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THE R&D TAX CREDIT IN FRANCE: ASSESSMENT AND EX-ANTE EVALUATION OF THE 2008 REFORM

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ABSTRACT

This article presents an econometric analysis of the direct effects of the R&D tax credit (RTC) on private R&D in France and proposes an ex ante evaluation of the major reform implemented in 2008. We first estimate an error correction model of a dynamic R&D demand function on a large panel data of R&D doing firms, obtaining a preferred estimate of -0.4 for the long run elasticity of the user cost of R&D capital. We then perform a micro-simulation of the effects of the 2008 RTC reform that shows that the implicit long run budget multiplier would be about 0.7.

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1. Introduction

In order to stimulate private R&D, the governments of most western nations have introduced fiscal incentives designed to complement direct public subsidies. These governments have realized that the administrative costs associated with direct subsidies for the designing of research and innovation policies and the selecting and monitoring of sound projects were often disproportionately high. They also considered that private firms have, in general, a better and more realistic understanding of research, innovation and market demand than do public agencies, even when these agencies have excellent, domain-specific expertise. The public support made available to private R&D for the purpose of increasing the inadequate supply of this quasi-public good has thus increasingly taken the form of a reduction of firms' tax liabilities in many countries. In France, according to official figures, the respective shares of direct public subsidies and fiscal incentives in total private R&D were 10.8% and 2.6% in 2000, and 11.8% and 17.9% in 2008.

This article presents an econometric analysis of the direct effects of the R&D tax credit (RTC) on private R&D investment and capital in France and proposes an *ex ante* evaluation of the major reform that has implemented, in 2008, a new regime of RTC much more generous than the previous ones. This new regime is fully based on nominal levels of R&D investment, using a 30% rate of tax reduction up to a high threshold. Since it entails significantly increased budgetary costs, it is particularly important to know whether or not it will be effective. To pursue this question we first measure the user cost of R&D capital and estimate an error correction model of a dynamic R&D demand function on a large panel data of French firms doing R&D over the period 2000-07, obtaining a preferred estimate of -0.4 for the long run elasticity of user cost of R&D capital. We then perform a micro-simulation of the effects of the 2008 RTC reform and compare it to a benchmark micro-simulation assuming no reform. We thus find that the benefit-to-cost ratio or budget multiplier —here understood as the ratio of additional private R&D expenditures to the lost tax revenue associated with the tax credit— would in the long run be about 0.7.

Hall and Van Reenen (2000) and, more recently, Ientile and Mairesse (2009) surveyed a large number of econometric studies that sought to estimate the effects of the R&D tax credit (RTC) in different countries and at different moments in time. In most such studies, the implicit budget multipliers, were positive but could differ widely depending on the country and period, the type of tax credit, its base and reduction rate, and its practical implementation. In France, since its introduction in 1983, the RTC has been analysed from various perspectives in a number of official reports (see for example the recent report for the Parliament by the Ministry of Higher Education and Research: MESR 2011). It has only been investigated, however, in a select few scientific studies, of which three of them have, like ours, benefitted from being directly based on panel data samples of R&D doing firms. They are Asmussen and Beriot (1993), Mairesse and Mulkay (2004), and Duguet (2007) who have based their analyses on samples of about respectively 350 firms covering the years 1985–1989, 750 covering 1983–1999 and 1500 covering 1983–2003, while we use here a larger sample of 2,800 firms for the more recent period 2000–2007. The results of these studies are for a number of reasons very difficult to compare. The "matching" approach applied by Duguet is very different from that followed by Asmussen and Beriot, and by us in our previous study and the present one.[1] Although they follow a similar structural econometric approach by estimating a firm R&D investment demand function, these three studies present important differences in their specification and estimation of such function.[2] However, in spite of all their differences, all four studies tend to conclude in favour of the overall effectiveness of the RTC.

Even if the matching methodology used by Duguet for France and other researchers in other countries has advantages, it provides an assessment of the RTC impact in a very precise contextual and institutional setting, but does not characterize firm R&D investment behaviour, and thus cannot support policy scenarios and simulations. It is complementary but cannot substitute to

[1] The matching method implemented by Duguet is based on the comparison of R&D investment by two groups of firms defined so as to be as similar as possible: the "treated group", which consisted of the firms that effectively benefitted from the RTC, and a "control" group, which consisted of firms that could also have benefitted from the RTC but that did not apply for it for various reasons despite being the "closest" to the firms of the "treated group" in terms of sales, R&D-to-sales ratios and industry classification. The reasons why the firms of the control group did not apply for the RTC are unknown reflecting the various costs associated with applying due to the complexity of the system, the uncertainty about its permanence and the fear of a fiscal audit—all of which may be deterrents for the firm if the expected benefits are not high enough.

[2] Asmussen and Beriot (1993), which have been using much simpler specification and estimation method than we do, found estimates we cannot precisely compare to ours. In our previous study we chose as preferred estimate a much larger user cost elasticity of R&D capital than here. This estimate was quite high, of about -2.8, but close to that found for the USA by B. H. Hall in her pioneering article (1993). It corresponded in fact to the elasticity of the tax credit component of the user cost of R&D capital in an attempt to correct for the downward biases due to errors of measurement in the total user cost, but it probably suffered from exacerbated upward endogeneity biases which we did not manage then to take into account properly. Our estimates based on the total user cost and on the component relative to the full fiscal deductibility of R&D were in fact much smaller, at about -0.15 and -0.50, respectively.

the structural econometric approach that is more appropriate in changing and complex settings, provides further economic understanding, and allows better informed policy recommendations. For example the matching method does not provide short- and long-term estimates of the user cost elasticity of R&D capital, where the impact of the RTC on the user-cost depends on its design and on the characteristics of the firm and the economic environment.

The econometric approach we are trying to implement, although rather simple in theory, raises numerous difficulties in practice. However, it allows us hopefully to obtain consistent estimates of the tax-price elasticity of R&D and assess the short-run and long-run effects of a change in the tax credit scheme. It is mainly based on a flexible autoregressive distributed lags or error correction specification of a dynamic R&D investment demand regression and it implies the hard choice of a proper estimation method (see Bond, Elston, Mairesse and Mulkay 1993, and Mairesse, Hall and Mulkay, 1999). It also crucially relies on the attentive measurement of a key price determinant: the user cost of R&D capital, which generalizes the standard physical capital user cost expression (see for example Hall and Jorgenson 1967, and Chirinko, Fazzari and Meyer 1999). The user cost of R&D capital takes into account the design and calibration of the RTC and other features of firm-level taxation, as well as characteristics of the firm and its economic environment.

The French RTC system, which has undergone several reforms since its inception—with a major reform having occurred in 2008—is presented in Section 2. We explain briefly in Section 3 the definition and measurement of the user cost of the firm R&D capital and investment in the presence of the RTC. We also present in this section the firm panel data sample and the descriptive statistics for the user cost and the other variables on which our analysis relies. In Section 4, we rationalise the specification of our firm dynamic R&D demand function as an error correction regression equation derived from a neoclassical model of optimal R&D capital, explain the choice of our preferred estimator, and comment on our main results. Finally, in Section 5, we propose an *ex ante* simulation of the effect of the 2008 major reform of the RTC that is based on our preferred estimates of the R&D demand function for the period before the reform. In Section 6, we make some brief concluding remarks and highlight the work that remains to be done, as more recent data becomes available in the coming years, to provide a better assessment of the RTC and be able to provide an *ex post* evaluation of the 2008 reform.

2. A bird's eye view of the evolution of the French R&D tax credit

A "marginal" or "incremental" RTC was introduced in France as early as 1983, allowing firms to reduce their corporate taxes in proportion to an increase in their R&D expenditures relative to a level of reference until this increase reached a given ceiling. The credit tax rate initially equal to 25% was doubled to 50% in 1985. The level of reference, which was at first the firm R&D expenditures in the previous year, was in 1991 set to the firms' average level of R&D expenditure over the two previous years. The ceiling was increased, by increments, from 0.5 M€ (million Euros) to 6.1 M€. In order to avoid that the incremental RTC might favour the adoption of up-and-downs or stop-and-go investment behaviours, firms were also assigned an implicit negative tax credit if they invested at a level less than their reference level, which could be carried forward over five years to be imputed in deduction of future positive tax credits.

This incremental RTC was designed mainly to minimise the potential windfall effect of a simpler "volume" RTC by not benefiting firms for the portion of R&D they would have invested even in its absence. As such, this might be deemed as a more effective use of public funds that could ensure similar increase of R&D expenditures for less costly reduction in taxes. However, for a firm looking to optimise its R&D investment over time the benefits of the incremental RTC are not simply proportional to the credit tax rate θ as in the case of volume RTC but they also depend on its expected discounting rate or after-tax rate of return. The parameter γ, which effectively measures the RTC reduction rate in the cost (or implicit rental price) of using one unit of R&D during one year, is not equal to θ as in the case of the volume RTC but it is equal to $\theta[k(\rho-\pi)/(1+\rho)]$ for the incremental RTC, where (ρ) is the nominal discounting rate or after-tax rate of return, (π) is the inflation rate, and k denotes a constant depending on the definition of the reference level.[3] The RTC reduction rate γ would thus be negligible or even negative, if the after-tax real rate of return ($\rho-\pi$) was about nil or negative. In this case, the reduction in corporate taxes that a firm investing in an optimal R&D programme can achieve in some years does not compensate the increase in taxes that will be incurred in other years. The fall of real interest rates during the 1990s is in fact a likely reason why benefits from the RTC to firms became less appealing and not

[3] The constant k is 1 if the reference level is set to the R&D in the previous year, and 1.5 if it set to the average R&D over the two previous years. See Appendix to the paper for a detailed demonstration. See also Eisner, Albert and Sullivan (1986).

able to outweigh the various costs associated with applying, and why a large number of them dropped out of the system.[4]

The declining attraction of the incremental RTC was also one reason why the French government decided to complement it by successively introducing, first in 2004 and again in 2006, a proportion of “volume” (or “level”) tax credit applicable to the level of R&D investment with a flat reduction rate θ^V, first of 5% and then of 10%, while it maintained the “incremental” tax credit with a rate θ^M, first of 45% and then of 40%, lower than the previous rate of 50%. At the same time, the tax credit ceiling was gradually raised from 6.1 M€ in 2003 to 16 M€ in 2007, so that only very few firms remained constrained by this ceiling in more recent years.

The 2008 reform was much more drastic than either the 2004 or the 2006 reforms. It disposed entirely of the more complex incremental RTC system and instead adopted in full a simpler “volume” tax credit scheme with a flat credit tax rate θ_1^V of 30% up to a threshold of R&D expenditures $\overline{RD} = 100$ M€, and with a credit tax rate θ_2^V of 5% above this threshold. Most firms, invest less than 100 M€ in R&D per year and thus can benefit from a RTC reduction rate γ simply equal to the maximum tax credit rate θ_1^V of 30%. For the handful of firms that invest more in R&D than the threshold, the reduction rate γ is lower but still higher than the minimum tax credit rate θ_2^V of 5%. For example, two firms that have respectively invested for 160 M€ and 500 M€ worth of R&D in 2008 have respectively received a rebate in their corporate taxes of 33 M€ ($\theta = 20.6\%$) and 50 M€ ($\theta = 10\%$) much higher than the maximum between 6.1 M€ and 16 M€ in the years prior to 2008.

<u>*< Table 1 about here>*</u>

Table 1 summarizes the changes in the design and main characteristics of the French RTC system that have been undertaken since 1991. Since 2004, the RTC—through the progressive introduction of a level design—has clearly become much more generous. Its budgetary cost has of

[4] The number of firms (or “fiscal groups” of affiliated firms) that benefitted from the RTC, which reached a maximum of 7,000 in 1993, decreased to only 3,000 as of 2003 before again rising to 5,000 in 2007 in the wake of reforms carried out in 2004 and 2006, respectively, and more than 10,000 in the wake of the 2008 reform.

course also dramatically increased. While it was roughly stable at about 500 M€ during the period 1991–2003, it increased to an average of 950 M€ in 2004–2005 and 1,600 M€ in 2006–2007; then it nearly tripled, to 4,300 M€ (4.3 billion Euros), with the 2008 reform. This last increase in budgetary cost is largely due to a 50% augmentation in the number of RTC applicants, although these new applicants tend to be smaller R&D investors, with an average R&D investment per applicant being about 1.2 M€ in 2008 as compared to 1.6 M€ in 2007.

3. Definition and measurement of the user cost of R&D capital, other variables and study sample

Generalizing the original expression of the user cost of physical capital (Hall and Jorgenson, 1967), we can derive an expression of the firm user cost *C* of R&D capital *K*, which takes into account not only the RTC but also relevant economic and institutional characteristics. This derivation assumes that the firm maximizes its market value MV_0 in year $t = 0$ as measured by the discounted sums of future dividends: $\max MV_0 = \sum_{t=0}^{\infty} \beta_t Div_t$ with discounting weights: $\beta_t = \prod_{t=0}^{t} \left(1+\rho_t\right)^{-1}$ where ρ_t is the firm nominal rate of discount in year *t*. It also assumes that the firm R&D capital *K* in real terms at the end of year *t* is measured using the standard "permanent inventory" method and the recursive formula $K_t = \left(1-\delta\right) K_{t-1} + (R_t / P^{RD})$, where (R_t / P^{RD}) is the firm R&D investment in year *t* deflated by an index P^{RD} of R&D price. *K* is thus simply equal to the cumulated sum of past deflated R&D investment assuming a geometric process of depreciation at the constant rate δ.

The full derivation of *C*, which also makes clear its connection with simpler formulas used by other authors for R&D capital and physical capital, is given in the Appendix. Ignoring the year index, *C* can be expressed as:

$$C = \left(P^{RD}\right)\left[\left(1-\eta\right)\left(1-\frac{\gamma}{1-\tau}\right)\left(\rho+\delta-\pi^{RD}\right)+s\left(r-\frac{\rho}{1-\tau}\right)\right] \quad (1)$$

where γ is the RTC cost reduction rate, which differs markedly between an incremental tax credit and a volume tax credit (Table 1), and where τ is the corporate tax rate, P^{RD} the price index of R&D and π^{RD} its rate of change, η the share of the firm's R&D financed by public subsidies, ρ the after-tax rate of return, δ the economic depreciation rate of the R&D capital, s the rate of firm indebtedness and r the interest rate on firm debt.

It is useful to distinguish the RTC component of C from its other components by considering the log difference ω of C and the user cost without RTC.[5] The latter is:

$$C_{Without} = \left(P^{RD}\right)\left[\left(1-\eta\right)\left(\rho+\delta-\pi\right)+s\left(r-\frac{\rho}{1-\tau}\right)\right] \tag{2}$$

and if the component imperfect capital markets can be neglected and γ is small enough, we approximately obtain that:

$$\omega = \log\Omega = \log(C / C_{Without}) = \log C - \log C_{Without} \cong \log\left[\left(1-\frac{\gamma}{1-\tau}\right)\right] \cong -\frac{\gamma}{1-\tau} \tag{3}$$

The RTC component ω is sometimes used in an "agnostic" regression (linear in logarithms) to directly assess the impact of the RTC on R&D, thereby avoiding the computation of the user cost C (as well as the computation of the R&D stock of capital).[6]

The data we use to compute our main variables and to construct our study sample was obtained primarily from the matching of two sources: the annual R&D surveys for the firm R&D investment series used to build the R&D capital stocks series, and the annual enterprise surveys for the accounting information used to compute the firm R&D capital user cost series and the firm value added series. In computing the R&D user cost C and $C_{Without}$, the RTC reduction rate (γ), the debt-to-capital ratio (s), the directly subsidized share of R&D (η), the after-tax rate of return (ρ) and the interest rate (r) are measured at firm level. The price level and rate of change of R&D (P^{RD}) and (π^{RD}) are taken from two-digit, industry-level, national account data. The corporate tax rate (τ),

[5] Among these other components, it may also be useful to separate the component relative to the full fiscal deductibility of R&D investment: see Mairesse and Mulkay (2004).

[6] Such regressions in terms of ω, or γ or even θ (and various control variables) can be used at an exploratory stage to assess whether the RTC has a significant impact. They can provide estimates of average elasticities at best roughly proportional (but different in magnitude) from those based on a dynamic R&D investment demand regression in terms of user cost of R&D capital as in the present study.

which is the same for all firms, has slowly decreased from 37.8% in 2000 to 34.4% in 2007. We assume that the rate of depreciation (δ) is constant and equal to 0.15, a reasonable order of magnitude that has been used in a number of studies.[7]

Since we need at least four consecutive years' worth of data if we are to have three years of lagged variables in growth rates in our dynamic model for R&D, we decided to trim from our original sample all firms with fewer than five consecutive years' of data. After also removing some firms with extreme outlier observations in our main variables, our overall study sample is an unbalanced panel of firms with at least five consecutive years of data, where large R&D-conducting firms are covered nearly exhaustively but R&D-conducting SMEs are under-represented. It consists of 2,782 firms with 20,978 observations over the twelve-year period 1996–2007 and has on average data for eight consecutive years for each firm. However, since we use three-year, lagged-growth-rate variables, we are left with a shorter estimation sample of 10,850 observations (20,978 minus 4×2,782) and covering the eight-year period 2000–2007.

< *Figure 1 about here*>

Figure 1 charts the sample-year averages of the nominal R&D user cost with and without RTC over the study period 2000–2007 and in 2008, for which we computed them with the new, much higher RTC reduction rate (γ) but with the same values as were used in 2007 for the other components. The average user cost without RTC has been changing more or less steadily, at an annual rate of 3.2% over the period 2000–2008, from 0.165 € to 0.210 €.[8] The average user cost reduction only 0.005 € (3%) in the period 2000–2003; it increased to 0.015 € (8%) in 2004–2005 and to 0.030 € (15%) in 2006–2007 with the progressive introduction of the volume RTC in these

[7] The R&D and enterprise annual surveys are conducted by the ministries in charge of research, manufacturing and other industries, respectively, under the coordination of INSEE, the French national statistical office. All enterprises investing in R&D as defined in the OECD Frascati manual are surveyed either yearly (for large firms) or on a rotating basis over a two- or three-year period for small- and medium-sized enterprises (SMEs). For details about the data, the computation of the firm user cost of R&D capital and additional descriptive statistics see Appendices 3 and 4 in Mulkay and Mairesse (2011).

[8] In real terms (i.e., deflated by the price index of the GDP in 2000 constant price), the user cost of R&D capital remained stable until 2005, at an average of approximately 0.17 €, before increasing to an average of 0.19 € in 2007.

years, which was meant to benefit all firms and not only those that were investing more in R&D. Following the 2008 reform, the average user cost reduction jumped to about 0.100 €, nearly a 50% reduction.

Figure 1 also shows the share of volume component in the total RTC, necessarily equal to 0% until 2003 when there was no volume RTC, between 0% and 100% from 2004 to 2007 when the incremental and volume RTCs co-existed, and equal to 100% in 2008 when the incremental RTC was discontinued in favour of a full volume RTC. This graph reveals a striking increase of this share, from 0% to 75–80% in the period 2004–2007, even though the volume tax credit rate θ^V was only 5% and 10% over that same period. It shows that in practise, from 2004 on, the RTC was already mostly a volume RTC. This is comforting for the reliability of our *ex ante* simulation of the 2008 reform based on the parameter estimates of R&D investment demand that we can only obtained for the period 2000–2007—since all the necessary firm data for the more recent years are not yet available for research purposes.

< Table 2 about here>

Table 2 provides several descriptive statistics (e.g., mean, standard deviation, min, median and max) for our main variables in log-levels and log-first differences as they are used in the econometric analysis: the R&D capital stock (K), the nominal value added (V), the nominal user cost of R&D with and without RTC (C) and ($C_{Without}$) and their log-difference (ω). The R&D capital-to-value added ratio is on average of the order of 0.5, which is to be expected because the average R&D investment-to-value added ratio is on the order of 0.2 (corresponding to an average R&D investment-to-sales ratio of 0.06). Note, however, that the R&D capital grows much more rapidly than does the value added: at an average annual rate of 4.6% versus 2.6°%, or 4.6% versus 2.2°% when both are in real terms (with the price index of value added declining over the period at an average rate of -0.4°%). As usual with microeconomic data, all the variables in levels, as in rates of growth (approximately equal to log-first differences), are highly dispersed.

Since we control for year and firm effects in the various estimations we perform and our preferred estimates are based on the within-year and within-firm variability of the variables, we also document in Table 2 the classical decomposition of their total variability in the time and cross-sectional dimensions of the data. As usual, the between-firm standard deviations are much higher for the variables in levels than the within-firm-year standard deviations, while the reverse is true for the variables in rates of growth and the user cost (C) and ($C_{Without}$). Note that the RTC component of the R&D capital user cost (ω) is the only one for which the share of between-year variability is predominant, reflecting the fact that its variability arise primarily from the successive reductions in the R&D user cost that result from the policy reforms. Since we control for year-fixed effects in all our estimations, our estimates do not depend on these overall changes but are based on the changes within each of the three RTC schemes or regimes of our study period.

4. Model specification, estimation methods and main results

We consider a relatively simple model of R&D investment that expresses the long-run equilibrium equality of the marginal productivity of R&D capital and its R&D user cost for a profit-maximizing firm. This model can be formally derived under the simplifying assumption of a production function with a constant elasticity of scale (ν) and a constant elasticity of substitution (σ) between R&D capital and all other factors of production, and on the hypothesis of imperfect competition on the firm product market with a constant mark up (μ). It can be written as:

$$k = \theta v - \sigma c + \alpha \tag{4}$$

where k, v and c are, respectively, the log levels of firm R&D capital K in real terms, value added V and R&D capital user cost C, and where α stands for firm and year individual effects and $\theta = \left(\sigma + \mu(1-\sigma)/\nu\right)$ if V and C are measured in nominal terms.[9]

[9] For more details on the derivation of this model, see Appendix 2 in Mulkay and Mairesse (2011). This derivation would be more straightforward and the expression of θ more simple if we could measure V and C satisfactorily in real terms. This is not really possible, however, for lack of data on output price changes at the firm level. Using the only available two-digit output price indices as deflators generates possibly correlated errors of measurement: see Klette and Griliches (1996); Griliches and Mairesse (1998); Mairesse and Jaumandreu (2005). Note that θ becomes equal to 1 assuming perfect competition in the firm product market (μ = 1) and constant returns to scale (ν = 1), and that it is equal to (μ/ ν) assuming a nul user cost elasticity (σ = 0).

To make equation (4) more realistic before taking it to the data, we also must specify the dynamics of R&D investment, and in particular we have to approximate firm expectations on demand and account for the costly adjustment process of R&D capital. A pragmatic way to do this is to insert the long-run relation (4) into an autoregressive distributed lags equation, or ADL linear regression equation, which we can write with three lags—on *k*, *v* and *c*, respectively—as:

$$\begin{aligned}k_{i,t} &= \gamma_1 k_{i,t-1} + \gamma_2 k_{i,t-2} + \gamma_3 k_{i,t-3} + \beta_0 v_{i,t} + \beta_1 v_{i,t-1} + \beta_2 v_{i,t-2} + \beta_3 v_{i,t-3} \\ &\quad + \sigma_0 c_{i,t} + \sigma_1 c_{i,t-1} + \sigma_2 c_{i,t-2} + \sigma_3 c_{i,t-3} + \alpha_t + \alpha_i + \varepsilon_{i,t}\end{aligned} \tag{5}$$

where α_t stands for fixed-year dummies that can account for economy-wide effects, α_i stands for random firm effects that act as a proxy for the (roughly) constant omitted firm characteristics and take care of firm unobserved heterogeneity, and ε_{it} represents the typical idiosyncratic errors in the regression that are assumed to be independent (non-autocorrelated) white noise errors.[10]

To clearly separate the short-run dynamics from the long-run relation and to allow for a more straightforward interpretation, we can rearrange the ADL equation in the strictly equivalent form of an error correction model (ECM), and we can write our empirical estimating dynamic model as the following linear regression:

$$\begin{aligned}\Delta k_{i,t} &= \eta_1 \Delta k_{i,t-1} + \eta_2 \Delta k_{i,t-2} \\ &\quad + \xi_0 \Delta v_{i,t} + \xi_1 \Delta v_{i,t-1} + \xi_2 \Delta v_{i,t-2} + \zeta_0 \Delta c_{i,t} + \zeta_1 \Delta c_{i,t-1} + \zeta_2 \Delta c_{i,t-2} + \\ &\quad + \varphi\left(k_{i,t-1} - v_{i,t-1} - c_{i,t-1}\right) + \lambda v_{i,t-1} + \lambda' c_{i,t-1} + \alpha_t + \alpha_i + \varepsilon_{i,t}\end{aligned} \tag{6}$$

where Δk, Δv and Δc denote the first differences of *k*, *v* and *c* (or the log-growth rates of *K*, *V* and *C*), respectively.

In this ECM regression (6) the coefficients η, ξ and ζ of the variables in first differences characterise the short-term dynamic adjustment of R&D capital to its user cost and to the product demand to the firm (as measured here by its value added), while the coefficients φ, λ and λ' of variables in levels characterise the long-run relation: $\varphi\left(k_{i,t-1} - v_{i,t-1} - c_{i,t-1}\right) + \lambda v_{i,t-1} + \lambda' c_{i,t-1}$. This relation can be rewritten as $\varphi\left(k_{i,t-1} - (1-\lambda/\varphi)v_{i,t-1} - (1-\lambda'/\varphi)c_{i,t-1})\right)$ showing that the long-term

[10] The number of lags on the dependent and other regressors has to be chosen so that the idiosyncratic errors $\varepsilon_{i,t}$ are white noise. We have found that three lags—on *k*, *v* and *c*, respectively—seem sufficient.

elasticity of R&D capital with respect to its user cost is $\sigma^{LT} = (1 - \lambda / \varphi)$ and that of long-term elasticity to product demand to the firm is $\theta^{LT} = (1 - \lambda' / \varphi)$.[11] The coefficient φ, or error correction coefficient of the ECM, is expected to be negative and between 0 and 1 in absolute value. It estimates the one year reduction in the proportion of the gap existing between the lagged R&D capital and its desired level (i.e., its long-run equilibrium level for the current demand and current user cost). The nearer to 1 this coefficient is, the more rapid the adjustment of the R&D capital stock to its equilibrium level for a given demand and the less persistent its dynamics. The mean lags, or mean numbers of years it will take to return to the long-run equilibrium following unexpected changes in product demand and in user cost, respectively, are: $\theta^{ML} = \frac{\xi_0 + \xi_1 + \xi_2}{\varphi - \lambda} + \frac{\eta_1 + \eta_2 - 1}{\varphi}$ and $\sigma^{ML} = \frac{\zeta_0 + \zeta_1 + \zeta_2}{\varphi - \lambda'} + \frac{\eta_1 + \eta_2 - 1}{\varphi}$.

< Table 3 about here>

Table 3 presents five different types of estimates of our regression equation (6) that are representative of various panel data estimators we can consider as most appropriate depending on the specification errors that are most likely to affect them and to be sources of sizeable biases. We will discuss each in turn. The second of the Generalized Method of Moment or GMM estimators, noted as GMM(2), which is given in the last column of the Table 3, appears as the least likely to suffer from such biases and, although not as precise as we would like, it nevertheless gives plausible results and thus can be rightly deemed as our preferred estimator.[12]

The first three estimators (Table 3: Columns 1–3) are the usual pooled least squares panel-data estimators computed for the regression as it is, then as written in within-firm deviations and

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[11] Note that we do not write the long-run relation in this way in ECM equation (6) simply to keep it fully linear while directly estimating the error correction coefficient φ. Of course, we still have to derive (in a second stage) the estimates of nonlinear long-term elasticities σ^{LT} and θ^{LT}, as well as the estimates of the nonlinear mean lags σ^{ML} and θ^{ML} (given below).

[12] Note that all five estimators control for year-fixed effects α_t by including, as usual, year dummies in regression (6), and that the last four estimators also address potentially correlated firm effects by writing, as usual, the regression (6) in within-firm deviations or in first differences.

then in first-differences—that is, on ($x_{i,t}$), ($x_{i,t} - \bar{x}_{i,.}$) and ($x_{i,t} - x_{i,t-1}$), respectively, where x denotes the variables in the equation.[13] All three estimators provide biased estimates of the coefficients of the lagged dependent variables (Δk and k). The first ones, or the total estimates, are biased because of the necessary correlation of these lagged variables with the firm effects α_i. Although they remove the α_i, the within and first-difference estimators are also biased for a similar reason: the correlation of the lagged dependent variables and the within and first-differenced idiosyncratic errors ($\varepsilon_{i,t} - \varepsilon_{i,.}$) and ($\varepsilon_{i,t} - \varepsilon_{i,t-1}$).[14] In simple cases, such as those with only a single one-year lagged dependent variable—here, $\Delta k_{i,t-1}$—we expect the total estimate of its coefficient—here, η_1—to be strongly biased, while the within and first-difference estimates would be also biased, but usually less so than the total estimates (especially for the within estimate, the bias of which tends toward zero with the average time length of the panel). We also expect these last two estimates to bracket the true value of estimated coefficient (see Sevestre and Trognon, 1985). Hence we should not be surprised if a consistent estimate of η_1 falls in the range of -0.04–0.30 and is nearer to 0.30. This is indeed what we find with our preferred estimator, GMM(2), which gives an estimated η_1 of 0.24 with an estimated standard error of 0.07.

Because of the expected endogeneity of the firm demand and R&D user cost, it is also likely that the firm effects α_i are correlated with the current and lagged log-level and growth rate variables v, c, Δv and Δc, and hence that the total estimator provides biased estimates of the coefficients ξ, ζ, λ, λ', and φ. It is similarly likely that the within and first-differenced estimators provide more- or less-biased estimates of these coefficients. The lagged idiosyncratic errors $\varepsilon_{i,t-1}, \varepsilon_{i,t-2}, \ldots$, and hence the mean errors $\varepsilon_{i,.}$, are indeed likely to be correlated with the current log-levels and growth rates of $v_{i,t}$, $c_{i,t}$, $\Delta v_{i,t}$ and $\Delta c_{i,t}$, even if we assume that they are uncorrelated with the current errors $\varepsilon_{i,t}$. We can see that the total estimator gives an estimated order of magnitude of 0.80 for the long-term elasticity of demand θ^{LT}, which seems reasonable, and one of around -0.30 for the long-term elasticity of the user cost σ^{LT} that, although also reasonable, nevertheless is very imprecise and not statistically different from zero. For the error correction

[13] The standard errors reported in Table 3 for the estimated coefficients with these three estimators are robust to general heteroskedasticity and autocorrelation of errors (Arellano, 1987).

[14] See Nickell (1981) for the within estimator and Balestra and Nerlove (1966) or Anderson and Hsiao (1981) for the first-difference estimator.

coefficient φ, however, it also gives an estimate that is both negligible and extremely precise, and hence completely unrealistic, and accordingly it gives mean lags for the demand θ^{ML} and user cost σ^{ML} that are incredibly high (36 and 61 years).[15] The within and first-differenced estimators, by removing the firm effects α_i, provide plausible estimates of the error correction coefficient and of the mean lags. However, they give implausibly low (about 0.40–0.45) estimates of the long-term elasticity of demand and estimates of the R&D user cost that are negligible and not significantly different from zero. Such low estimates appear to reflect endogeneity biases that are mainly due to errors in measurement in the firm expected demand and R&D user cost and not to simultaneity biases, *stricto sensu*, which might result in upward biases.[16] This is confirmed by considering our two selected GMM estimates.

We basically rely here on the GMM estimator, or differenced GMM, as initially proposed by Arellano and Bond (1991), which is computed by writing in first differences the ECM regression (6), or the ADL regression (5), to remove the individual firm effects α_i, and then by using lagged levels of the endogenous variables as instruments to correct for the biases due to the presence of the lagged dependent variables and the measurement errors and simultaneity of the other explanatory variables.[17] One problem associated with these estimators, especially in instances in which the dependent variable is persistent, is that of weak estimators, which results in very imprecise estimates.[18]

Our best estimator, although not fully satisfactory, is the GMM(2) estimator using the following set of instruments: two- and three-year lagged k, two- or three-year lagged Δv, and current to three-year lagged c. As can be seen in Table 3, it passes at the 5% level of confidence the

[15] Note that for all of our estimators there is a tradeoff between a high auto-regression coefficient η_1 that expresses the persistence of R&D capital and a low error correction coefficient φ that expresses the speed of adjustment in returning to the long-run equilibrium level for a given demand and user cost. This is clearly the case for the total estimator.

[16] See Griliches and Mairesse (1998), who make the point that such errors of measurement and the resulting attenuation downward biases are very much exacerbated in first-differenced estimators (and to a somewhat lesser degree in within-firm estimators).

[17] The GMM estimates reported in Table 3 are the optimal (second-step) estimates, with estimated standard errors computed using the Windmeijer correction (2005) to control for the downward small-sample biases identified by Arellano and Bond (1991).

[18] We have also tried to use the level and system GMM suggested by Arellano and Bover (1995) and Blundell and Bond (1998) to correct for this problem, but we have only obtained poor estimates that did not pass the Sargan over-identification test or the *m*2 test of non-autocorrelation of the idiosyncratic errors.

Sargan test and also *m*2 test—albeit barely—and it provides estimates that are all reasonably plausible and accurate. We also report the GMM(1) estimator using as instruments only the two- and three-years lagged of the endogenous variable k in levels, as proposed by Arellano and Bond (1991). It also passes the Sargan and m2 tests but provides in fact estimates very close to the first-differenced ones, with a long-term elasticity that is also negligible for the user cost of R&D capital and also very low for demand.

Overall we obtain as our preferred estimates: a long-term R&D user cost elasticity of -0.40 (with a standard error of 0.16) that is in line with a credible elasticity of substitution between R&D capital and the other inputs in the production function; a long-term product demand elasticity of 0.65 (0.14) that is plausible but probably on the low side; an error coefficient of -0.24 (0.04) that is perhaps somewhat small; and mean lags of 4.2 and 2.9 years (both with a standard error of 0.3) for the user cost and the demand and the demand, respectively, that seem reasonable if somewhat long.[19]

5. *Ex ante* evaluation of the 2008 reform

One aim of this study was to propose an *ex ante* evaluation of the 2008 RTC reform, because we need to wait a number of years until its actual effects on private R&D have unfolded and until we can also have access to the firm data that will allow a thorough econometric analysis and assessment.[20] We cannot conduct such an evaluation without making two crucial assumptions as well as some simplifying hypotheses for the sake of convenience. The two crucial assumptions are: i) that the coefficients of our firm R&D investment are structural parameters consistently

[19] Note that a current change $\Delta c_{i,t}$ on the user cost of R&D capital has a negligible effect on the current change $\Delta k_{i,t}$ of R&D capital (ζ_0 = -0.01), whereas this effect is sizeable for a current change $\Delta v_{i,t}$ in demand (ξ_0 = 0.07). This accounts for the slow adjustment of R&D capital, and hence of R&D investment, to changes in the user cost, and for the more rapid adjustment to changes in demand.

[20] In practice, firm R&D survey data and firm accounting information for year t are at best available in year t+2 for official analysis by government agencies, and accessible in year t+3 for researchers under specific confidentiality agreements.

estimated using our preferred GMM(2) estimator; and ii) that these coefficients apply after the 2008 reform as they do before despite the drastic nature of the reform.

Essentially, we conduct our evaluation by performing and comparing two simulations of R&D capital and investment evolutions for a given economic environment from 2007 onward: a "Benchmark simulation", conducted with the RTC as of 2007, and a "Reform simulation", conducted with the RTC as implemented in the 2008 reform. To be coherent with our firm panel econometric analysis, we have run these simulations at the firm level for the 1,319 firms included in our study sample and still in operation in 2007. For the sake of simplicity, we have also assumed a stationary environment. We thus suppose that firms' value added remain constant at its 2007 level and that all components of its R&D user cost as defined in formula (1) also remain constant at their 2007 values, with the one exception of the RTC cost reduction rate γ. For the Benchmark simulation, we keep γ equal to its 2007 value before the reform, and for the Reform simulation we take it equal to its 2008, post-reform value. For both simulations and all years from 2007 onward, we first compute for all firms their individual R&D capital paths using the GMM(2) estimated regression equation (7).[21] We can then also derive for all of them their R&D investment path by using the permanent inventory recursive formula.

<u>*< Figures 2(a) and 2(b) about here>*</u>

The results of our simulations aggregated at the level of our sample are shown in Figures 2(a) and 2(b) for R&D capital and investment, respectively. Each figure consists of two pairs of two graphs: the first graph being the Benchmark simulation and the second the Reform simulation. The first pair of graphs in each figure displays only long run changes. Assuming that R&D capital and investment are already at their long-run equilibrium levels in 2007, they remain at these levels in 2008 and in subsequent years in the Benchmark simulation, while in the Reform simulation they jump immediately in 2008 to their new equilibrium levels. The second pair of graphs in each figure

[21] Note that in the simulation we take into account the threshold of 100 M€ for the RTC after the 2008 reform, above which the nominal rate decreases from 30% to 5%. Note also that since firms are usually out of equilibrium at any point in time, in order to keep their R&D capital at its observed value in 2007 and to avoid an initial discontinuity, we also must adjust the computed R&D capital after 2007 for each firm by its estimated regression residual in 2007 (the sum of estimated firm effect and 2007 idiosyncratic error).

illustrates more realistically dynamic evolutions. Starting from their observed levels, R&D capital and investment converge over time toward their 2007 equilibrium levels in the Benchmark simulation in 2008 and in subsequent years, while they simultaneously converge to these levels and adjust to the new 2008 equilibrium levels in the Reform simulation. Since R&D capital and investment are actually far enough from their equilibrium level in 2007, the two pairs of graphs in both figures remain quite distinct over approximately a 10-year period.

Looking at the orders of magnitude, we see that in 2007 the R&D capital stock was actually 60.6 B€ (billions Euros), 9°% smaller than its long-run equilibrium level of 66.2 B€, while the R&D investment flow was 11.8 B€, 5°% higher than its long run equilibrium level of 11.2 B€. We also see in figure 2(a) that the 2008 RTC reform involves an important increase of R&D capital of some 11.5% from the previous 2007 long-run equilibrium to the new post-reform long-run equilibrium of 73.8°B€, and thus an even larger increase of about 20% from its actual 2007 level to this new equilibrium. This increase is, however, very progressive over a period of about 10 years, with half of it occurring over some 4 years. The corresponding evolution of R&D investment in Figure 2(b) appears very different. We first see only a small increase (0.7°% or + 80°M€) of R&D investment in 2008, then a rapid increase up to a maximum of 13.8°B€ in 2012 overshooting by 10°% the post-reform long-run equilibrium of 12.5°B€; and we finally see until about 2019 a gradual decrease back to this new long-run equilibrium.

<u>< Figures 3 about here></u>

It is also possible, and clearly of major interest, to simulate the implicit RTC budget multiplier (or "bang-for-the-buck" multiplier, as it is casually referred to). Here we compute it as the ratio between the increase in R&D investment following the 2008 RTC reform and the resulting increase in budgetary cost. Figure 3 presents the difference in R&D investment between our Reform and Benchmark simulations as shown in Figure 2(b) and the corresponding difference in budgetary cost (with the corresponding scales in M€ on the left Y-axis), together with the RTC budget multiplier computed as the ratio of these two differences (with the corresponding scale on the right Y-axis). Since R&D investment increased progressively from 2008 to a maximum in 2012, while the budgetary cost of the reform began to increase immediately, we see that the budget multiplier remains small in the first three years of the reform (0.1 in 2008, 0.3 in 2009 and 0.5 in 2010), then increases significantly in the next three years (2011–2013) up to 1 or slightly more, and finally slowly declines to a long-run value of 0.7. The standard error that can be estimated for this long run value is approximately 0.3, showing that at a 5% level of confidence it is statistically positive and also not statistically less than 1.

6. CONCLUSIONS

In France since the 2008 reform, the RTC system has become the main public policy tool designed to sustain and increase private R&D. The RTC has shifted from being a pure incremental RTC (up to 2003) to a pure volume RTC in 2008, with a brief period, 2004–2007, during which both types coexisted. We have derived and computed the user cost of R&D capital under these two designs and we have estimated an R&D error correction investment model on a large panel of firms for the period 2000–2007. We obtain reasonable values with our preferred GMM estimator for the long-run elasticities of product demand and the user cost of R&D capital about 0.65 and -0.40, respectively, while the speed of the dynamic adjustment to the desired level of R&D capital may appear to be somewhat slow, with estimated mean lags of 2.9 and 4.2 years, respectively.

Based on our estimates, we have performed an *ex ante* evaluation of the 2008 reform by comparing the adjustment path of R&D capital and investment for two firm-level simulations—one without the reform and one with the reform. We find that the reform has a positive and significant effect on R&D capital and investment, which are higher in the long run by about 12% than they would have been without it. Such an effect corresponds to an implicit long run budget multiplier about 0.7, a quite significant order of magnitude. It is important in this regard to remember that this multiplier only corresponds to the direct effects of the RTC on business R&D investments without taking into account their spillover effects at the level of the economy, which are actually the main rationale for the public support in the form of RTC.

Such first *ex ante* evaluation of the 2008 RTC reform should of course be confirmed by an *ex post* empirical assessment after its actual effects on private R&D have been allowed to unfold over at least a three- to four-year period and when the accounting data for this period become accessible. It will be important to take into account both the general context of economic crisis and the slowdown, and even decline, of French industries and its consequences on firms' demand prospects and R&D projects. It will also be interesting to evaluate the extent to which the changes introduced by the 2008 RTC reforms, meant to institute a simpler and more generous system, have led more new firms, and especially SMEs, to engage in R&D activities. Taking such new firms into account in the econometric analysis and more generally considering firm size, financial situation and other relevant characteristics should be part of a better and more useful evaluation of R&D policy.

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Table 1: The French R&D Tax Credit system

	Tax credit rate θ	Ceiling in M€	Reduction rate of the cost of using one unit of R&D per year γ	γ reduction rate†
1991–2003	$\theta^M = 50\%$ $\theta^V = 0\%$	6.1 M€	$\gamma = \theta^V + \theta^M \left(\frac{\rho - \pi}{1+\rho} 1.5 \right)$	3.5%
2004–2005	$\theta^M = 45\%$ $\theta^V = 5\%$	8 M€		8.1%
2006	$\theta^M = 40\%$ $\theta^V = 10\%$	10 M€		12.8%
2007		16 M€		
from 2008	$\theta_1^V = 30\%$ $\theta_2^V = 5\%$	Not a ceiling, a threshold: $\overline{RD} = 100$ M€	$\begin{cases} \gamma = \theta_1^V & \text{if } RD \le \overline{RD} \\ \gamma = \theta_1^V \frac{\overline{RD}}{RD} + \theta_2^V (1 - \frac{\overline{RD}}{RD}) & \text{if } RD > \overline{RD} \end{cases}$	$\gamma = 30\%$ $5\% < \gamma < 30\%$ * and **

† The cost reduction is computed for a firm with an R&D investment that is below the ceiling, assuming a given nominal discounting rate and a given inflation rate of 8% and 3%, respectively.
* γ = 20.6% for a firm with an R&D investment of 160 M€, corresponding to the ceiling of 16 M€ of the level of RTC in 2007.
** γ = 10.0% for a firm with an R&D investment of 500 M€—that is, 400 M€ above the threshold.

Table 2: Descriptive Statistics

	log(*K*)	Δlog(*K*)	log(*V*)	Δlog(*V*)	log($C_{Without}$)	log(*C*)	ω=log(Ω)
Mean	8.553	0.046	9.247	0.026	-1.733	-1.807	-0.074
Standard Deviation.	1.694	0.107	1.647	0.213	0.244	0.253	0.072
Minimum	3.039	-0.161	3.871	-1.662	-4.605	-4.605	-0.490
Median	8.309	0.031	9.225	0.032	-1.726	-1.799	-0.066
Maximum	15.592	1.205	16.419	1.371	-0.858	-0.929	0.000
Std. Dev. between-year	0.102	0.004	0.081	0.012	0.024	0.040	0.051
Std. Dev. between-firm	1.171	0.059	1.142	0.077	0.139	0.143	0.011
Std. Dev. within-year-firm	0.226	0.077	0.247	0.210	0.161	0.162	0.017
Share Var. between year	0.7%	0.2%	0.4%	0.6%	1.7%	4.4%	90.9%
Share Var. between firm	98.0%	61.6%	98.7%	27.1%	66.4%	65.1%	4.9%
Share Var. within-year-firm	1.3%	38.2%	1.7%	72.3%	31.9%	30.5%	4.2%

Unbalanced sample: 10,850 observations, 2,782 firms, 8 years (2000–2007). All variables are in Euros.
V: nominal value added. *K*: R&D capital stock (in constant 2000 prices). $C_{Without}$: Nominal user cost of capital without RTC (but after taxes and subsidies). *C*: Nominal user cost of capital with RTC. *ω*: Effect of RTC.

Table 3: Estimations Results

	TOTAL	WITHIN	FIRST DIF.	GMM (1)	GMM (2)
	Parameter Estimates				
Δk (t-1)	0.556 ***	0.302 ***	-0.043 ***	0.315 *	0.239 ***
	(0.019)	(0.021)	(0.014)	(0.178)	(0.073)
Δk (t-2)	0.026 **	-0.031 **	-0.043 ***	0.016	0.028
	(0.014)	(0.013)	(0.010)	(0.050)	(0.031)
Δv (t)	0.065 ***	0.060 ***	0.061 ***	0.053 ***	0.074 *
	(0.005)	(0.005)	(0.005)	(0.006)	(0.032)
Δv (t-1)	0.036 ***	-0.023 ***	-0.056 ***	-0.012	-0.028 ***
	(0.004)	(0.006)	(0.006)	(0.021)	(0.010)
Δv (t-2)	0.026 ***	-0.013 ***	-0.022 ***	-0.007	-0.015 ***
	(0.004)	(0.004)	(0.004)	(0.008)	(0.005)
Δc (t)	0.000	0.005	0.009 *	0.000	-0.012 *
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Δc (t-1)	0.003	0.004	0.005	0.005	0.067 ***
	(0.004)	(0.006)	(0.006)	(0.006)	(0.024)
Δc (t-2)	0.005	0.006	0.006	0.006	0.051 ***
	(0.004)	(0.005)	(0.004)	(0.005)	(0.017)
Error (t-1)	-0.007 ***	-0.193 ***	-0.402 ***	-0.185 *	-0.236 ***
	(0.001)	(0.010)	(0.011)	(0.100)	(0.044)
v (t-1)	-0.001 **	-0.105 ***	-0.245 ***	-0.118 **	-0.083 **
	(0.001)	(0.009)	(0.012)	(0.058)	(0.037)
c (t-1)	-0.010 **	-0.198 ***	-0.396 ***	-0.193 *	-0.332 ***
	(0.004)	(0.015)	(0.015)	(0.099)	(0.052)
Constant	0.009	0.849 ***	0.003 ***	0.965 **	0.449
	(0.009)	(0.081)	(0.001)	(0.485)	(0.334)
	Long-Run Effects				
log(V)	0.819 ***	0.456 ***	0.387 ***	0.364 ***	0.650 ***
	(0.069)	(0.036)	(0.022)	(0.050)	(0.144)
log(C)	-0.327	-0.029	-0.019	-0.040	-0.406 ***
	(0.512)	(0.052)	(0.028)	(0.065)	(0.158)
	Mean Lags				
log(V)	36.55 ***	3.49 ***	2.76 ***	3.11 ***	2.90 ***
	(4.58)	(0.18)	(0.10)	(0.21)	(0.34)
log(C)	61.28 ***	6.30	3.89 ***	5.10 **	4.21 ***
	(9.30)	(4.08)	(1.59)	(2.00)	(0.32)
	Statistics				
SSR	66.9524	33.5009	66.9182		
s	0.078597	0.064486	0.078577		
Adjusted R^2	0.9978	0.9986	0.4587		
Sargan				14.41 [0.346]	69.30 [0.192]
m1				-1.886 [0.059]	-3.170 [0.002]
m2				-1.146 [0.252]	-1.954 [0.051]

10,850 observations, 2,782 firms, (2000–2007); average number of years per firm = 3.9. Standard errors robust to heteroskedasticity and autocorrelation in parentheses. GMM second step (optimal) with corrected standard errors (Windmeijer, 2005). P-values of tests in brackets for GMM estimations. Sargan test has 28 degrees of freedom for GMM(1), and 60 for GMM (2). m1 and m2 are tests of autocorrelation of order 1 and 2 for the idiosyncratic errors $\varepsilon_{i,t}$. SSR stands for the sum of squares of the residuals and s for the estimated regression standard error of the regression. GMM (1) is estimated with the following 25 instruments: k, t-2–t-3; GMM (2) is estimated with the following 72 instruments: k, t-2–t-3; Δv, t-2–t-3; and c, t–t-3.

Figure 1: User cost of R&D capital with and without RTC (LH scale); share of "volume" component in RTC (RH scale %)

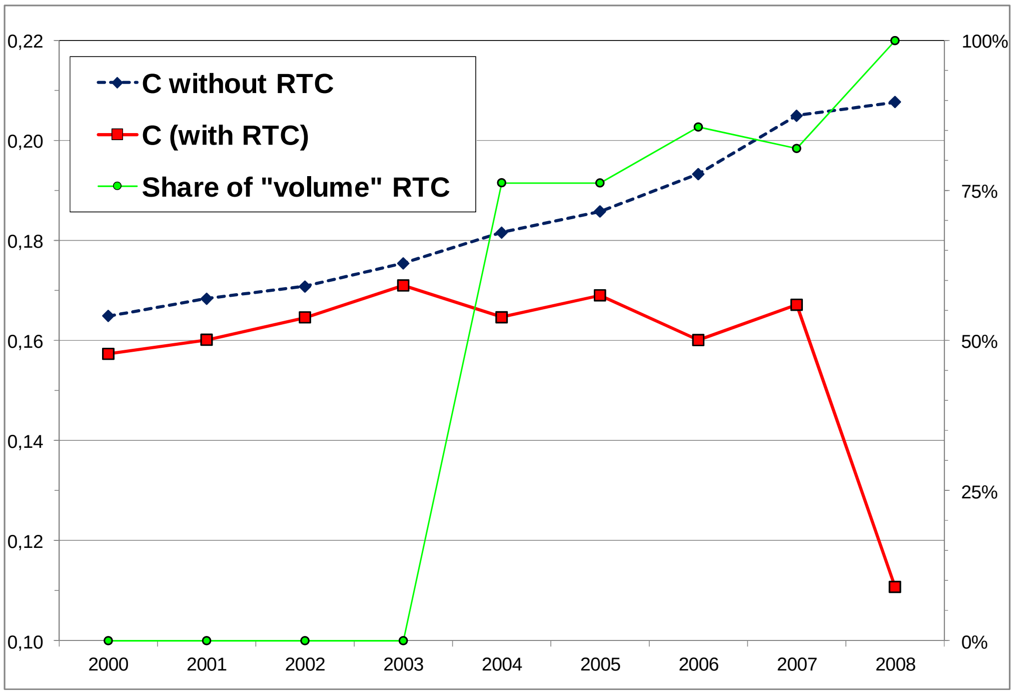


Figure 2(a) : Simulated evolutions of R&D capital (in B€)

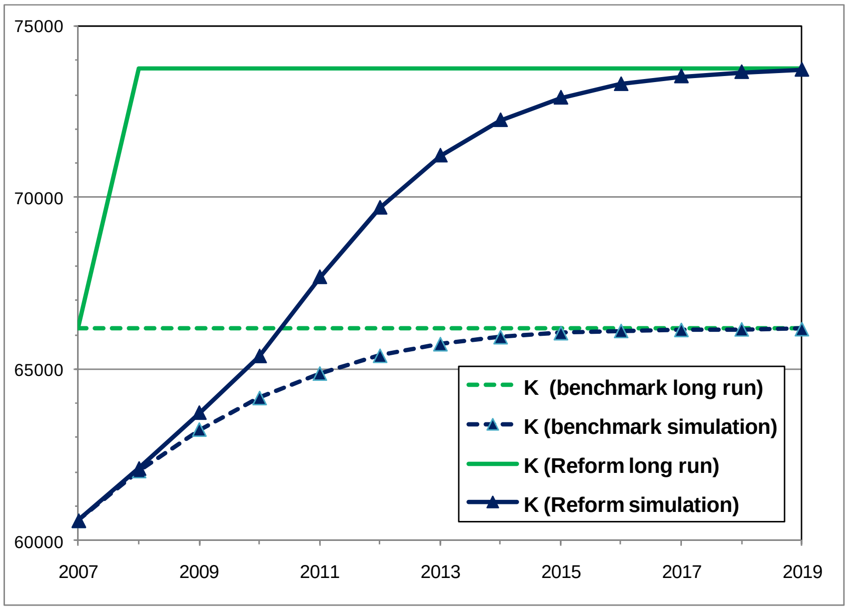


Figure 2(b): Simulated evolutions of R&D investment (in B€)

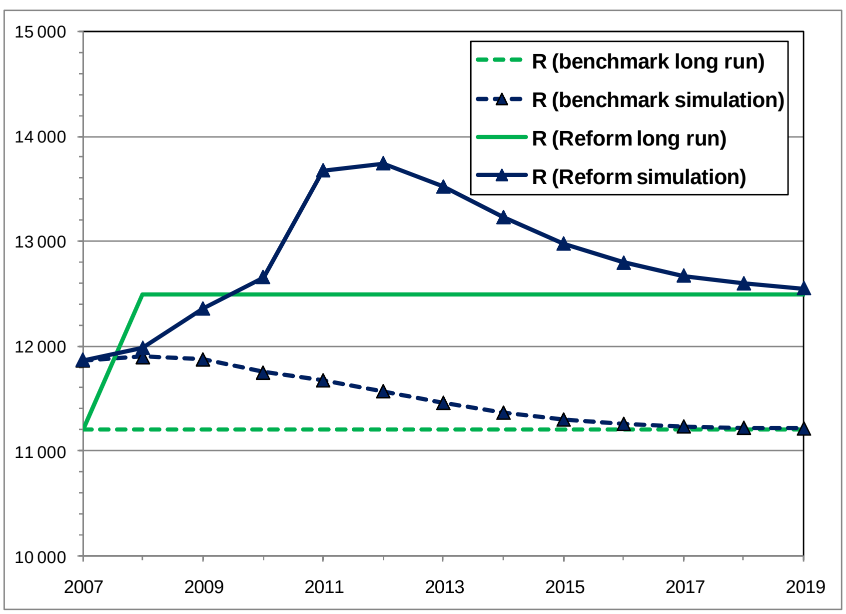
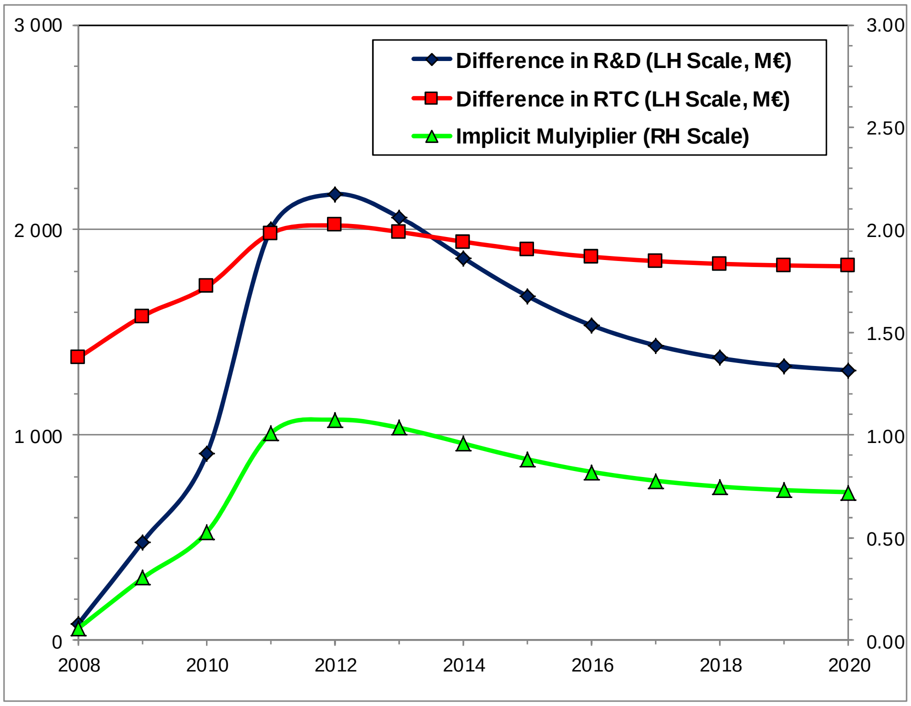


Figure 3: Simulated evolution of budget multiplier of 2008 RTC reform



Appendix

Derivation of the user cost of R&D capital in the presence of an R&D tax credit

The firm optimization problem

The user cost of capital, i.e. the cost of using one unit of R&D capital during one period is derived below assuming that the firm maximizes its market value is measured by the discounting sums of future dividends:

$$\max MV_0 = \sum_{t=0}^{\infty} \beta_t Div_t \tag{A.1}$$

with a discounting rate : $\beta_t = \prod_{i=0}^{t} (1+\rho_i)^{-1}$ where ρ is the firm's net of taxes rate of return. The dividend is defined by the difference between the resources and the uses of funds. For the sake of simplicity, it is assumed that there are no new share issues. Retained earnings and new debts are the only changes of the firm's liability.

$$Div_t = OP_t - r_t D_{t-1} - TX_t - \left(P_t^{RD} R_t - Subv_t\right) + D_t - D_{t-1}$$

$$\text{Where} \quad \begin{cases} OP_t & \text{: Operating profits} \\ r_t & \text{: Interest rate on firm's debt} \\ TX_t & \text{: Coporate taxes} \\ D_t & \text{: Firm's debt (end - of - period)} \\ R_t & \text{: R \& D expenditures (real)} \\ Subv_t & \text{: Subsidies on R \& D expenditures} \\ Div_t & \text{: Dividends} \end{cases}$$

The corporate tax, at a rate τ[22], is computed on the basis of operating profits less the interest charges and the full cost of R&D net of subsidies[23]. A tax credit on the R&D expenditure (RTC) is also allowed as a rebate on the corporate taxes for the company[24].

$$TX_t = \tau_t\left(OP_t - r_t D_{t-1} - \left(P_t^{RD} R_t - Subv_t\right)\right) - RTC_t$$

This R&D tax credit relies either on the value of the current R&D (net of subsidies), what we called the "*volume*" or "*level*" *RTC* or on the increase in R&D (net of subsidies) for an "*incremental*" or "*marginal*" *RTC*. To take account of these two forms of tax credit, it is assumed that it depends on the R&D expenditure of the current year and of the previous period. In the French system, the RTC[25] is computed on the basis of the R&D expenditures net of subsidies, and they are revaluated at the current prices:

$$\begin{aligned} RTC_t &= \theta_0\left(P_t^{RD} R_t - Subv_t\right) + \theta_1 \frac{P_t^{RD}}{P_{t-1}^{RD}}\left(P_{t-1}^{RD} R_{t-1} - Subv_{t-1}\right) + \theta_2 \frac{P_t^{RD}}{P_{t-2}^{RD}}\left(P_{t-2}^{RD} R_{t-2} - Subv_{t-2}\right) \\ &= \sum_{j=0}^{2} \theta_j \frac{P_t^{RD}}{P_{t-j}^{RD}}\left(P_{t-j}^{RD} R_{t-j} - Subv_{t-j}\right) \end{aligned} \qquad \text{(A.2)}$$

with θ_i the nominal rates of tax credit. If $\theta_0 > 0$ and $\theta_1 = \theta_2 = 0$, this is a "*level*" tax credit, whereas if $\theta_1 < 0$ and $\theta_2 < 0$, the RTC system is incremental. All the intermediate cases can be studied within this framework.

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[22] We consider here that all the firms face the same rate on profits even though there is a reduced rate for very small firms.

[23] We assume implicitly that R&D subsidy is taxable revenue for the firms.

[24] This R&D tax credit is assumed as an immediate reduction on total taxes for the firms which are paid in the current year.

[25] We will not enter into the details of the French tax system which does not allow the negative tax or the refunding of tax credit if it would be higher than the corporate taxes, nor difficulties of the carry forward of the losses over several years in order to eliminate a taxation from the future or former profits. In fact a negative R&D tax credit is carried forward against next positive tax credit during a maximum of 5 years. In the same way, the difficulties related to the possible thresholds of the tax credit will not be assessed here.

We assume that the subsidies are decided exogenously by the government and cannot exceed the amount of R&D expenditures. Therefore we can express a R&D subsidy rate as:

$$\eta_t = \frac{Subv_t}{P_t^{RD} R_t} \quad \Rightarrow \quad Subv_t = \eta_t P_t^{RD} R_t \quad \Rightarrow \quad \left(P_t^{RD} R_t - Subv_t\right) = \left(1 - \eta_t\right) P_t^{RD} R_t$$

Therefore the R&D tax credit can be written as:

$$RTC_t = \sum_{i=0}^{I} \theta_i \frac{P_t^{RD}}{P_{t-i}^{RD}} \left(P_{t-i}^{RD} R_{t-i} - Subv_{t-i}\right) = \sum_{i=0}^{I} \theta_i \left(1 - \eta_{t-i}\right) P_t^{RD} R_{t-i} \tag{A.3}$$

Finally the following expression for the dividends of the firm can be written as:

$$Div_t = (1 - \tau_t)\left(OP_t - r_t D_{t-1} - \left(1 - \eta_t\right) P_t^{RD} R_t\right) + D_t - D_{t-1} + RTC_t \tag{A.4}$$

We assume here that the firm's indebtedness is proportional to the value of the assets of the firm measured by the value of the R&D capital at the replacement cost:

$$D_t = s_t P_t^{RD} K_t \tag{A.5}$$

Finally the last constraint is the equation for the evolution of the R&D capital stock, which depreciates economically at a constant rate δ:

$$K_t = (1 - \delta) K_{t-1} + R_t \tag{A.6}$$

By substituting the expressions for the R&D tax credit (A.3), the dividends (A.4), and the debt (A.5) in the firm's maximization program (A.1) and by taking account of the constraint (A.6), the discrete-time generalized Lagrangian is obtained for the firm optimization problem with the Lagrange multipliers λ_{t+j} of the discounted constraints for the change in R&D capital stock:

$$\max MV_0 = \sum_{t=0}^{\infty} \beta_t \begin{Bmatrix} (1-\tau_t)\left[P_t F_t(K_{t-1}) - r_t s_{t-1} P_{t-1}^{RD} K_{t-1}\right] - (1-\eta_t) P_t^{RD} R_t \\ + s_t P_t^{RD} K_t - s_{t-1} P_{t-1}^{RD} K_{t-1} + \sum_{i=0}^{I} \theta_i (1-\eta_{t-i}) P_t^{RD} R_{t-i} \\ - \lambda_t \left[K_t - (1-\delta) K_{t-1} - R_t\right] \end{Bmatrix} \tag{A.7}$$

<u>The shadow price of R&D</u>

The first order condition for the R&D expenditure allows expressing the Lagrange multiplier as:

$$\begin{aligned} \lambda_t &= \left[1 - \tau_t - \underbrace{\left(\theta_0 + \frac{\theta_1}{1+\rho_{t+1}} \frac{P_{t+1}^{RD}}{P_t^{RD}} + \frac{\theta_2}{(1+\rho_{t+1})(1+\rho_{t+2})} \frac{P_{t+2}^{RD}}{P_t^{RD}} \right)}_{\gamma_t} \right] (1-\eta_t) P_t^{RD} \\ &= (1 - \tau_t - \gamma_t)(1-\eta_t) P_t^{RD} \end{aligned} \tag{A.8}$$

This Lagrange multiplier should be viewed as the marginal value of one unit of R&D capital at the period *t*. It is equal to the price of R&D (net of subsidies), corrected by the tax credit effect and the tax rate[26]. γ in the expression (A.8) measures the tax credit effect on the user cost of capital. In fact the price (net of subsidies) of the R&D is reduced by this factor.

If there is no tax credit $\theta_0 = \theta_1 = \theta_2 = 0$ and the firm's faces the full cost, less subsidies, of the R&D with $\gamma = 0$. During the period 1983 to 1990, the incremental R&D tax credit was based on the difference between the current and the first lag of R&D expenditures. Therefore $\theta_M = \theta_1 = -\theta_0$ and $\theta_2 = 0$, the price of the R&D (net of subsidies) will then be reduced by:

$$\gamma_t = \theta_M \left(\frac{\rho_{t+1} - \pi_{t+1}^{RD}}{1+\rho_{t+1}} \right)$$

where $\pi_{t+1}^{RD} = \left(P_{t+1}^{RD} - P_t^{RD}\right) / P_t^{RD}$ is the inflation rate on the price of R&D between *t* and *t*+1.

[26] The tax rate reduces the cost of R&D because the expenditures can be offset immediately from the firm's operating profit. It has the same effect than an immediate depreciation of these R&D expenditures.

In 1991 the computation of the incremental RTC was based on the comparison of the current and two first lags of revaluated R&D expenditures. The RTC coefficients becomes then $\theta_0 = \theta_M$ and $\theta_1 = \theta_2 = -\theta_M/2$. And the price of the R&D (net of subsidies) is reduced by a factor:

$$\gamma_t = \theta_M \left[\left(\frac{\rho_{t+1} - \pi_{t+1}^{RD}}{1+\rho_{t+1}} \right) + \frac{1}{2} \left(\frac{1+\pi_{t+1}^{RD}}{1+\rho_{t+1}} \right) \left(\frac{\rho_{t+2} - \pi_{t+2}^{RD}}{1+\rho_{t+2}} \right) \right]$$

The first term in square brackets is the same effect than the previous incremental RTC. The change on the comparison basis with the last two years increases by about 50% the effect of the tax credit. Assuming a constant rate of returns $\rho_{t+1} = \rho_{t+2}$ and a constant inflation rate $\pi_{t+1}^{RD} = \pi_{t+2}^{RD}$, we obtain:

$$\gamma_t = \theta_M \left(\frac{\rho_{t+1} - \pi_{t+1}^{RD}}{1+\rho_{t+1}} \right) \left[1 + \frac{1}{2} \left(\frac{1+\pi_{t+1}^{RD}}{1+\rho_{t+1}} \right) \right] \cong \theta_M \left(\frac{\rho_{t+1} - \pi_{t+1}^{RD}}{1+\rho_{t+1}} \right) \times 1.5$$

When the tax credit depends only of the current R&D expenditures, it is called a "*level*" RTC. In this case, only $\theta_0 = \theta_V > 0$ while $\theta_1 = \theta_2 = 0$. A "*level*" RTC was introduced in France in 2004 at a rate of 5%, modified to 10% in 2006. The effect of this RTC on the cost of R&D is obviously this rate because:

$$\gamma_t = \theta_V \,.$$

The optimal R&D capital stock

The first order condition for the R&D capital stock is obtained as:

$$\frac{\partial V_0}{\partial K_t} = \beta_t \left[s_t P_t^{RD} - \lambda_t \right] + \beta_{t+1} \left[(1-\tau_{t+1}) \left\{ P_{t+1} \frac{\partial F_{t+1}}{\partial K_t} - r_{t+1} s_t P_t^{RD} \right\} - s_t P_t^{RD} + \lambda_{t+1}(1-\delta) \right] = 0$$

After introducing the Lagrange multiplier found in expression (A.8), this yields the expression for the after-taxes marginal productivity of the capital in value (with $\beta_t / \beta_{t+1} = 1 + \rho_{t+1}$):

$$(1-\tau)P_{t+1}\frac{\partial F_{t+1}}{\partial K_t} = \left[(1+\rho_{t+1})(1-\tau_t-\gamma_t)(1-\eta_t)-(1-\delta)(1-\tau_{t+1}-\gamma_{t+1})(1-\eta_{t+1})\left(1+\pi_{t+1}^{RD}\right)\right]P_t^{RD} \\ +\left[(1-\tau)r_{t+1}-\rho_{t+1}\right]s_t P_t^{RD} \tag{A.9}$$

where $\pi_{t+1}^{RD} = (P_{t+1}^{RD} - P_t^{RD})/P_t^{RD}$ is the rate of inflation on R&D which measures the capital gains carried out by the detention of one of R&D.

It is assumed for simplicity that the changes between two periods in the tax credit parameter γ_t is negligible, $\gamma_t \cong \gamma_{t+1}$, as well as the subsidy rate on R&D : $\eta_t \cong \eta_{t+1}$. The change in the rate of taxes on profits is not anticipated by the firm: $\tau_t = \tau_{t+1}$. Finally with a small value for $\delta\pi_{t+1}^{RD} \cong 0$, (A.9) simplifies to:

$$(1-\tau_t)P_{t+1}\frac{\partial F_{t+1}}{\partial K_t} \cong (1-\tau_t-\gamma_t)(1-\eta_t)P_t^{RD}\left(\rho_{t+1}+\delta-\pi_{t+1}^{RD}\right) - s_t\left((1-\tau_t)r_{t+1}-\rho_{t+1}\right)P_t^{RD} \tag{A.10}$$

Therefore we end up with the traditional expression for the marginal productivity in value of the R&D capital and its user cost of the capital (*C*):

$$P_{t+1}\frac{\partial F_{t+1}}{\partial K_t} = C_{t+1} \tag{A.11}$$

where the user-cost of capital is defined by:

$$C_{t+1} = \left(1-\eta_t\right)\left(1-\frac{\gamma_t}{1-\tau_t}\right)P_t^{RD}\left[\left(\rho_{t+1}+\delta-\pi_{t+1}^{RD}\right)+\left(s_t\left(1-\tau_t\right)r_{t+1}-\rho_{t+1}\right)\right] \tag{A.12}$$

This user cost of R&D capital is also the same as the one proposed by Hall (1993) and Hall and Van Reenen (2000) which is frequently used in the empirical studies of R&D cost. This expression is close from the one obtained by Hall and Jorgenson (1967), Stiglitz (1973), Auerbach (1983), King and Fullerton (1984) or Mayer (1986). The only differences come from the interest rate term where the rate of return on firm's equity can be different from the firm's interest rate on its debt. If there is no leverage effect of the debt or if there is no differential between the interest rate on the debt and the required yield on equity, the cost of the capital is rewritten like the Hall and Jorgenson user cost of capital expression:

$$C_{t+1} = (1-\eta_t)\left(1-\frac{\gamma_t}{1-\tau_t}\right)P_t^{RD}\left[\rho_{t+1}+\delta-\pi_{t+1}^{RD}\right]$$

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