term	0.769***
$\hat{\alpha}$:	Elasticity of output wrt capital	0.694***
$\hat{\mu}_a$:	Average TFP over types	-9.172***
$\hat{\sigma}_a$:	Variance of TFP over types	19.871***
		Estimated Parameters by MSM [tentative: below are from an earlier version of the model which assumed 50% of population was permanently facing the high constraint]
$\hat{\lambda}^{Low}$:	Cost of external finance	0.020
$\hat{\lambda}^{High}$:	Cost of external finance	0.136***

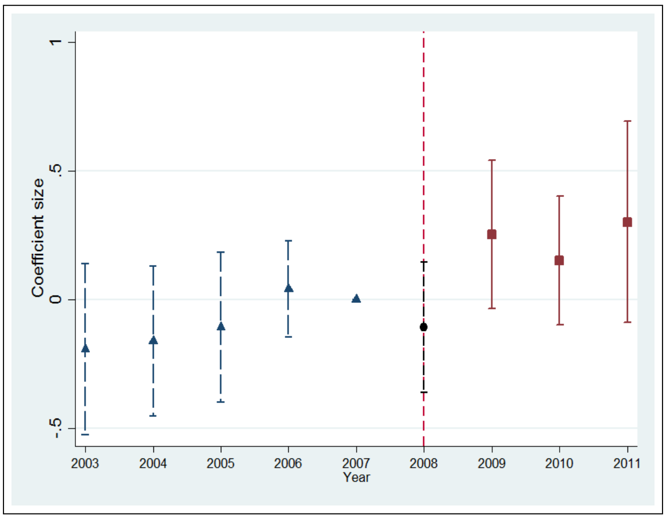
4.4 Reduced-form evidence on financing constraints

The expansion of the SME relief to include medium-sized firms with 250-500 employees in this policy, which has a more generous treatment of investment in R&D leads to a useful diff-in-diff setup. The pre- and post-reform performance of medium-sized firms can be benchmarked against the performance of larger firms, for whom there is no immediate cash option and the user cost of capital remained roughly stable before and after the reforms. Having assigned companies into treated and control groups, the specification in Equation 20 can be estimated using a Poisson regression approach, because of the prevalence of zeros in the outcome variable(Silva and Tenreyro, 2006). In Equation 20, we include year effects, firm fixed effects and controls for lagged firm size and growth rate (vector $\mathbf{X}_{it}$), alongside the diff-in-diff interaction term Treated$_i \times$Post-reform

$$\mathbb{E}[R_{it}|\text{Treated}_i, \mathbf{X}_{it}] = \exp(\eta_i + \delta_I \times \text{Treated}_i \times \text{Post-reform} + \mathbf{X}'_{it}\beta_x + \phi_t) \tag{20}$$

Mechanically, as each treated company increases its investment in R&D, its profit drops. This renders the loss status of the company, and therefore the choice of immediate cash or a carry-forward, to be simultaneously determined as the outcome variable in this framework. Moreover, financing constraints, or whether the effect of the policy operates through the user cost mechanism or the cash flow mechanism is not observed. To address these challenges, we propose a taxonomy of cash refund choices that potentially reveals the probability of facing a high cost of finance in a reduced form approach. We then evaluate the investment responses of firms to the policy, with a breakdown of firms into those with high and low probability of facing a high cost of finance.

Figure 14. Common trends and policy effect on medium-sized companies



Note: Source: Guceri and Liu (2019).

To establish the validity of this diff-in-diff approach, Figure 14 shows the difference between the average R&D investment of medium-sized treated firms and that of larger control firms across years before and after the reform. Firm size is measured at the last pre-reform period for each firm and is fixed to determine assignment to treatment. Figure 14 shows both common pre-reform trends and also the diff-in-diff result that treated firms increase their investment in R&D on average, as already established in the literature. The specification used to produce this graph controls for a variety of time-varying variables and firm fixed effects (Guceri and Liu, 2019).

We build on the diff-in-diff result of Figure 14 to trace whether the firms that respond to the policy by increasing their investment in R&D are predominantly the ones that are more financially constrained. In each pre-reform period, we determine rules to assign each firm into the following four groups, based on information at two consecutive periods t and $t+1$.

(1) financially constrained, negative outlook: firms that face a high cost of finance, and have experienced a recent adverse shock

(2) financially unconstrained, negative outlook: firms that face a low cost of finance, and have experienced a recent adverse shock

(3) financially constrained, positive outlook: firms that face a high cost of finance, and have experienced a recent positive shock

(4) financially unconstrained, positive outlook: firms that face a low cost of finance, and have experienced a recent positive shock

In each pre-reform year, this categorization is possible for the companies that have invested a positive amount in R&D and that also reported a trading loss in period t. Among these, companies that then move to profitable position in period $t+1$ are then labeled as 'positive outlook, financially constrained'. Companies that move from not choosing to take the cash immediately, and that report a trading profit at $t+1$ are labeled as 'positive outlook, unconstrained', while companies that report a trading loss following a choice of not taking the cash immediately are labeled as 'negative outlook, unconstrained'. The sub-group that chooses the immediate cash option in period t and then reports a trading loss in period $t+1$ is 'negative outlook', but it is unclear whether such firms are constrained or unconstrained. Once a company is labeled as 'constrained' or 'unconstrained', the financial constraint dummy becomes a time-invariant characteristic for the company and we extrapolate it to the other years for the same firm for all pre-reform periods.[16]

Having labeled a set of companies as financially constrained, we use a rich set of observed pre-reform characteristics to form predicted probabilities of constrained status ($\hat{P}$) for medium-sized firms that did not have access to the cash option in the pre-reform period and therefore had not revealed their type. We then use $\hat{P}$'s to estimate:

$$\text{Prob}(\text{Cash}_{it+1}|\text{Loss}_{it}, R_{it} > 0)$$

for the group of medium-sized firms that only got access to cash in the post-reform period. Predicted probabilities of high constraint status can either be directly used to obtain interaction terms, or a dummy variable that captures above- and below-median probability of facing high financing constraints can be constructed. Using a dummy variable H_{it} that takes one for firms with a 'high likelihood of being constrained' and

[16]In Appendix **??**, we explain how we additionally use switching between cash and carry-forward to categorize additional companies.

Table 4. Characteristics that correlate with constrained status

Dep. var: 1 (Constrained= 1)	LPM	Probit
Freq. Equity Issue	0.528***	1.459***
	(0.044)	(0.131)
Age	-0.006***	-0.015***
	(0.001)	(0.004)
Turnover	-0.009***	-0.028***
	(0.002)	(0.008)
Turn. Growth	0.015***	0.048***
	(0.005)	(0.017)
Group sub.	0.084***	0.248***
	(0.023)	(0.064)
Group parent	-0.102	-0.267
	(0.091)	(0.268)
R&D / Turnover	0.043***	0.241***
	(0.004)	(0.052)
N	7986	7986

zero otherwise, we estimate:

$$\mathbb{E}[R_{it}|\text{Treated}_i, H_i, \mathbf{X}_{it}] = \exp(a_i + \delta_I \times \text{Treated}_i \times \text{Post-reform} + ... \\ \delta_I^H \times \text{Treated}_i \times \text{Post-reform} \times H_i + \delta_T^H \times \text{Post-reform} \times H_i + \mathbf{X}'_{it}\beta_x + \phi_t) \tag{21}$$

Table 4 presents the determinants of the probability of high financing constraints captured by a linear probability model in Column (1) and by probit in Column (2). In Table 5, in Column (1), we present the estimates for the simple diff-in-diff specification of Equation 20. In Column (2) and Column (3), we introduce the triple interaction terms as in Equation 21. We present the results from the Poisson regression of this specification in Column (2), and OLS results from a linear triple difference specification in Column (3). Results in both Columns (2) and (3) support the hypothesis that the driving force of increased average investment in R&D in response to tax incentives is that such incentives relax the financing constraints of some beneficiary firms.

5 Counterfactual experiments

[to be updated with additional experiments using new estimates]

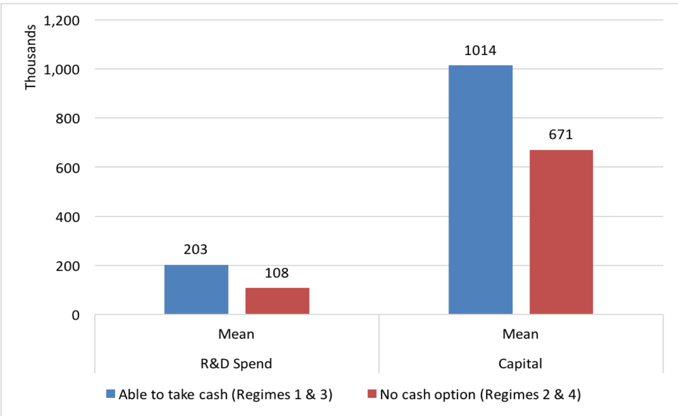
Is the cash refund policy useful to stimulate more investment?

Figure 15 compares the behaviour of different types of companies that choose the cash option instead of carrying their losses forward. There are two main reasons why companies may take the cash option, even though it is not as valuable as a carry forward.

Table 5. Results from diff-in-diff analysis

Dep.var:	(1) R&D (level)	(2) R&D (level)	(3) R&D (in log)
Treated × Post Reform	0.271***	0.389***	-0.073
	(0.104)	(0.147)	(0.085)
Treated × Post Reform × Constrained		1.316*	1.626***
		(0.722)	(0.146)
Post Reform × Constrained		-1.597**	-1.603***
		(0.704)	(0.101)
Method	Poisson	Poisson	OLS
Dep.var: real R&D in	level	level	log
Firm fixed effects?	Yes	Yes	Yes
Year effects?	Yes	Yes	Yes
Turnover (lagged) control?	Yes	Yes	Yes
Turn. Growth (lagged) control?	Yes	Yes	Yes
N	10450	7675	4051

Figure 15. Counterfactuals for the constrained firms



6 Next steps

Work in progress and short-run next steps:

1. Estimate the MSM using the version of the model described in Section 3 and quasi-MCMC, also estimate the depreciation rate in the MSM procedure.

2. Carry out sensitivity tests for identification of financing constraint-related parameters.

3. Present comparative statics based on the model's implications on investment-cash flow sensitivities.

4. Further counterfactual policy experiments to be added based on the expansion of the cash-now option to large firms in 2014. Comments on whether this is interesting are welcome.

7 Discussion

Gomes (2001) discusses that external financing costs may arise from transactional or informational sources. For privately-held innovative companies, the external financing cost typically arises as a result of informational asymmetries, given the difficulty that external funders face to understand potential success of investments in innovation. We may categorize search costs by the entrepreneur for a suitable angel investor as a type of informational cost.

[to be continued]

8 Conclusion

We develop a partial equilibrium, infinite-horizon firm model to describe innovative firms' optimization problem when faced with financing frictions and policy options that address these frictions. Preliminary findings show that the extent of the cost of external financing for investment is high: moments related to financing constraints support that, for highly-constrained firms, about 13.7 percent of total external funding 'evaporates' in transaction. This estimate is close to, but higher than Hennessy and Whited (2007)'s finding of 10.7 percent for the relatively small, listed firms in Compustat. This finding supports the claim that innovative firms face steep financing constraints, and they substantially increase their investment when such constraints are relaxed by a policy such as refundable tax credits.

To our knowledge, the finding in this paper constitutes the first estimates for financing constraints which focus on both listed and unlisted companies, with a particular emphasis on financing for investment in R&D. Available evidence on financing constraints rely on data from publicly traded companies and/or large firms with publicly available information (Compustat or equivalent European data). Indices used to capture financing constraints have been shown to undermine heterogeneities among firms similar in observed characteristics (Farre-Mensa and Ljungqvist (2016)). From the perspective of evaluating the impact of R&D tax incentives, this paper offers the first structural estimates on the heterogeneous effects on companies that face financing frictions.

Cash refund policies help in increasing R&D investment by innovative firms, but they are costly. Based on the findings of this study, the revenue authority only recovers £0.57 for each £1 foregone in CT revenue for constrained firms, and £0.73 for each £1 for firms which are persistently loss-making. If the government believes that there are spillovers and other public benefits from supporting such activity, then the fact that the full pound is not recovered in terms of in-house R&D may be a good use of resources.

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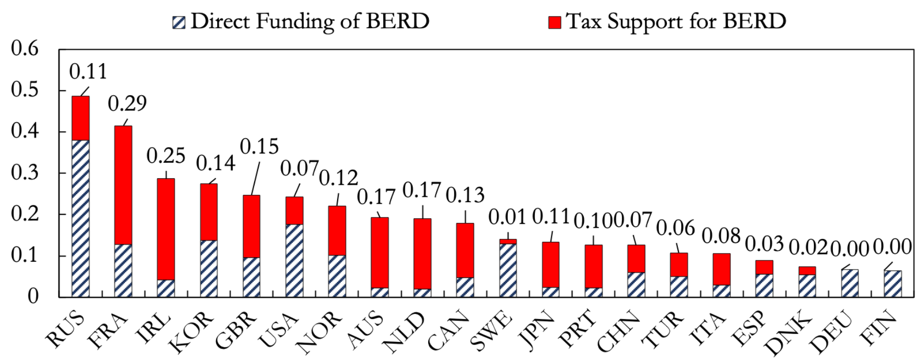
A Detailed information on the policy environment

Globally, government support to business investment in R&D through the tax system has been increasingly popular (Appelt, Galindo-Rueda and Cabral, 2019); Figure 16 highlights the importance of such tax-based measures relative to non-tax support for R&D.

Figure 16. Share of government support for business R&D, direct and tax support



Note: This figure shows government funding of business R&D through: (1) the tax system, and (2) direct subsidies. Vertical axis values are represented as percent of GDP for each of the countries listed on the horizontal axis. The blue-and-white dashed diagonal patterns represent direct support, and the red solid section of the bars represent tax system support. The source for this data is the OECD R&D Tax Incentive Database.

The designs of tax incentive policies for investment and R&D vary across countries. When a company makes a loss, it cannot immediately benefit from a tax deduction or a credit. Many countries allow loss-makers to carry the period loss to the future to set off against the profits of these periods (carryforwards).[17] If the tax benefit from the incentive can also be carried forward in the same way as the loss, then the company can make use of tax incentives in a future period, with the value of future benefits discounted in accordance with the firm's outside options. The effectiveness of investment tax incentives on loss-making companies is not clear, and in fact there is some reduced-form evidence available, which suggests that tax breaks facilitate investment only for the companies which can use them immediately (Zwick and Mahon (2017), Edgerton (2010)).

In light of concerns related to asymmetries in the tax system, supported by vast anecdotal evidence, governments started implementing refundable tax incentives. Specifically in the case of R&D-performing firms, projects take many years until they start generating positive profits, which, due to discounting, may mean that the value of tax breaks

[17] Many countries also allow losses to be carried one or two years back (carrybacks).

becomes negligible to the firm in the absence of a cash refund.

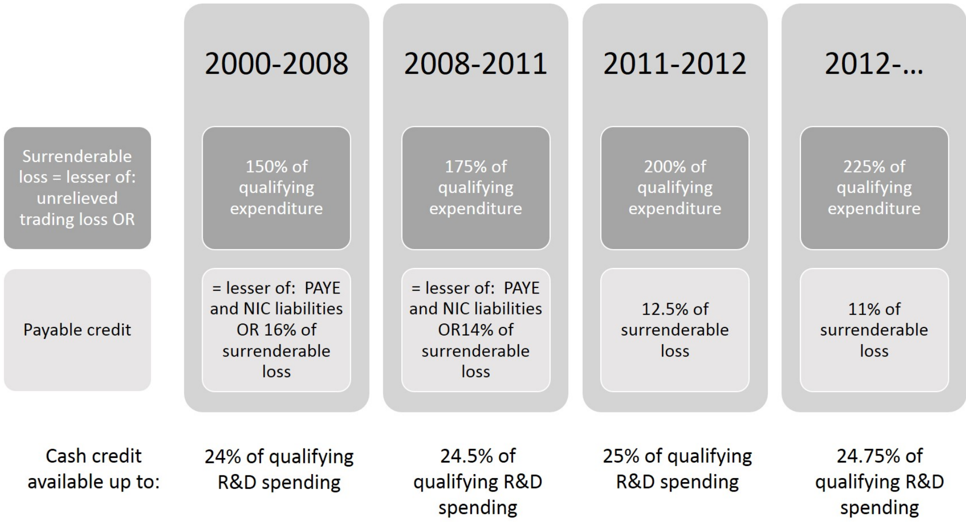
The UK policy provides cash refunds to loss-making firms which cannot immediately benefit from a tax deduction, provided that they perform qualifying R&D in the reference year. Importantly, firms cannot receive the full amount of the tax gain in cash – if they choose to take the cash option, then the nominal value of the cash benefit is lower than the tax gain for a profitable firm. On the other hand, if the firms wait and carry the loss forward to set off against future profits, they can use the full amount in terms of a reduction in tax liability. This set-up, along with a few exogenous policy changes that took place during the data period offer valuable sources of variation to explore heterogeneities in firms' choices. Next, we describe the policy environment and the policy changes in more detail.

The UK introduced its R&D tax relief scheme for SMEs in 2000 and for large companies in 2002. Between 2000-2008, the deduction rates were 150 percent for SMEs and 125 percent for large companies. For example, each profitable SME with qualifying R&D spending of £100 could deduct £150 from its taxable profit and each profitable large firm with the same R&D spending could deduct £125 from its taxable profit. Both SMEs and large companies were allowed to carry forward the losses arising in each period, including the loss arising due to the enhanced deduction. Loss-making SMEs also had the option of a cash refund. In sum, each loss-making SME with £100 of qualifying R&D spending could either calculate its current period loss using the enhanced deduction, and carry forward the loss amount, with a nominal value of the future deduction of £150 $\times \tau$ (where τ is the corporation tax rate) or claim a maximum immediate cash refund from the government of £24. In Figure 17, we present the timeline of rate changes in the SME deduction rates and the corresponding rates of cash claims available to firms.[18]

There are various sources of identifying variation both in the time series and the panel dimensions of the data. In 2008, the definition of an 'SME' for the purpose of the R&D tax relief changed to include a set of larger companies. First of all, for the duration of our dataset, only the SME scheme allowed cash refunds for loss-making companies. In 2008, the binding threshold of 250 employees to define an SME was doubled to include companies with 250-500 employees (See Guceri and Liu (2015), Dechezlepretre et al. (2016) and Guceri (2017) for reduced form analyses which exploit this variation).

[18]For a company that invests £1 and is in loss position in 2006, the gain from claiming cash immediately is $(1 + d) \times c$, which is $1.5 \times 0.16 = 0.24$ in 2006. If the company switches to profit in 2007, the gain from carrying forward to claim against future tax is $(1 + d) \times \tau$, which is $1.5 \times 0.3 = 0.45$ for main rate taxpayers and $1.5 \times 0.2 = 0.3$ for taxpayers at the small profits rate if we assume there is no discounting.

Figure 17. Rates of relief under the SME scheme



Notes: From 1 April 2014 onwards, the deduction rate increased to 230 percent and the rate of payable credit on surrenderable loss increased from 11 percent to 14.5 percent. From 2013 onwards, the design of the large company scheme changed from a deduction to an optional 'above-the-line' tax credit. Subsequently, large companies also started receiving a cash refund when in a loss-making position. These firms are outside the period studied in this paper.

B Data and descriptives

[here: include match rates between tax returns and BvD data, around 95%, include nonmissing ratios for key variables in CT600 and FAME.]