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A Computational Analysis of R&D Support Programs

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Abstract

Government R&D support programs are examined within a dynamic equilibrium model of imperfectly competitive industries in order to study the effectiveness of such programs and the extent to which their design matters. We compare two common support schemes, R&D tax credit and direct R&D grants. Adopting comprehensive welfare measures that take into account government, producer and consumer surpluses, we find that both schemes exhibit positive social returns. Mid-range R&D intensive sectors exhibit higher social returns than either high or low R&D intensive sectors. Both incentive schemes generate positive measures of R&D input additionality of magnitudes consistent with empirical R&D research. However, R&D grants that require firms to allocate subsidy funds to R&D spur *less* R&D than a more flexible R&D tax credit. Subsidy schemes can even induce competing firms to over-spend on R&D, generating negative producer surplus and possibly negative social returns.

JEL Classifications: H25, H32, O31, O32, O38, C63.

Keywords: R&D subsidies, tax credits, competition, process and product R&D, R&D price elasticity, R&D additionality, social welfare.

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1 Introduction

Based on the premise that unfettered markets under-provide R&D investments, most industrialized countries offer generous support programs to business expenditures on R&D. These support measures include *direct* subsidies and grants to approved projects, as well as *indirect* fiscal incentives in the form of tax credits to corporate R&D. Canada, France and the U.S. were among the first to introduce R&D tax credit schemes in the early 1980's. As of 2011, two thirds of the OECD countries have some form of R&D tax credit incentives in place, as compared with only one third in 1996. Underlying the massive support from public sources for inventive activities is a solid foundation in economic theory starting with Arrow (1962), with additional impetus provided by the endogenous growth literature (Romer 1990). R&D subsidies are further justified by empirical findings that social returns on R&D activities exceed private returns (see Hall, Mairesse, and Mohnen 2009 for a recent survey).

Are different R&D subsidy schemes equally effective? Which metrics should be used to evaluate an R&D support program? Which subsidy scheme is "best" and at what level of support? Which industries should be targeted? Should all corporate R&D activities be subsidized, or should governments target only incremental R&D? These fundamental questions address the *design* of a subsidy program, and different countries resolve them in drastically different ways. Many countries offer both direct and indirect support programs to encourage R&D. Most countries offer full tax deductions on R&D expenditures, and in some cases these deductions can exceed reported expenditures (e.g. deductions of 125% in Australia and UK). Many countries, such as UK, USA, Ireland, Japan, Korea, and France, offer tax credits calculated as a percentage of R&D expenses above certain thresholds. Some countries provide direct support at the project level — for example, the SBIR program in the US and the financing of up to 50% of approved R&D projects costs in Israel. Given the plethora of the type, scope and levels of such programs, it is apparent that there is little consensus among policy makers about how to answer these questions.

Virtually all developed countries offer direct subsidy measures to business expenditures on R&D, while many of them, including two thirds of OECD countries, also rely on indirect support in the form of R&D tax credit to stimulate R&D. While both direct and indirect support measures refund some of the accrued R&D expenditures to the firm, the mechanism by which they do that is quite different. R&D grants are allocated through a government agency review of a detailed project application using a pre-set criteria, and the recipient must spend the grant on the selected project. R&D tax credits are handled through the tax system on the basis of self-reported qualifying expenditures, with no restrictions on how these credits can be used by the recipient.

Such differences between the two forms of support can have several consequences. Tax credits avoid asymmetric information and bureaucratic hurdles that may hinder the sorting process for direct R&D funding, and are more attuned to market forces by allowing firms to decide on the best use of the support received. On the other hand, direct R&D grants can be targeted to specific technologies, and can be granted on the basis of prior success in R&D endeavors. In general, R&D support programs can affect the number of firms performing R&D (extensive margin) as well as the level of R&D expenditures by any given firm (intensive margin). While both tax credits and direct grants are expected to increase R&D activities along the intensive and extensive margins, a tax credit may have an advantage on the extensive margin due to its relative simplicity, universality and absence of disclosure risks.

To address the subsidy program design questions, we develop a dynamic model of R&D investment that incorporates three main channels for reinvestment by firms, namely, funds to (i) improve product quality, (ii) reduce cost of production, and (iii) increase production capacity. R&D activities create spillover benefits (positive externalities) among competing firms within the industry. Inter-industry and intra-industry competition provide firms with incentives to invest in various channels. These investments are determined by each firm in the market in equilibrium. We use this framework to examine the equilibrium responses to direct R&D grants versus indirect R&D tax credits. Our analysis tackles only the intensive margin difference between the schemes, and so it might underestimate the overall benefits and costs of R&D tax credits. As our focus is on the strategic implications of the support program design, we ignore other aforementioned differences between the two schemes.

In lieu of arbitrarily picking a handful of model parameter settings, we simulate over 10,000 sample industries using guidance from COMPUSTAT data to specify reasonable ranges for the parameters. For each industry sample, we numerically find the equilibrium over a multi-period planning horizon, and compute various measures of the equilibrium impacts of the subsidy schemes considered. In particular, we compute the *social welfare gain* — a comprehensive measure of how a subsidy scheme affects all stakeholders (consumers, producers and the government), as well as the subsidy cost of the program. We evaluate each subsidy scheme according to two welfare metrics: the *net social welfare gain*, which is the social welfare gain minus the subsidy cost, and the *benefit/cost* ratio which is the ratio of the social welfare gain to the subsidy cost. We also consider more the familiar impact measures, *additionality* and *R&D price elasticity*, often used in empirical evaluations of government R&D support programs.

Our approach to evaluating and comparing R&D support programs differs from most existing analyses in three important ways:

- *Use of comprehensive metrics.* Our metrics for policy evaluation incorporate the welfare of all stakeholders involved, in addition to measures of inventive efforts, output volumes, prices and product qualities.
- *Use of equilibrium outcomes.* Our analysis of the policy effects of government stimuli use equilibrium outcomes that reflect both the dynamic optimization and strategic interactions among firms in the industry.
- *Use of a large sample of industries.* We gauge the expected impact of government stimuli by constructing a large sample of industries with a broad range of realistic parameter values that represent dimensions of firm diversity which are pertinent to how firms respond to R&D stimuli.

1.1 Main results

We compare two of the most common forms of R&D subsidy programs, *R&D tax credits* and *R&D grants.* Tax credits allow a firm to deduct a fraction of its qualifying R&D expenses from its tax liability. R&D grants involve government refunding of some fraction of expenditures of approved R&D projects. Thus, R&D tax credits increase a firm's free cash flow, and so the firm may use the extra funds for non-R&D activities or even for shareholders dividends. R&D grants are more restrictive, as they must be spent on R&D activities. Given this more restrictive nature of R&D grants, it may seem obvious to infer *a priori* that they will spur more R&D additional investment as compared to a tax credit, which can be used for anything, even for dividends. Our results prove that this inference is generally not correct. Another obvious inference is that the restriction on the use of R&D grant money would never affect firms who have R&D expenditures that exceed the grant amount. This inference ignores the important fact that in this subsidy scheme only firm-own R&D expenditures are the basis for *future* subsidies.

Analysis of our model generates these main findings:

- *Are the subsidy schemes effective?* On average, both subsidy schemes are effective on all measures, generating additional R&D and welfare gains. However, approximately 10% of the sample pool of industries exhibit a negative net social welfare gain or benefit to cost ratio of less than one.

- *Which subsidy scheme is best and at what level of support?* It depends on the metric chosen. With respect to the net social welfare gain, additionality and the R&D price elasticity, the R&D tax credit is, on average, superior to the grant subsidy at all levels of support. In fact, the industry sample distribution of net social welfare gain under R&D tax credit stochastically dominates that distribution under direct grants. However, with respect to the benefit to cost ratio, there are some levels of support for which the grant subsidy is more effective than the tax credit. As the level of support increases, the net social welfare gain also increases whereas the benefit to cost ratio and additionality decrease.

- *Which industries should be targeted?* Industries that exhibit "medium" levels of R&D intensity (pre-subsidy) are the most responsive to R&D stimuli. Targeting industries with "high" levels of R&D intensity is only moderately beneficial, while targeting industries with "low" levels of R&D intensity produces very little gain.

1.2 Model overview

We examine a monopolistically competitive duopoly with imperfectly substitutable goods. A representative consumer combines the industry goods and a composite of all "other goods" to derive his total utility. Thus, each producer not only faces an intra-industry competition but also a broader competition with all other goods for the consumer's spending share.

The decisions to be taken by the producers and the consumer are divided into two classes. In each period within the planning horizon (taken to be ten years), a single-period equilibrium is derived as a Cournot-Nash equilibrium in quantities. In this equilibrium, each producer takes as given consumer spending in the industry, the qualities of his own and his rival's product, and his cost efficiency, and determines his profit maximizing production level for that period. The consumer takes as given his total income for that period and the qualities and prices of each of the industry goods, and maximizes his utility by allocating his income between the industry goods and the other composite good.

At any point in time, the productive capacity, cost efficiency, and product quality of each firm are determined by past investments in each of these reinvestment channels. The functional forms we use to model the respective returns-to-R&D within each period exhibit positive but decreasing returns from both firm own current R&D investments as well as from cumulative industry aggregate past investments due to technological spillovers. The key decision of a firm is how to allocate its after-tax cash flow between dividends and each of these possible reinvestment activities to maximize its value. To render our model computationally tractable, we restrict firm strategies to a static share allocation of cash flows to dividends and the possible investment activities. Actual investment and dividend levels will vary over time, as they are proportional to the firm's cash flows each period. A pure-strategy Nash equilibrium in reinvestment strategies is found numerically.

1.3 Related literature

Evaluations of R&D support programs tend to focus on relatively simple metrics of how much additional *R&D input* they generate. Although recent papers, such as Ientile and Mairesse (2009), strongly advocate the use of broader *output* metrics, especially welfare, for evaluating R&D support programs and compare alternative possible designs, attempts to do so are scarce (e.g. Griffith, Redding and Van Reenen 2004; Parsons and Phillips 2007). These studies abstract from the modeling challenges we undertake here, specifically incorporating how producers allocate investments between competing R&D channels and capacity formation in the face of market competition, and how consumers benefit from higher quality and lower prices.

Empirical R&D research focuses on the question of whether R&D support programs do in fact stimulate more corporate R&D. This research is fraught with several methodological challenges (David, Hall and Toole 2000; Cerulli 2010). First, controlled studies are usually unavailable for policy changes. Second, R&D support programs are voluntary, raising the issue of selection bias in comparing performance of participants and non-participants. Wallsten (2000), Busom (2000) and Lach (2002) represent some of the first attempts to correct for this source of biased estimation. Third, resolving the counterfactual question of how much R&D would have been undertaken by a corporation without R&D subsidies is also inherently difficult. Fourth, traditional econometric studies do not account for the effects of market competition among firms on their response to R&D stimuli. Nevertheless, there is a vast and growing empirical literature that attempts to gauge the impact of R&D support programs (Hall and Van Reenen 2000; Takalo, Tanayama and Toivanen 2008; Aerts and Schmidt 2008; Hall, Mairesse, and Mohnen 2009; Thomson 2010). Ientile and Mairesse (2009) provide a comprehensive summary of the wealth of methods and results of the empirical evaluations of the effectiveness of policy support for R&D.

The two most common metrics of policy impact on R&D inputs are additionality, which measures the additional R&D expenditure spurred by a dollar of R&D subsidy, and the elasticity of R&D expenditures with respect to its own price, which is directly affected by the subsidy. Most estimates of additionality exceed 1; that is, a dollar of subsidy increases R&D expenditures by at least one dollar. Some estimates of additionality exceed 2 (Ientile and Mairesse 2009). Differences in the estimates mainly reflect the short-run verses long-run effects, whether firm-level data or aggregated data are used and which estimation method is employed (Guellec and van Pottelsberghe 2003). As with the additionality, there are also pronounced differences between estimates of the price elasticity of R&D. A number of authors have found this elasticity to be around -1, meaning that a $\alpha\%$ reduction in the cost to the firm would result in an $\alpha\%$ increase in its R&D expenditures in the long run. Other estimates range between as low as -0.25 and as high as -2.7 (Parsons and Phillips 2007).

In our analysis of all sample industries, additionality ranges between \$1.8 - \$2.6, in line with some of the reported empirical estimates. Additionality is highest for the *low* R&D group (followed by the medium R&D group). One of our main findings — low R&D group provides the lowest social returns for any given support — suggests that additionality (while more easily measured in practice) may be a misleading metric from a public policy perspective. We generally find R&D investments to be highly responsive to subsidies: full sample average price elasticities of R&D are between -2 and -3 for the grant policy and between -3.5 and -4 for the tax credit. These high elasticity estimates reflect the inclusion of low R&D-intensity (pre-subsidy) sectors in the sample for which the stimuli has the strongest effect on R&D expenditures. Indeed, for the high R&D-intensity sector our R&D price elasticity estimate is between -0.61 and -1.88.

Recent developments in full dynamic equilibrium models of industrial organization (e.g. Doraszelski and Pakes 2007) have been advocated by some researchers as an appropriate platform for analyzing public support for R&D (Cerulli 2010). Along these lines, Finger (2008) develops a dynamic equilibrium model of the chemical industry in the US, and uses his estimated model to simulate the impact of an R&D tax credit on public policy. However, due to the inherent complexity of the full dynamic equilibrium approach, his model captures only a fraction of the forces and features that affect corporate R&D decisions included in our model.

Only a few papers focus on comparing the effectiveness of tax credits versus direct grants. Haegeland and Moen (2007a) is perhaps the only paper to empirically compare alternative R&D support schemes. They find that R&D tax credit, introduced in Norway in 2002, had a much larger additionality impact than direct R&D subsidies. In a companion paper, Haegeland and

Moen (2007b) claim that most of the effect of the Norwegian R&D tax credit comes from firms that would have done little or no R&D without this incentive, i.e., what we refer to above as the extensive margin. Strong advocates for tax credits for R&D include Tassey (2007), Atkinson (2007) and Van Reenen (2011), who all promote the extension and expansion of these programs. In contrast, some researchers report no evidence of effectiveness of fiscal incentives for R&D (e.g. Wallsten (2000) and Thomson 2010).

1.4 Outline

Section 2 presents the single-period core theoretical model used in this paper. Section 3 describes how the two subsidy policies we investigate here affect a firm's free cash flow. Section 4 describes how the inter-temporal equilibrium is obtained. Section 5 formally defines the various metrics we use to compare the alternative subsidy policies. Section 6 presents our numerical results, and Section 7 discusses our findings and relates them to empirical literature on the impact of R&D subsidies. Section 8 contains concluding remarks. Appendix A derives the explicit solution to the single-period equilibrium, and Appendix B describes the model's specifications, namely, how the parameters were chosen and how the sample pool of industries was constructed.

2 A duopoly model of strategic investments

Each stakeholder is affected by a subsidy scheme in fundamentally different and subtle ways, which this framework attempts to incorporate. Consumers benefit from a subsidy scheme if it results in an increase in (quality-adjusted) output accompanied by lower prices. The degree to which consumers benefit critically depends on the extent of competition within the industry that would spur firms to invest in the first place. Firms, on the other hand, only benefit from a subsidy scheme if it results in an increase in firm value (the present value of their free cash flows). The degree to which firms benefit critically depends on how the firms choose to allocate their reinvestment. Do they reinvest to improve product quality, or to lower the cost of production, or to increase plant capacity to generate more output, or some combination of all three options? The allocation decision will depend on the firm's returns on investment for each reinvestment option. Government, as an entity unto itself, can benefit from a subsidy scheme, too, if it results in an increase in tax revenue. Each of these influence factors is included in our modeling framework that we describe in the next three sections.

The industry consists of two firms, each producing a differentiated single good. Every good has its own quality that can vary over time, and its price is determined in equilibrium each period. Each period begins with an investment phase and ends with a production/consumption phase. In the investment phase, producers reinvest a portion of their previous period's after-tax cash flow into three categories of investment, which we term quality enhancement, productivity improvement and capacity expansion. The investment phase determines each firm's product quality and cost structure. The production phase determines the output levels and price of each product, which subsequently determines each firm's after-tax cash flow for the current period, and the whole process repeats itself over the planning horizon. At the time of production the product qualities are known to all market participants. In the notation to follow, we shall suppress the time index.

2.1 Consumers

Within each period, the (representative) consumer chooses his expenditure E of his exogenous income I to acquire industry goods, with the rest spent on non-industry goods. In making this decision, the consumer takes the market prices $p = (p_1, p_2)$ and product qualities $q = (q_1, q_2)$ for the industry goods as given. The choices of the consumer are the quantities x_1 and x_2 of each good to be consumed according to:

$$U = \max_{x_1, x_2, E} \left\{ \left([(q_1 x_1)^\rho + (q_2 x_2)^\rho]^{\beta/\rho} + \omega (I - E)^\beta \right)^{1/\beta} : \; E = p_1 x_1 + p_2 x_2 \right\}, \tag{1}$$

where $1/(1-\rho)$ is the constant elasticity of substitution between the industry goods, $1/(1-\beta)$ is the constant elasticity of substitution between the industry and the non-industry goods, and $\omega > 0$ is a weight parameter describing the relative utility from the non-industry goods. We include the non-industry good so that the consumer expenditure or, equivalently, aggregate industry revenue, is *endogenously* determined over time. In our numerical experiments, the parameter ω grows at an exogenous rate chosen so that the average revenue in our industry sample grows at 2.5% per annum (see Appendix B for details). Consequently, if both firms choose not to invest to improve their product quality over time, the consumer will lower his allocation of income to that industry sector. The non-industry good sector is therefore a critical driving force in our modeling framework. Consumer income remains fixed so that our estimates of social returns are arguably more conservative.

2.2 Producers

At the beginning of the production phase within a period, producers take the expenditure E as given and choose output levels, $X = (X_1, X_2)$, to maximize their respective profits, where each producer takes as given the output choice of his rival. In addition, each producer assumes prices will adjust so that the product markets clear.

2.2.1 Revenue

Since prices adjust to clear the product markets, the first-order optimality conditions associated with the consumer's indirect utility optimization problem imply that the market share for producer i, expressed in terms of outputs, is

$$S_i(X) := \frac{(q_i X_i)^\rho}{\sum_k \left(q_k X_k\right)^\rho} . \tag{2}$$

Firm revenue for producer i is therefore the product of its market share and consumer expenditure E and the market clearing prices are the ratio of firm revenue to output.

2.2.2 Cost

At the beginning of the production phase within a period, each producer i has K_i units of installed capital (plant and equipment) that when operated at "normal" capacity (e.g. two production shifts per day for five days per week) will generate $\Phi(K_i) := K_i^\gamma$ units of output. The parameter $\gamma \in (0,1)$ models the usual diminishing marginal physical product of capital.

The *fixed* cost of production due to selling, general and administrative costs is taken to be proportional to installed capital and is given by

$$FC_i := c_i \kappa_F K_i. \tag{3}$$

The calibrating parameter κ_F converts units of installed capital to fixed cost, and does not change through time. The parameter c_i is an index of productivity that the firm can choose to lower over time via R&D investment.

As for the variable cost of production, if it is profitable, the producer may increase output by utilizing the plant at greater than normal capacity (e.g. adding shifts or using overtime), or decrease output by operating the plant at less than normal capacity. If producer i chooses *utilization rate*

u_i, then the output produced will be

$$X_i \ := \ u_i\Phi(K_i). \tag{4}$$

Since installed capital is known at the time of production, selection of the output is equivalent to selection of the corresponding utilization rate. In what follows, we shall use X or u interchangeably in the equations and discussions to follow when referring to the output choices of the producers.

When the plant is running at normal capacity, i.e., $u_i = 1$, then the *variable* cost of production due to labor, materials, etc. is

$$VC_i(1) := c_i\kappa_V\Phi(K_i).$$

The calibrating parameter κ_V converts units of installed capital to variable cost, and does not change through time. When the plant is running at a utilization rate *other* than unity, then its variable cost of production is

$$VC_i(u_i) \ := \ \phi(u_i)VC_i(1), \tag{5}$$

where $\phi(u_i) \ = \ \frac{u_i^m}{m} + (1 - \frac{1}{m})$ represents a penalty function for deviating from normal capacity. The function $\phi(\cdot)$ is increasing and convex on $[0, +\infty)$ if $m > 2$, which we shall assume. Under this assumption, the average variable cost is convex and minimized at normal utilization. The choice for m dictates the severity of the penalty for running the plant at high or low utilization rates.

2.2.3 Operating profit

The operating profit for producer i is the total revenue $S_i(X)E$ less the total operating cost $C_i(X_i)$, which is the sum of the fixed (3) and variable (5) costs, plus a tax benefit for depreciation and R&D investment that is not within the control of the producer during the production phase. Expressed in terms of utilization, the operating profit is given by

$$\pi_i(u, E) \ := \ \frac{(q_iK_i^\gamma u_i)^\rho}{\sum_k(q_kK_k^\gamma u_k)^\rho} \cdot E \ - \ [c_ik_VK_i^\gamma]\frac{u_i^m}{m} \ - \ Constant. \tag{6}$$

Producer i maximizes $\pi_i(u, E)$ assuming that the producer j's utilization rate u_j (output) is given. Assuming it exists and is unique, we let $X(E) = (X_1(E), X_2(E))$ denote the Nash Equilibrium output levels for this Cournot quantity game.

2.3 Single-period market equilibrium

At the end of the production phase, a single-period market equilibrium exists when the observed prices support the choice of consumer's expenditure and demands for the industry goods, and when producers take this consumer expenditure as given, their Nash Equilibrium output levels clears the market at these prices. In Appendix A, we derive the unique single-period market equilibrium, which includes closed-form expressions for the outputs, prices, and industry expenditure.

3 Investment decisions and R&D subsidies

In the single-period equilibrium described in the previous section firms take capital stock, production capacity, cost structure and product qualities as given. However, these variables evolve over time according to firms' investment strategies, and these strategies are influenced by the government subsidy programs in force. This responsiveness of corporate investments to government stimuli provides the prima facie rational for these support programs. To examine how sensitive corporate investments are to the alternative forms of government program stimuli, we now turn to describe the intertemporal behavior of firms under two canonical forms of R&D schemes.

Government intervention is modeled as a subsidy to business R&D. The subsidy entitles the firms to a refund of $\alpha\%$ of their R&D expenses incurred during the period. At the end of the period, the government accounts for the appropriate expenses and pays a lump sum equivalent to $\alpha\%$ of the validated amount spent. Firms receive the subsidy amount just prior to the start of the next period of operations. For example, a 50% R&D subsidy program implies that a \$100 investment in total R&D operations at the beginning of a period will result in a \$50 payment received from the government at the end of the period. We consider two variations of the $\alpha\%$ subsidy program:

- *R&D tax credit.* The government subsidy is added to the firm's cash flow, and the firm is free to use the subsidy for any purpose, including dividend payments.
- *Government R&D grant.* Firms are required to invest public funds received as subsidy in approved R&D projects. Additionally, the basis for computing government subsidies consists only of own-financed R&D investment, and excludes past government subsidies. This form of subsidy avoids double subsidization, and presumably is designed to maximize corporate incentives for own R&D investments. As we will see, this goal is not necessarily achieved by this type of subsidy.

3.1 Model of R&D productivity

A firm's operating profit will depend on the relative level of product quality, productivity, and installed capital (or production capacity). These state variables are affected by three types of investments: *physical capital formation*, I^k_{it}, which accumulates the stock of capital K_{it}, *R&D in cost reduction (process improvement)*, I^c_{it}, which improves productivity by lowering the index c_{it}, and *R&D in product quality improvement*, I^q_{it}, which raises the quality index q_{it}.

The capital stock for producer i evolves according to

$$K_{it+1} := (1-\delta)K_{it} + I^k_{it},$$

where δ denotes the depreciation rate assumed constant over time.

The growth rates in product quality and productivity of each firm depend on the current level of its own investment, as well as on the *cumulative* investments of same type made by *both* firms in the past. Thus, returns to R&D investments explicitly incorporate positive spillovers across firms. Let

$$I^q_t := \sum_{\bar{t}=0}^{t-1} \left(I^q_{1\bar{t}} \ + \ I^q_{2\bar{t}} \right) \tag{7}$$

represent the sum of all industry firms' *past* investments in quality improvement up to time $t-1$. The *growth rate* in the product quality index evolves as

$$\frac{q_{it+1} - q_{it}}{q_{it}} := f^q_t(I^q_{it}, I^q_t), \tag{8}$$

Similarly, the growth rate in the variable component of the productivity index evolves as

$$\frac{c_{it+1} - c_{it}}{c_{it}} := -f^c_t(I^c_{it}, I^c_t). \tag{9}$$

where I^c_t is defined in the same fashion as I^q_t. Each function f^q_t and f^c_t belongs to the class of functions $h_t : R^2_+ \to R_+$ defined as

$$h_t(x,y) \ = \ g_t(y)\big(1 - e^{-\lambda_t x}\big) = \varrho\big(1 - \varsigma e^{-\theta_t y}\big)\big(1 - e^{-\lambda_t x}\big), \tag{10}$$

where $0 < \lambda_t, \theta_t, \varrho, \varsigma < 1$. Here, x represents the current period's R&D investment of a particular kind by any single firm and y represents the cumulative past R&D investment of the same type by all industry firms. Note that $h_t(x,y)$ is bounded above by $g_t(y)$. Consequently, in our model, the percentage increase in the quality index or percentage decrease in the productivity index in each period is bounded no matter how large the current period's investment may be. Moreover, each index is zero if there is no R&D investment in it in the current period. Thus, our formulation of R&D processes admits spillovers across industry firms, and these spillovers are more pronounced for firms that invest more. The parameters λ_t and θ_t determine the rates at which the current period's investment level and the aggregate investment level move the index.

3.2 Investment strategy and government policies

Given period t levels of installed capacity, quality and productivity for each firm (determined by past investments), the single-period market equilibrium determines each producer's (after-tax) cash flow for the period, CF_{it}. Investments during the next period and dividends are financed by this cash flow and any subsidy to which the firm is entitled, which obviously depends on the subsidy policy in effect and the particular restrictions associated with how the subsidy can be used.

The firm's reinvestment strategy is described as follows. Producer i allocates each period a percentage φ_i of his after-tax cash flow CF_{it} for reinvestment in the firm, as capital and R&D investments. This reinvestment is divided among the three types of investment categories using the percentages $(\varphi_i^k, \varphi_i^q, \varphi_i^c)$ so that

$$I_{it} = \varphi_i CF_{it} = \varphi_i^k I_{it} + \varphi_i^q I_{it} + \varphi_i^c I_{it} = I_{it}^k + I_{it}^q + I_{it}^c.$$

Thus, we have formulated the reinvestment strategy as a time-invariant four-tuple, $\{\varphi_i, \varphi_i^k, \varphi_i^c, \varphi_i^q\}$, subject to the constraint that $\varphi_i^k + \varphi_i^q + \varphi_i^c = 1$.

We now turn to describe the derivation of the cash flow and the reinvestment strategy of the firms under each of the subsidy policies under consideration.

Tax credit policy. Under the tax credit subsidy policy, firms receive tax allowance for capital depreciation and full tax deduction for last period's R&D expenditures. The government subsidy is considered part of the cash flow, since the firm is unrestricted in how this subsidy is being used. Consequently, the free cash flow, subsidy amount, and R&D investment under the tax credit policy are:

$$CF_{it} = (1-\tau)\pi_{it} + \tau(\delta K_{it} + R_{it-1}) + S_{it}^G \tag{11}$$

$$S_{it}^G = \alpha R_{it-1} \tag{12}$$

$$R_{it} = (\varphi_i^c + \varphi_i^q)\varphi_i \cdot CF_{it} \tag{13}$$

R&D grant policy. Under the R&D grant policy, the subsidy does *not* enter the cash flow, and must be invested in R&D related projects. Moreover, the firm cannot deduct from taxable income the portion of its R&D expenses financed by the government subsidy. Consequently, the free cash flow, subsidy amount, and R&D investment in this setting are:

$$CF_{it} = (1-\tau)\pi_{it} + \tau\delta K_{it} + \tau\left[R_{it-1} - S_{it-1}^G\right] \tag{14}$$

$$S_{it}^G = \alpha[R_{it-1} - S_{it-1}^G] \tag{15}$$

$$R_{it} = (\varphi_i^c + \varphi_i^q)\varphi_i \cdot CF_{it} + S_{it}^G \tag{16}$$

The R&D grant policy implies that funds received must be invested in R&D activities, but does not specify how to split them between process or quality improvements. While in practice such grants can only be used for pre-approved specific projects, we assume here that public funds received under this scheme are divided according to the strategic action chosen by the firm.

4 Model equilibrium

After determining how much of the cash flow will be reinvested, the firm pays the residual free cash flow as dividends to its shareholders, expressed as $DIV_{it} := CF_{it}(1 - \varphi_i)$. We define the value of firm i,

$$V_i := \sum_{t=1}^{T} [DIV_{it}\, e^{-rt}] \;+\; K_{iT}\, e^{-rT}, \tag{17}$$

to be the sum of the present value of the dividend cash flow stream generated over the planning horizon $[0, T]$, and the discounted value of liquidation, which, for simplicity, is set to the level of capital at time T.

When producer i selects strategy $m := (\varphi_i, \varphi_i^k, \varphi_i^q, \varphi_i^c)$ and producer j selects strategy $n := (\varphi_j, \varphi_j^k, \varphi_j^q, \varphi_j^c)$ the resulting values V_{im} and V_{jm} for each producer are computed according to (17). The pair of numbers (V_{im}, V_{jn}) are entries in the m^{th} row and n^{th} column of the matrix V, which defines a bimatrix game. (Only a finite number of strategies are considered in our numerical experiments.) An industry equilibrium here is taken to be any pure strategy Nash equilibrium for the bimatrix game. For bimatrix games there are no guarantees that a pure strategy Nash equilibrium exists, or that it is unique when it does exist. In cases with multiple equilibria, we select the equilibrium that maximizes the aggregate industry value.

Firm actions are limited to reinvestment policies and investment distribution. To facilitate computational tractability, the strategic space is limited to those actions $[\varphi, \varphi^k, \varphi^c, \varphi^q]$ in which aggregate reinvestment rate φ is a multiple of 0.10 and each of the reinvestment options, φ^k, φ^c, φ^q, are multiples of 1/6. (A "do-nothing" alternative is also included.)

5 Measures of subsidy impact

We group the subsidy impacts into two groups of measures. In the first group we include measures that are directly related to R&D investment. In the second group we include welfare related measures such as social welfare, tax revenue and producer surplus. The majority of the measures record the change between when there is a subsidy policy present and when there is no subsidy. We therefore use the superscript Sub to denote the presence of the examined subsidy policy and the subscript $NoSub$ to denote the no subsidy setting.

5.1 R&D measures

We consider three R&D measures. R&D intensity of the firm in each period is the ratio between the firm's R&D related (cost and quality) expenditures and the firm's revenue in the period. *Mean R&D Intensity* is the average of the R&D intensities over the planning horizon. For subsidy rate α, the *price elasticity of R&D expenditures* is defined as

$$R\&D\ elasticity := \frac{R^{Sub(\alpha+0.1)} - R^{Sub(\alpha)}}{R^{Sub(\alpha)} * 0.1}.$$

Here, R denotes the discounted value of the firm's R&D expenditures along the planning horizon. This R&D elasticity has opposite sign of the conventional price elasticity of R&D, because a higher α rate lowers the price of R&D. *Additionality* measures the ratio of the increase (or possibly decrease) in total R&D expenditures as a result of a government subsidy policy intervention to the cost of these subsidies, and is defined as

$$Additionality := \frac{R^{Sub(\alpha)} - R^{NoSub}}{SubCost}. \tag{18}$$

Here, *SubCost* denotes the present value of government subsidy cash flows over the planning horizon.

5.2 Welfare measures

R&D affects social welfare via its impact on the consumers, producers and the government.

In each period we compare the change in government tax revenue between the no-subsidy scenario and the subsidy scenario. The *tax surplus* is the discounted present value of this change in tax revenue. The change in firm value between the no-subsidy scenario and the subsidy scenario is the *producer surplus* $= V^{Sub} - V^{NoSub}$, where V is defined in (17).

Since utility is not measured in dollars, the change in consumer utility in each period must be assigned a dollar equivalent. To compare the change in consumer utilities between the subsidy scenario and the no-subsidy scenario, $U_t^{Sub} - U_t^{NoSub}$, we determine the *compensating variation*—the incremental income in each period (positive or negative) the consumer would need as compensation to remain in the no-subsidy utility level. For this purpose we assume that the equilibrium prices in the no-subsidy environment remain constant. Under this assumption, it follows that the consumer's utility is proportional to income I. Letting Δ_t denote this proportionality constant in period t, the compensating variation in period t is $[U_t^{Sub} - U_t^{NoSub}]/\Delta_t$. We define the *consumer surplus* to be the present value of this compensating variation cash flow stream.

The *social welfare gain* is defined to be the sum of the producer, consumer and tax surplus obtained via government subsidy. The *net social welfare gain* measures the total net effect of a particular government policy, and is defined as the social welfare gain minus the present value of the government subsidy cash flow stream ($SubCost$). The *benefit/cost* is the ratio of the social welfare gain to $SubCost$.

6 Comparative analysis of subsidy impacts

Government agencies use classification of manufacturing industries into categories based on their average R&D intensities (OECD 2011). As established by many studies, and which is reflected in the model we have developed here, R&D intensities result from a confluence of many factors: the nature of the industry, the intensity of intra- and inter-industry competition, firm-specific productivity parameters and resources and idiosyncratic random factors. However, economic theory has yet to deliver a clear mapping from these features into technology classes as defined by R&D intensity. It is therefore practically impossible to examine the precise effect of a universal subsidy policy change on each and every type of firm. Moreover, forecasting the aggregate impact of a policy change of this type requires an empirical multi-attribute distribution of firms, to properly weigh responses by firms with different attributes. Lacking such a distribution, and rather than arbitrarily assigning an industry with a given set of attributes to a technology-intensity class, we generate a large population (over 10,000) sample industries with a wide range of characteristics. (In Appendix B we describe how we chose ranges of parameters for our model and how we generated this sample pool of industries.) For each sample industry, we execute experiments corresponding to the no subsidy baseline case, and the grant and tax credit policies using various subsidy rates. We rank the sample industries from high to low in terms of the average R&D intensity (over the 10-year horizon) in the no subsidy case. We then divide the population into three groups: "High" (H), those industries in the top one-third with respect to mean R&D intensity, "Medium" (M), the next one-third, and "Low" (L), the bottom one-third. In the tables to follow, the group labeled "All" represents the entire population.

We present our main results in two tables: one table reports net present value metrics (net social welfare gain and its components) and the other table reports rate of return metrics (benefit/cost, additionality and R&D elasticity). Each table consists of two blocks that report the corresponding grant and tax credit policy outcomes. For each policy we present five levels of support, ranging from 10% to 50% subsidy rates. Table 1 reports the average values of net social welfare gain and its components. The values are normalized by the present value of the income stream over the 10-year horizon, and are recorded in basis (hundredths of a percentage) points. For each subsidy type and level of support and for each industry group, Table 2 reports the mean value of the benefit/cost ratio, the additionality and the price elasticity of the R&D expenditures.

To translate basis points to an equivalent dollar amount, we note that US private consumption is $\sim$ 70% of the $\sim$ \$15 trillion US GDP. Thus, a basis point corresponds to $\sim$ \$1 billion (on a yearly basis). In our analysis, we set the initial industry size to 1% of private consumption. We therefore suggest a conservative multiple of 20 to estimate the aggregate impact across all industry sectors that might be responsive to R&D stimuli in the entire economy. For instance, according to the "All" block of results in Table 1, a 30% tax credit scheme can generate a net social welfare gain equivalent to 20(21.5) = \$430 billion.

Both R&D subsidy schemes produce positive results on average, across all subsidy rates. These positive results are generally true for the welfare measures as well as the R&D measures. However, the average results in Tables 1 and 2 conceal a very large heterogeneity of results across firm types and technology intensity industry groups. For this reason we report in Tables 3 and 4 a more detailed description of the distributions of the net social welfare gain and benefit/cost measures, respectively. For each policy and support level we report the minimum value, the decile points and the maximum value of each of our sample industry types. This is repeated for the high, medium and low R&D intensity industry groups.

Tables 1-4 here.

6.1 Subsidy impacts on welfare

As shown in Table 1, for a given subsidy policy, the net social welfare gain increases with the level of support but at a decreasing rate. When we examine the distribution of the net social welfare gain, we find that within each subsidy type the distribution of net social welfare gain at higher subsidy rates stochastically dominate those at lower subsidy rates. The results for the benefit/cost measure are different, with the benefit/cost ratio decreasing with the level of support but with no stochastic dominance.

When we compare the subsidy policies we find that, on average, the R&D tax credit subsidy is more effective than R&D grants across all subsidy rates. Here, too, when we observe the distribution of the net social welfare gain we find that the tax credit policy's net social welfare gain distribution stochastically dominates the grant policy's counterpart. The results for the benefit/cost ratio measure are mixed. The average benefit/cost ratio is higher for the tax credit policy than for the grant policy in most scenarios. The exceptions to this are the medium and low R&D intensity industries when the level of support is very high. With respect to the benefit/cost ratio distributions, the grant policy distributions exhibit more variability, especially at the tails. That is, within all R&D groups, it is more likely to find industries with negative or less than one ratios, or those with extremely high ratios under a grant policy than in the tax credit policy.

When comparing between industries, we find that, on average, the medium R&D intensity group is the most responsive to R&D stimuli under both welfare measures. For net social welfare gain, the high R&D intensity group is the next most responsive, whereas for the benefit/cost ratio it is the low R&D intensity group. More specifically, for each subsidy type and level of support, the medium R&D intensity group's net social welfare gain or benefit/cost distribution stochastically dominates the high and low R&D intensity group's respective counterparts.

Of the three components to the social welfare gain, the consumer surplus represents the lion's share. On average, the consumer surplus is positive in every scenario. This is true also for the tax surplus, i.e., the government takes in more tax revenue as a result of a subsidy. However, on average, the subsidy cost exceeds the tax surplus by a large margin, and so net government outlays are required to achieve the social welfare gains.

Our welfare metric captures only the direct effects of the subsidy on all stakeholders (consumers, producers and the government). It obviously abstracts from other indirect costs and benefits, such as distortions due to additional taxes, compliance costs, inter-industry technology spillovers and benefits from increased product variety. Parsons and Phillips (2007) is the only other study of potential welfare gains from R&D support programs of which we are aware. They compute a welfare gain of 11 cents for each dollar of R&D tax credit, where their calculations take into account R&D spillovers, administration and compliance costs and tax distortion welfare costs. It is difficult to compare our numerical results with their back of the envelope calculation. While we obviously ignore important practical and indirect consequences of the subsidy schemes considered, our reported welfare results are mainly driven by changes in consumer surplus, reflecting equilibrium product quality and price changes emanating from additional R&D efforts. These effects are even more pronounced due to the strategic interaction between the firms that receive the R&D subsidies. Such equilibrium considerations are absent in Parsons and Phillips (2007).

Interestingly, subsidies can be "too much of a good thing" for producing firms. For the low R&D intensity group, on average, producer surplus under the grant policy is actually *negative.* More specifically, an analysis of the distribution of producer surplus reveals that 20% of the medium and low R&D intensity groups realized a negative producer surplus under the grant subsidy, and 10% of all sample industries realized a negative producer surplus under the tax credit policy.

6.2 Subsidy impacts on R&D investments

Additionality is greater than one for every scenario that we investigate. However, within each subsidy type, additionality declines with increasing levels of support. The low R&D group has the highest additionality. We find that across all sampled industries in our analysis additionality ranges between \$1.8 - \$2.61, (see Table 2), which is within bounds of estimates obtained from empirical studies. Most empirical estimates of additionality exceed 1; that is, a dollar of subsidy increases R&D expenditures by at least one dollar. Ientile and Mairesse (2009) report an average additionality estimate of 1.09 across thirty three studies conducted in the period 1983-2009 with five of those reporting estimates exceeding 2.0 and the highest estimate at 2.96 (Klassen, Pittman and Reed 2004). Employing a unique company level data and using propensity score methods to overcome the selectivity bias, Lach, Parizat and Wassereil (2008) estimate additionality of 2.28 in the manufacturing sector in Israel and 2.81 in certain high-tech sectors.

Under the grant policy, the elasticity of the R&D expenditures decreases with the level of support (see Table 2). For the tax credit policy the results are mixed: the dependence of the elasticity of the R&D expenditures on the level of support varies across technology intensity groups. The elasticity of the R&D expenditures increases with the level of support for the high R&D intensity group, decreases with the level of support for the medium R&D intensity group and shows no trend for the low R&D intensity group.

A number of studies, using aggregate data, estimate the long-run price elasticity of R&D expenditures to be around -1 (see, for example, Hall and Van Reenan 2000; Bloom, Griffith, and Van Reenan 2002). Other studies, using firm level data, typically report higher elasticities. For example, Harris, Li and Trainor (2009) estimate a long-run price elasticity of R&D in Northern Ireland to be -1.4. Hall (1993) estimates the elasticity to be between -2 and -2.7, values similar to Wilson's (2009) findings of 2.5. Our report of elasticity is based on firm level analysis and the results vary with the subsidy policy and scope. On average we find that R&D investments are highly responsive to subsidies, with R&D elasticities between -2 and -3 for the grant policy, and between -3.5 and -4 for the tax credit.

Our estimates suggest an advantage to tax credit over grant policy in terms of elasticity. This result is true for all levels of support and all technology intensity industry groups. In contrast, additionality does not demonstrate a consistent advantage to either the tax credit or the grant policy.

7 Discussion

To interpret the results of the previous section, we examine the evolution of key economic variables in the model.

Table 5 here

Table 5 reports the growth rates of key economic variables — productivity index, quality index, output and price — along with the average reinvestment percentage chosen for the no subsidy baseline case and for each subsidy type and level of support. An examination of Table 5 clearly shows that the marginal gains from increasing the subsidy rate are quite modest for both the high and low R&D intensity groups, but are far more significant for the medium intensity group. This table clearly shows how different the reinvestment responses of firms from various R&D intensity groups are to the government stimuli.

Generally speaking, industries that belong to the high R&D intensity group have excellent returns to R&D and exhibit relatively high inter-industry competition (higher values of the parameter ρ). These conditions drive both firms to invest heavily in R&D (pre-subsidy), because if one firm chooses a lower reinvestment action, it will cede too much market share to the other firm. A government subsidy is still a net plus; however, the incremental benefit to utility (as measured by consumer surplus) is relatively low and the cost of the subsidy is high, since the industry is already spending a sizeable portion on R&D. The producing firms are well along the diminishing portion of their returns to R&D. Consequently, the net social welfare gain is relatively low. This may be the reason why some countries opt to offer tax credits only on incremental R&D expenditures rather than basing the credit on the entire volume of R&D expenditures.

At the opposite end, industries that belong to the low R&D intensity group have poor returns to R&D and exhibit relatively low inter-industry competition (lower values of the parameter ρ).

Such conditions are not ripe for each firm to invest heavily in R&D (pre-subsidy) since if one firm chooses a higher reinvestment action, it gains little in market share. Government subsidies have a less pronounced effect, since the marginal return on investment in R&D is not high in the first place. On the other hand, medium R&D intensive industries have good returns to R&D, which provides the conditions for both firms to invest moderately in R&D (pre-subsidy). Now, government subsidies have a more pronounced effect, spurring the industry to invest more heavily in R&D, generating a sizeable increase in output, much higher quality and lower prices *relative to the no subsidy baseline case.*

Many advocates for R&D subsidies support government R&D grants over tax credit because they assume that forcing the recipient firms to invest the government support in R&D ensures that these firms will increase their R&D activity. Our results show that this intuition could be wrong and that, in stark contrast, tax credit could be more effective than grant policy in spurring R&D. When offered as an R&D grant, competing firms, due to strategic interaction, are forced to increase their reinvestment rates, and all government dollars *must* be invested in R&D. Consequently, spurred on by the subsidy, firms can spend too much on R&D. Consumers are better off, but producer profits can actually decline, as the industry revenue growth is not sufficient to offset the higher reinvestments.

For example, suppose a rival firm increases R&D investment in response to a subsidy scheme but the firm chooses not to do so. If, as a consequence, the firm cedes too much market share to its rival, its value will decrease. In anticipation of such an outcome, the firm may have to increase its R&D just to keep up. But if both firms undertake such policies — in an equilibrium response to each other — and if both firms are well along their points of diminishing returns to R&D, then in the end both firms will over-invest in R&D thereby lowering both firm values, which results in a negative (or reduced) producer surplus. The tax credit policy, on the other hand, gives firms more flexibility. This allows them to channel more funds to capital expansion, which reduces their costs, increases their profits and output relative to the grant policy scenario. This leads to an increase in net social welfare gains relative to the grant policy.

The benefit/cost is a "rate of return" metric whereas the net social welfare gain is a "net present value" metric. Not surprisingly, at lower subsidy rates, the subsidy cost to the government is much lower under either subsidy policy, which explains, in part, why the benefit/cost declines with increasing subsidy rates. Similarly, additionality is decreasing as subsidy rates increase. The additional R&D investments by the firms fall short of matching the increase in subsidy cost as the subsidy support is increased. From a policy perspective, *lower subsidy rates are more effective* when there are limited funds for government stimuli.

The average values of the additionality for the entire pool of industries are between 1.85 and 2.28 for the grant policy and 1.8 and 2.61 for the tax credit policy. These values are within range of empirical findings. The mean values for R&D elasticity are higher than reported in empirical research. However, when observing the *distribution* of this measure, we find that for almost all scenarios (that is, all industry groups, subsidy policies and subsidy rates), over 70% of the industry population have R&D elasticities between 0.4 and 2.7, values that fall within the range of empirical evidence. The exception to this rule is the low R&D intensity industry group, which enjoys high R&D elasticity for the tax credit policy. The reason for this is that this industry group has very low levels of R&D absent subsidy, and therefore R&D levels with subsidy are high relative to this initial low level of expenditures. Indeed, we see that the additionality of this group (see Table 2) is high when compared to the other groups. The reason here, too, lies with the low base level which is greatly surpassed when subsidies are given. In contrast to our analysis, which covers many different types of firms, most empirical estimates of R&D elasticity and additionality are performed on samples comprised of mostly R&D intensive firms. As can be seen in Table 2, the elasticities of the high R&D intensive group are consistent with estimates in the literature based on firm level data.

While our results for additionality and the R&D elasticity concur with empirical evidence, they also highlight their weakness as appropriate measures for policy evaluation. This is because we find that additionality is highest for the low R&D group, whereas this group actually displays the lowest net social welfare gain. Since additionality and R&D elasticity are relatively easy to measure, they are gaining popularity among researchers as measures for the effectiveness of R&D incentives. Our results, therefore, suggest that policy makers should not rely solely on these measures for enhancing social welfare.

8 Conclusions

We construct a dynamic model for firms' capital and R&D investments within an imperfectly competitive environment in order to evaluate and compare R&D grants and R&D tax credits as means for stimulating inventive activities. The main advantage of our theoretical construct is that it recognizes that R&D is inherently an industrial organization issue, namely, market structure and intensity of competition are allowed to affect firms' decisions on the magnitude and allocation of R&D efforts. In particular, product and process R&D decisions are made by forward looking firms which consider alternative uses of resources, interact repeatedly with rival firms and compete for customers who value product quality and allocate their budgets among competing goods within and outside the industry. The model is relatively simple, and can be easily modified to reflect different market conditions and industry types.

We use this framework to compare two of the most common forms of R&D support now in use by most OECD members, as well as many other developed countries. While both methods refund a certain fraction of qualifying R&D expenditures to the firms, their main difference is that R&D grants are earmarked for R&D, whereas R&D tax credits can be used by the recipient for any purpose. Our analysis focuses on the *intensive margin* effects of these policies, namely, the impact of government stimuli on the conduct of R&D performing firms. For such firms, the name given to the subsidy received should make little difference. Yet, we find that firms are much more responsive to the R&D tax credit stimuli than to an R&D grant of the same subsidy rate. This is reflected in our results by much higher R&D elasticities and higher government costs — by an average of about 50% — for the R&D tax credit. More importantly, at the 30-40% subsidy rates the welfare gains to all stakeholders associated with the R&D tax credit are almost 100% larger than those generated by R&D grants. In contrast, benefit/cost ratios are much more similar across the two schemes, reflecting the rates-of-return nature of that metric.

We evaluate the policy effects on a large sample of industries with a broad range of realistic parameter values that represent dimensions of firm diversity that are highly pertinent to how firms respond to R&D stimuli. We believe that this approach, rather than trying to infer the effects of an R&D policy by analyzing data from a particular market or industry, provides a more comprehensive analysis of the potential aggregate effects of an R&D policy. The quite reasonable results generated by our model for metrics that have empirical counterparts (e.g. R&D additionality) render credibility to our welfare results.

Our model is suited for studying the effects of alternative tax policies such as incremental R&D rather than the volume-based version we have analyzed here. It can also be used to assess some of the extensive margin impacts of R&D support programs. Indeed, R&D tax credits, due to their simplicity and universality, may have an important advantage over R&D grants along this dimension. We leave this question for extensions of our work.

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A Derivation of the single period market equilibrium

Consumer Behavior. For a given expenditure level E, the demand functions that solve the consumer's problem are well-known and given by

$$D_i(p,q,E) = \left[\frac{(q_i/p_i)^{\frac{\rho}{1-\rho}}}{\sum_k (q_k/p_k)^{\frac{\rho}{1-\rho}}}\right] \frac{E}{p_i}. \tag{19}$$

The consumer's indirect utility, $\Gamma(p,q,E)$, is given by

$$\Gamma(p,q,E) \;:=\; \left[\sum_k \left(\frac{q_k}{p_k}\right)^{\frac{\rho}{1-\rho}}\right]^{\frac{1-\rho}{\rho}} \cdot E \;=\; \Gamma(p,q,1)\cdot E, \tag{20}$$

and the optimal expenditure on the industry goods, $E(p,q)$, is given by

$$E(p,q) \;=\; \left[\frac{1}{\left(\frac{\omega}{\Gamma(p,q,1)}\right)^{\beta/(1-\beta)} \;+\; 1}\right] I\,. \tag{21}$$

Producer Behavior. Producer i takes u_j as given and seeks to maximize $\pi_i(u,E)$ given in (6). Let $d_i := c_i k_V K_i^\gamma$ and $e_i := q_i K_i^\gamma$. First-order optimality conditions imply that the partial derivatives

$$\begin{aligned}
\frac{\partial \pi_i(u_i,u_j)}{\partial u_i} &= \frac{\rho e_i u_i^{\rho-1}[e_i u_i^\rho + e_j u_j^\rho] \;-\; e_i u_i^\rho[\rho e_i u_i^{\rho-1}]}{[e_i u_i^\rho + e_j u_j^\rho]^2}\cdot E \;-\; d_i u_i^{m-1} \\
&= \rho\frac{e_i e_j u_i^{\rho-1} u_j^\rho}{[e_i u_i^\rho + e_j u_j^\rho]^2}\cdot E \;-\; d_i u_i^{m-1}
\end{aligned}$$

must vanish. Since equilibrium output levels must be positive,

$$u_i \frac{\partial \pi_i(u_i,u_j)}{\partial u_i} = 0 \implies d_i u_i^m \;=\; \frac{e_i e_j u_i^\rho u_j^\rho}{[e_i u_i^\rho + e_j u_j^\rho]^2}\,\rho E. \tag{22}$$

Since (22) is identical for both firms a Nash Equilibrium necessarily satisfies $d_i u_i^m = d_j u_j^m$, so

$$u_j \;=\; \left(\frac{d_i}{d_j}\right)^{\frac{1}{m}} u_i. \tag{23}$$

Equations (22) and (23) imply the Nash equilibrium utilization rate $u_i(E)$ for firm i is derived as

$$u_i(E) \;:=\; \left(\frac{\rho E}{d_i}\;\frac{e_i d_j^{\frac{\rho}{m}}\cdot e_j d_i^{\frac{\rho}{m}}}{\left[e_i d_j^{\frac{\rho}{m}} \;+\; e_j d_i^{\frac{\rho}{m}}\right]^2}\right)^{\frac{1}{m}} \;=\; u_i(1)\cdot E^{\frac{1}{m}}. \tag{24}$$

The output levels and market clearing prices are respectively given by

$$X_i(E) \;=\; u_i(E)\Phi(K_i) \tag{25}$$

$$p_i(E) \;=\; \left[\frac{(q_i X_i)^\rho}{\sum_k \left(q_k X_k\right)^\rho}\right]\frac{E}{X_i}. \tag{26}$$

The market clearing prices consistent with the Nash Equilibrium choice of output levels by the producers are therefore given by

$$p_i(X(E), E) \;=\; \xi_i \cdot E^{\frac{m-1}{m}}, \tag{27}$$

where

$$\xi_i \;=\; \frac{q_i^{\rho}\Big[u_i(1)\Phi(K_i)\Big]^{\rho-1}}{\sum_k \Big(q_k\Big[u_k(1)\Phi(K_k)\Big]\Big)^{\rho}}\;. \tag{28}$$

Substituting these market clearing prices into (20) shows that

$$\Gamma(p(X(E), E), E) \;=\; \mathcal{H} \cdot E^{\frac{1-m}{m}}. \tag{29}$$

where

$$\mathcal{H} := \left[\sum_k \left(\frac{\xi_k}{q_k}\right)^{\frac{\rho}{\rho-1}}\right]^{\frac{1-\rho}{\rho}} \tag{30}$$

is a known constant and therefore can be pre-computed. In equilibrium, $E = E(p, q)$. Substituting this identity and (29) into (21) yields

$$E(p, q) \;=\; E \;=\; \frac{\omega^{\frac{\beta}{\beta-1}}}{\Big[\mathcal{H}E^{\frac{1-m}{m}}\Big]^{\frac{\beta}{\beta-1}} + \omega^{\frac{\beta}{\beta-1}}}\; I,$$

from which it follows that the equilibrium level of consumer expenditure E satisfies

$$\vartheta(E) \;:=\; \left(\frac{\omega}{\mathcal{H}}\right)^{\frac{\beta}{1-\beta}} E^{1+\vartheta_o} \;+\; E = I, \tag{31}$$

where $\vartheta_o \;=\; \frac{m-1}{m} \cdot \frac{\beta}{1-\beta} > 0$. Since the function $\vartheta(E)$ is monotonically increasing without bound such that $\vartheta(0) = 0$, there is a unique value for E that solves (31).

In sum, there is a unique equilibrium (X, p, q, E) for the model, which is obtained by solving (31) for consumers' endogenous expenditure on the industry goods, E, and then determining the output levels via (25) and (24), and prices via (27).

B Model specifications

As explained in the text, we fix the value of some parameters, and randomize other parameters to generate a large pool of different industries. Here, we describe how this pool is constructed.

To obtain guidance on setting the values of certain parameters below, we examined COMPUSTAT data for 1987 and 2006 for four representative two-digit industries: (1) SIC20, Food and Kindred Products (e.g. Nestle, Pepsico, Kraft, Tyson Foods, Sara Lee, Kellogg); (2) SIC28, Chemicals and Allied Products (e.g., Proctor and Gamble, Johnson and Johnson, Dow Chemical, Pfizer, DuPont, Merck); (3) SIC33, Primary Metal Industries (e.g. Alcoa, US Steel, Novelis, Nucor); and (4) SIC36, Electronic, Electrical Equipment and Components (e.g. General Electic, Sony, Nokia, Motorola, Intel, Emerson Electric, Whirlpool). The data examined included net sales; operating costs; selling, general, and administrative costs; plant, property and equipment used to proxy installed capital. Extreme choices for the parameters will result in unreasonable values for the economic variables of interest. For example, if the parameters for the returns to R&D functions and consumer preferences are too high, terminal values for the ratios of industry revenue to consumer income and industry revenue to capital, as well as the gross profit margins, will be inconsistent with the empirical data. An extensive, initial round of experimentation was undertaken to narrow down reasonable values or ranges from the parameters of the model.

State parameters set the relative position of each firm in the market. There are four state parameters for each firm in each period: the amount of installed capital K_{it}; the productivity index c_{it}; the quality index q_{it}; and the after-tax cash flow CF_{it}, which determines the level of reinvestment in the three R&D categories. These state variables must be initialized at time 0, after which the reinvestment policy and single-period equilibrium update them over time.

Firms' initial installed capital is normalized to 1,000. (This parameter can be viewed as a numeraire.) We assume an initial sales-to-capital ratio $R_{i0}/K_{i0} = 10$, the approximate midpoint of the COMPUSTAT data examined, which sets the initial consumer industry expenditure $E = R_{10} + R_{20} = 10(K_{10} + K_{20}) = 20,000$. Without loss of generality, we set the initial values for the productivity and quality indices for the base firm to be 100.

We pin down the values for the calibrating constants κ_V and κ_F as follows. Since both firms are initially identical, it follows directly from (24) that $u_i(1)^m = \frac{\rho}{4c_i\kappa_V\Phi(K_i)}$. Using this fact and substituting equation (24) within equation (5) shows that the variable cost

$$VC_i(u_i(E)) \;=\; \frac{\rho E}{4m} \;+\; (1-\frac{1}{m})c_i\Phi(K_i)\kappa_V$$

is *linear* in κ_V. The fixed cost, Equation (3), is obviously linear in κ_F. To pin down the values for κ_V and κ_F, we assume a total operating cost to revenue ratio of 0.60 and a fixed cost (selling, general and administrative) to total cost ratio of 0.40. These values were most representative of the

COMPUSTAT data examined. The final state variables are the respective cash flows. The industry expenditure E, the values for κ_V and κ_F, and the other state variables determine the value for $u(E)$ via (24), which then sets the after-tax cash flows for each firm.

Industry parameters describe the economic market in which the industry operates. Initial income I is taken to be a multiple of 100 times the initial industry expenditure, i.e., $I = 100E = 2$ million. (Experiments suggest that ratios greater than 100 do not appreciably affect our findings.) Income grows at an exogenous rate of 2.5% per period. Once the initial values for E and I are set, there is a unique choice for the initial value of the parameter ω that makes equation (31) a valid identity, i.e., that puts the initial values for E and I "into equilibrium." The constant $\mathcal{H}$ defined in (30) is determined by the initial state variables $(K_{i0}, c_{i0}, q_{i0}, CF_{i0})$ and the constant κ_V via equations (27) and (24).

R&D parameters describe the return on investment in quality enhancement and productivity improvement. Four parameters, λ_t, ς, ϱ, and θ_t, describe each of the two returns to R&D functions associated with the quality and productivity indexes (see equation (10)).

The parameter ϱ determines the absolute maximum growth rate per period in the index, and the parameter ς determines the first period's maximum growth rate. One of the highest technology-oriented sectors in the economy is the microelectronics industry. Moore's Law states that processor speed doubles every 18 months, which would imply a 60% growth rate per year. Of course this rate corresponds to observed rates, which are less than the *maximum* rates achievable with unlimited resources. More mature industries such as consumer products presumably have a much smaller absolute maximum rate of growth per period. We set $\varrho = 0.30$ and $\varsigma = 0.5$ (so that the initial one-period maximum growth rate is 15%) for both returns to R&D functions.

The parameter λ_t determines the amount of investment required to achieve half of the current maximum growth rate per period in the index. Accordingly, setting $1 - e^{-\lambda_t x} = 1/2$ in equation (10), we have that obtaining half of the maximum growth rate, $g_t(y)$, requires investment level x such that $\lambda_t x = ln(2)$, or $x = ln(2)/\lambda_t$. We link R&D expenses and costs to the more tangible entity of firm cash flow. Let $cost^{R\&D}$ denote the amount of money required to achieve half of the initial maximum growth rate per period, measured as a percentage of initial cash flow. For each returns to R&D function, we take $cost^{R\&D}$ to be a uniformly distributed random variable over the range $[10\%, 90\%]$. Given $cost^{R\&D}$, the value of λ_0 equals $ln(2)/cost^{R\&D}$. For each returns to R&D function, this cost parameter grows at an exogenous growth rate of 2.5% per period so that $\lambda_t = \lambda_0(1.025)^t$.

The parameter θ_t determines the amount of total past R&D investment by all industry firms required to move the current maximum growth rate per period to half the distance between it and the absolute maximum growth rate (set to 30%). For example, if the current value for the maximum growth rate per period is 18%, then the amount of cumulative aggregate investment required to change the current period's maximum growth rate from 18% to $18\% + 0.5(30\% - 18\%) = 24\%$ is given by $ln(2)/\theta_t$. For the initial value, we set $\theta_0 = \lambda_0/Z$ where, for each returns to R&D function, we take Z to be a uniformly distributed random variable over the range $[20, 80]$. For each returns to R&D function, this cost parameter grows at an exogenous growth rate of 2.5% per period so that $\theta_t = \theta_0(1.025)^t$.

Consumer preference parameters. The parameters in this category are ρ, β, and the exogenous growth rate of the parameter ω. The parameter β is fixed at 0.5. The values for ρ vary uniformly between $[2/3, 10/11]$. (The elasticity of substitution of the consumer's industry utility function is $1/(1-\rho)$.) In the model, each firm takes the process (growth rate) of ω as given. In effect, the exogenous growth rate of ω sets industry firms' expectations regarding the growth in the price-adjusted quality of all other non-industry goods and services. Moreover, the growth rate of ω influences the *ex-post* growth rate of industry revenue. The value for the growth rate of ω is determined by adjusting its value so that the *ex-post* average growth rate of the price-adjusted quality for the sample of 10,000 industries equals the chosen value for the growth rate of ω as closely as possible. (Keep in mind that for each iteration the no subsidy case has to be solved for each of the 10,000 sample industries.)

Production function parameters. There is one parameter γ, which is taken to be uniformly distributed between 2/3 and 10/11.

Financial (Accounting) parameters determine firm value based on its after-tax cash flows. This category includes the cost of equity capital, r; corporate tax rate, τ; physical capital depreciation rate, δ, and the utilization penalty cost factor, m. The value for r is set to 10%, which is consistent with the CAPM model when the risk-free rate is 3%, the risk-premium is 7%, and the beta for the industry is 1.0. The average corporate tax rate τ is set to 30%. The physical capital depreciation rate δ is set to 10%, which is consistent with a 10-year straight line depreciation method. The utilization penalty cost factor m is set to 4, which implies that the baseline cost associated with running the plant at a utilization rate of 150% is twice the cost of running the plant at normal operations, i.e., $\phi(1.5) = \frac{1.5^4}{4} + (1 - \frac{1}{4}) \approx 2$.

Table 1: Net social welfare gain and its components.

The table shows the average values for net social welfare gain (NSWG) and its components for the different subsidy policies (grant and tax credit) and level of supports (10%, 20%, ..., 50%). Values are normalized by the present value of the income stream over the 10-year horizon and are recorded in basis points. ‘All’ denotes the entire industry sample. ‘H’,‘M’ and ‘L’ denote the sub-samples of industries that correspond to the high, medium and low mean R&D intensity rates in the no subsidy case. ‘CS’, ‘PS’ and ‘TS’ denote the consumer, producer and tax surplus, respectively.

		Grant					**Tax Credit**				
		10%	**20%**	**30%**	**40%**	**50%**	**10%**	**20%**	**30%**	**40%**	**50%**
H	**NSWG**	2.5	4.0	5.7	6.8	7.8	7.0	14.1	21.1	27.6	33.1
	CS	4.1	7.6	11.4	14.7	18.1	8.5	17.9	28.4	39.6	51.8
	PS	1.7	3.2	4.6	6.0	7.2	2.3	5.0	8.2	12.2	16.9
	TS	0.8	1.5	2.2	2.8	3.4	0.8	1.8	2.8	3.9	5.1
	SubCost	4.2	8.3	12.6	16.7	20.9	4.6	10.6	18.2	28.1	40.8
M	**NSWG**	8.4	15.7	20.7	25.1	28.0	10.5	20.7	31.3	41.1	49.4
	CS	10.1	19.4	26.6	33.4	38.7	12.4	25.2	39.6	54.5	69.6
	PS	0.1	0.4	1.0	1.7	2.5	0.2	1.0	2.2	4.2	7.1
	TS	0.3	0.7	1.1	1.6	2.0	0.3	0.7	1.3	1.9	2.7
	SubCost	2.1	4.8	8.0	11.5	15.2	2.4	6.2	11.8	19.6	30.0
L	**NSWG**	2.4	5.7	8.9	12.7	16.7	2.8	7.2	12.2	18.8	27.6
	CS	3.0	7.4	12.0	17.8	24.1	3.5	9.3	16.7	27.4	43.2
	PS	0.0	-0.2	-0.2	-0.3	-0.4	0.0	0.0	0.2	0.6	1.3
	TS	0.1	0.2	0.3	0.4	0.5	0.1	0.2	0.4	0.6	0.8
	SubCost	0.6	1.7	3.1	5.1	7.6	0.7	2.3	5.0	9.9	17.7
All	**NSWG**	4.4	8.5	11.8	14.9	17.5	6.8	14.0	21.5	29.1	36.7
	CS	5.7	11.5	16.7	22.0	26.9	8.1	17.4	28.2	40.5	54.8
	PS	0.6	1.2	1.8	2.4	3.1	0.8	2.0	3.5	5.6	8.4
	TS	0.4	0.8	1.2	1.6	2.0	0.4	0.9	1.5	2.1	2.9
	SubCost	2.3	4.9	7.9	11.1	14.5	2.6	6.3	11.7	19.2	29.5

Table 2: Benefit/cost, R&D additionality and R&D elasticity.

The table shows the average values of the benefit to cost, additionality and the R&D elasticity measures for the different subsidy policies (grant and tax credit) and level of supports (10%, 20%, ..., 50%). ‘All’ denotes the entire industry sample. ‘H’,‘M’ and ‘L’ denote the sub-samples of industries that correspond to the high, medium and low mean R&D intensity rates in the no subsidy case. ‘B/C’ denotes benefit/cost, ‘Add’ denotes the additionality and ‘Elast’ denotes the R&D price elasticity.

		Grant					**Tax Credit**				
		10%	**20%**	**30%**	**40%**	**50%**	**10%**	**20%**	**30%**	**40%**	**50%**
H	**B/C**	1.56	1.46	1.44	1.40	1.37	2.47	2.31	2.15	1.98	1.81
	Add	1.22	1.14	1.13	1.10	1.09	1.61	1.57	1.52	1.47	1.42
	Elast	0.86	0.81	0.67	0.65	0.61	1.60	1.69	1.72	1.79	1.88
M	**B/C**	3.95	3.62	3.24	2.97	2.73	4.35	3.78	3.33	2.92	2.56
	Add	2.65	2.50	2.32	2.19	2.07	2.91	2.57	2.30	2.07	1.90
	Elast	3.62	2.68	2.43	1.90	1.54	4.43	4.22	3.83	3.56	3.30
L	**B/C**	3.03	2.92	2.64	2.51	2.41	3.32	2.98	2.55	2.25	2.09
	Add	2.98	2.88	2.65	2.51	2.38	3.29	3.09	2.60	2.31	2.08
	Elast	5.03	4.23	4.34	3.96	3.83	6.92	5.62	6.46	6.49	5.59
All	**B/C**	2.85	2.67	2.44	2.29	2.17	3.38	3.02	2.68	2.38	2.15
	Add	2.28	2.17	2.03	1.93	1.85	2.61	2.41	2.14	1.95	1.80
	Elast	3.17	2.57	2.48	2.17	1.99	4.32	3.84	4.00	3.95	3.59

Table 3: Net social welfare gain: Sample distributions.

The table shows the minimum value, the first to ninth decile value and the maximal value of the net social welfare gain measure for the different subsidy policies (grant and tax credit) and level of supports (10%, 20%, ..., 50%). Values are normalized by the present value of the income stream over the 10-year horizon and are recorded in basis points. 'All' denotes the entire industry sample. 'H','M' and 'L' denote the sub-samples of industries that correspond to the high, medium and low mean R&D intensity rates in the no subsidy case.

		Grant					**Tax Credit**				
	Decile	**10%**	**20%**	**30%**	**40%**	**50%**	**10%**	**20%**	**30%**	**40%**	**50%**
H	**Min**	-20.5	-16.1	-13.5	-12.6	-11.4	-11.1	-7.7	-4.4	7.9	10.8
	1	-8.7	-8.1	-6.3	-5.1	-4.1	3.1	6.8	10.8	16.2	22.3
	2	2.0	-5.4	-4.2	-2.8	-1.9	3.6	7.9	13.0	19.7	25.5
	3	2.5	3.0	-2.2	-1.0	0.0	4.0	8.9	15.0	22.7	28.3
	4	2.9	4.3	4.1	1.4	1.8	4.4	9.9	17.6	25.2	30.3
	5	3.3	5.5	6.4	6.0	4.8	4.8	11.1	20.0	27.5	32.4
	6	3.7	6.4	8.2	9.1	8.9	5.2	13.0	23.2	29.8	34.6
	7	4.1	7.4	9.9	11.9	12.9	5.9	17.2	26.2	32.2	37.2
	8	4.6	8.7	12.4	14.8	17.4	7.5	21.6	29.1	35.0	40.2
	9	5.8	12.3	17.2	19.7	23.0	16.9	25.9	32.9	39.1	44.3
	Max	46.5	53.9	59.6	56.4	54.1	33.1	40.3	50.2	66.2	79.8
M	**Min**	-15.1	-11.6	-9.1	-7.3	-8.9	-1.6	-3.7	-1.6	-0.6	-1.7
	1	0.5	0.9	1.4	1.9	2.3	0.2	0.7	3.4	4.2	4.8
	2	0.6	1.3	1.9	2.8	5.2	0.3	3.3	4.8	12.6	28.2
	3	0.8	1.6	3.8	8.8	11.9	0.4	4.5	14.3	26.3	33.6
	4	0.9	3.8	8.6	12.6	16.0	2.7	7.9	21.4	30.8	39.6
	5	1.4	6.6	12.0	17.0	19.7	4.1	14.1	25.7	36.5	46.4
	6	3.0	9.4	16.7	21.0	26.1	6.0	18.7	30.8	43.1	54.5
	7	5.0	14.8	21.4	32.9	42.7	10.0	23.2	37.0	53.6	63.3
	8	8.4	22.8	45.7	51.1	53.2	15.4	29.7	55.9	66.8	74.2
	9	22.3	56.1	60.8	63.6	64.5	23.4	60.6	74.3	82.1	88.9
	Max	87.7	93.3	95.2	98.9	101.6	101.6	109.7	117.8	125.8	133.5
L	**Min**	-2.7	-0.2	-0.2	-0.3	-0.6	-0.8	0.0	-0.1	-0.5	-0.9
	1	0.0	0.0	0.0	0.3	0.4	0.0	0.3	0.7	1.4	1.4
	2	0.0	0.5	1.0	1.4	1.8	0.0	1.2	2.5	3.1	2.8
	3	0.1	0.8	1.4	1.9	2.3	0.1	2.0	3.1	3.7	3.6
	4	0.3	1.1	1.8	2.4	2.9	0.2	2.5	3.5	4.2	4.2
	5	0.5	1.6	2.3	3.0	3.5	1.4	3.0	3.9	4.8	5.3
	6	0.6	2.1	2.8	3.6	4.5	1.8	3.3	4.3	5.5	8.2
	7	1.2	2.5	3.3	4.5	20.8	2.1	3.7	5.0	6.5	53.6
	8	2.1	3.1	4.4	23.3	41.8	2.5	4.3	6.4	48.6	63.2
	9	2.8	16.0	40.2	51.3	54.6	3.3	17.9	52.9	66.0	73.7
	Max	79.1	84.2	88.0	93.0	83.8	79.4	90.4	97.4	106.0	111.0
All	**Min**	-20.5	-16.1	-13.5	-12.6	-11.4	-11.1	-7.7	-4.4	-0.6	-1.7
	1	0.0	-3.2	-2.7	-1.6	-0.7	0.1	0.8	2.6	3.4	3.2
	2	0.3	0.7	0.7	1.0	1.5	0.3	2.6	3.8	4.6	5.2
	3	0.6	1.2	1.7	2.1	2.6	1.6	3.6	4.9	6.9	23.8
	4	0.8	2.0	2.6	3.2	3.9	2.4	4.9	10.8	20.7	29.7
	5	2.0	3.2	4.2	6.0	8.6	3.4	8.0	16.3	26.3	34.3
	6	2.7	5.1	8.0	11.4	14.9	4.2	10.7	21.8	30.9	39.5
	7	3.4	7.3	11.7	16.7	21.0	5.1	15.6	26.8	36.6	46.9
	8	4.5	11.0	17.8	25.1	36.4	7.5	22.2	32.8	45.4	58.6
	9	8.6	22.7	44.6	51.2	53.6	17.2	29.8	54.7	66.2	74.1
	Max	87.7	93.3	95.2	98.9	101.6	101.6	109.7	117.8	125.8	133.5

Table 4: Benefit/cost: Sample distributions.

The table shows the minimum value, the first to ninth decile value and the maximal value of the benefit/cost measure for the different subsidy policies (grant and tax credit) and level of supports (10%, 20%, ..., 50%). Values are normalized by the present value of the income stream over the 10-year horizon and are recorded in basis points. ‘All’ denotes the entire industry sample. ‘H’,‘M’ and ‘L’ denote the sub-samples of industries that correspond to the high, medium and low mean R&D intensity rates in the no subsidy case.

		Grant					**Tax Credit**				
	Decile	**10%**	**20%**	**30%**	**40%**	**50%**	**10%**	**20%**	**30%**	**40%**	**50%**
H	**Min**	-4.0	-1.1	-0.2	0.1	0.5	-1.4	0.2	0.7	1.3	1.2
	1	-1.3	0.0	0.5	0.7	0.8	1.8	1.7	1.7	1.6	1.6
	2	1.5	0.3	0.6	0.8	0.9	1.9	1.8	1.8	1.7	1.7
	3	1.6	1.4	0.8	0.9	1.0	1.9	1.9	1.8	1.8	1.7
	4	1.7	1.5	1.3	1.1	1.1	2.0	1.9	1.9	1.9	1.8
	5	1.8	1.6	1.5	1.3	1.2	2.0	2.0	2.1	2.0	1.8
	6	1.9	1.7	1.6	1.5	1.4	2.1	2.2	2.3	2.0	1.8
	7	2.0	1.9	1.8	1.7	1.6	2.2	2.7	2.4	2.1	1.9
	8	2.1	2.0	2.0	1.9	1.8	2.5	3.0	2.5	2.2	2.0
	9	2.4	2.5	2.4	2.2	2.1	4.4	3.2	2.7	2.3	2.1
	Max	12.1	7.1	5.3	4.1	3.6	7.3	4.7	3.7	2.9	2.8
M	**Min**	-6.7	-2.3	-0.9	-0.4	0.1	-0.1	0.6	0.9	0.9	0.8
	1	1.4	1.4	1.4	1.4	1.3	1.2	1.3	1.6	1.6	1.4
	2	1.5	1.6	1.6	1.6	1.5	1.3	1.9	1.9	1.8	1.9
	3	1.7	1.7	1.7	1.8	1.7	1.4	2.3	2.2	2.2	2.1
	4	1.8	1.9	1.9	2.0	2.0	1.9	2.6	2.6	2.4	2.2
	5	1.9	2.1	2.3	2.4	2.2	2.9	3.0	2.9	2.7	2.4
	6	2.1	2.7	2.8	2.7	2.7	4.1	3.4	3.3	3.0	2.7
	7	2.4	3.6	3.5	3.6	3.9	4.8	4.1	3.7	3.5	3.1
	8	4.8	5.3	6.0	5.1	4.3	5.7	5.1	5.1	4.2	3.4
	9	9.3	9.7	7.0	5.6	4.7	8.2	8.5	6.1	4.7	3.7
	Max	30.9	15.2	10.8	7.1	5.7	22.7	11.7	7.4	5.6	4.5
L	**Min**	-1.3	0.9	0.9	0.8	0.7	0.0	1.0	1.0	0.9	0.9
	1	1.0	1.0	1.0	1.1	1.2	1.0	1.3	1.3	1.3	1.1
	2	1.1	1.4	1.4	1.4	1.4	1.0	1.8	1.7	1.4	1.2
	3	1.4	1.5	1.6	1.6	1.5	1.2	2.1	1.8	1.5	1.3
	4	1.5	1.7	1.8	1.7	1.7	1.2	2.3	1.9	1.6	1.4
	5	1.6	2.3	2.1	1.9	1.8	3.0	2.4	2.0	1.7	1.5
	6	1.7	2.6	2.3	2.1	2.0	3.6	2.6	2.1	1.8	1.8
	7	3.0	2.9	2.5	2.4	3.5	4.0	2.8	2.3	2.0	3.1
	8	4.4	3.3	2.9	4.5	4.0	4.5	3.2	2.7	3.9	3.3
	9	5.6	7.6	6.4	5.2	4.4	5.3	5.5	5.6	4.3	3.5
	Max	23.2	12.1	8.4	6.5	5.4	21.4	11.1	6.9	5.5	4.0
All	**Min**	-6.7	-2.3	-0.9	-0.4	0.1	-1.4	0.2	0.7	0.9	0.8
	1	1.0	0.5	0.7	0.9	0.9	1.1	1.5	1.6	1.5	1.3
	2	1.4	1.4	1.3	1.1	1.1	1.2	1.8	1.8	1.6	1.4
	3	1.5	1.5	1.5	1.5	1.4	1.8	2.0	1.9	1.7	1.6
	4	1.7	1.7	1.6	1.6	1.6	2.0	2.2	2.0	1.9	1.8
	5	1.8	1.8	1.8	1.8	1.7	2.1	2.4	2.2	2.0	1.9
	6	1.9	2.1	2.1	2.0	2.0	2.9	2.7	2.4	2.2	2.1
	7	2.1	2.6	2.4	2.3	2.3	3.9	3.0	2.6	2.4	2.4
	8	3.3	3.3	3.0	3.1	3.7	4.6	3.4	3.2	3.2	3.1
	9	5.5	5.5	6.2	5.1	4.3	5.6	5.1	5.4	4.3	3.5
	Max	30.9	15.2	10.8	7.1	5.7	22.7	11.7	7.4	5.6	4.5

Table 5: Average values for key economic variables.

The table shows the average reinvestment percentage and the annual average growth rates of the productivity index, the quality index, output and price for the two subsidy policies (grant and tax credit) and for different support levels (10%, 20%, ..., 50%) including the no subsidy case (denoted by NoS). ‘All’ denotes the entire industry sample. ‘H’,‘M’ and ‘L’ denote the sub-samples of industries that correspond to the high, medium and low mean R&D intensity (pre-subsidy). ‘C_g’, ‘Q_g’, ‘Out_g’ and ‘Pr_g’ denote the average growth of the productivity index, quality index, output and price, respectively. ’ReInv’ denotes the average reinvestment rate. Values are given in percents.

		NoS	**Grant**					**Tax Credit**				
			10	**20**	**30**	**40**	**50**	**10**	**20**	**30**	**40**	**50**
H	**C_g**	-15.6	-15.9	-16.2	-16.5	-16.7	-16.9	-16.2	-16.8	-17.3	-18.0	-18.5
	Q_g	13.9	14.5	15.0	15.4	15.8	16.1	14.7	15.5	16.2	16.9	17.6
	Out_g	22.4	23.1	23.6	24.2	24.8	25.3	23.9	25.6	27.3	29.1	30.9
	Pr_g	-7.7	-7.7	-7.7	-7.8	-7.8	-7.9	-8.0	-8.3	-8.6	-9.0	-9.4
	ReInv	85.6	84.9	84.1	83.6	83.0	82.6	87.6	89.5	91.5	93.3	95.1
M	**C_g**	-7.8	-9.2	-10.4	-11.4	-12.2	-12.9	-9.3	-10.7	-12.1	-13.4	-14.7
	Q_g	9.0	10.1	11.1	12.0	12.8	13.4	10.4	11.8	13.2	14.3	15.3
	Out_g	5.5	8.6	11.4	13.5	15.4	16.8	9.0	12.4	16.1	19.6	22.9
	Pr_g	-2.2	-3.1	-4.0	-4.5	-5.0	-5.4	-3.1	-4.0	-5.0	-6.0	-7.0
	ReInv	49.9	56.3	61.8	65.4	68.5	70.5	59.7	68.2	76.1	82.9	88.7
L	**C_g**	-1.3	-1.9	-2.7	-3.5	-4.5	-5.6	-1.9	-2.9	-4.2	-5.9	-8.1
	Q_g	2.8	3.6	4.5	5.3	6.3	7.2	3.8	5.2	6.6	8.4	10.2
	Out_g	-6.9	-5.9	-4.4	-2.9	-0.9	1.3	-5.9	-4.1	-1.9	1.3	6.1
	Pr_g	0.7	0.6	0.3	0.0	-0.5	-1.1	0.7	0.5	0.1	-0.5	-1.8
	ReInv	19.7	24.3	29.6	34.5	40.0	45.4	27.0	36.7	46.1	57.7	70.1
All	**C_g**	-8.2	-9.0	-9.8	-10.5	-11.1	-11.8	-9.1	-10.1	-11.2	-12.4	-13.8
	Q_g	8.6	9.4	10.2	10.9	11.6	12.2	9.7	10.8	12.0	13.2	14.4
	Out_g	7.0	8.6	10.2	11.6	13.1	14.5	9.0	11.3	13.8	16.6	20.0
	Pr_g	-3.1	-3.4	-3.8	-4.1	-4.5	-4.8	-3.5	-3.9	-4.5	-5.2	-6.1
	ReInv	51.7	55.1	58.5	61.2	63.8	66.2	58.0	64.8	71.2	78.0	84.6

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