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Research and Development as an Initiator of Fixed Capital Investment

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Abstract:

This paper investigates the causal relationship between firms' research and development expenditures (R&D) and their investments into fixed capital. The literature provides two contrasting views in this respect. The first view holds that a firm's research activity causes, via the creation of inventions, subsequent investment into fixed capital, as the firm needs additional capacities to produce the new goods or services that follow from the inventions. The second view holds that firms' fixed capital investments cause intensified research activity, as novel capital goods from external suppliers offer the firms' researchers a wide range of additional technical possibilities of how to build new prototypes. Using panel data of Swiss firms ranging from 1990 to 2014, the paper applies, contrasting the existing empirical literature only based on VARs, a 2SLS approach to uncover the direction of causality between R&D and fixed capital investment. In order to obtain exogenous instruments, the paper exploits shocks to i) technological opportunities and ii) sales from capital goods suppliers. Results show a one-way causal relationship; we find evidence for that firms' R&D expenditures cause fixed capital investments, but we do not find evidence for the reverse effect. When additionally looking at innovation performance, R&D activities turn out to be complementary to fixed capital investment, in the sense that they markedly increase the expected return on investment. Thus, increasing research activity may not just be valuable for long-run economic growth but, via investment, may also give the economy a head start in times of a prolonged economic downturn.

JEL Classification: O33

Keywords: Investment, Research and Development, Invention, Technological Opportunities, Complementarity

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1. Introduction

Since the financial crisis of 2008, low economic growth rates in advanced economies have illustrated that near-zero interest rates are probably a necessary, but clearly not a sufficient condition for firms to increase investment into fixed capital. Even though interest rates have been on a record low for almost a decade, business fixed capital investment has not really accelerated. In this paper, we argue that for firms to be willing to undertake fixed capital investments, they first need to have profitable growth opportunities at hand. Without such opportunities, firms will, irrespective of the cost of borrowing capital, not be willing to extend their existing capacities. This argument sides with traditional supply-side economics; in order to grow and thus to contribute to aggregate economic growth, a firm first needs a technical invention into which it can invest and which, subsequently, enables the firm to produce a novel good or to produce an existing good more efficiently. This argument dates back to Schumpeter (1934, 1939), who sees innovation not just as the key to economic progress, but also as the decisive factor in causing economic business cycles, as firms with new technologies tend to arrive in waves and therefore cause, via the implementation of their innovations, aggregate investment and thus also production to fluctuate. Whereas Schumpeter's business cycle theory is often considered as rather controversial, economists unanimously agree that aggregate business cycle fluctuations are to a high degree caused by volatility in fixed capital investments. It is therefore key for politicians and academics alike to gain a good understanding of the factors causing investments into fixed capital. In this paper we argue, vindicating Schumpeter's controversial thinking, that R&D expenditures are such a crucial determinant of aggregate movements in fixed capital investments.

The aim of the paper at hand is threefold. First, it investigates whether firms' R&D expenditures, which eventually lead to new inventions, cause, via the implementation of these inventions, investment into fixed capital and, thus, whether R&D expenditures constitute a potential factor in determining aggregate investment activity in an economy (Lach and Schankerman 1989). Second, the paper investigates whether the reverse effect also holds true, whether fixed capital investments cause R&D expenditures. According to this perspective, novel capital goods from external suppliers provide the firm's researchers with valuable ideas for innovative products and processes (Toivanen and Stoneman 1998). For example, after the purchase of a new machine for the production process, learning will take place and by using the new machine researchers will step-by-step discover new ways of how to build novel prototypes. Third, and very much related to the first two points, the paper investigates, by looking at innovation performance, whether R&D activities are complementary to fixed capital investments, in the sense that, because of the greater degree of novelty they imply, R&D activities increase the expected return on fixed capital investments.

In his paper, we solve the simultaneity issue between R&D and fixed capital investment by using a Two-Stage Least Squares (2SLS) framework with instruments identifying clear causal mechanisms, contrasting the existing literature, which is only based on atheoretical Vector Autoregressive (VAR) models. Every econometric estimation of a causal relation between R&D expenditures and fixed capital investments also faces the problem of omitted variable bias implied by the firm's liquidity situation, which is itself dependent upon changes in

consumer demand, resulting from, for example, regulation, consumer taste, or actions of competitors. A decrease in the availability of cash is likely to simultaneously lower both R&D expenditures and fixed capital investments. Thus, a valid instrument has not only to solve the simultaneity issue between R&D and investment, but has also to be independent of the joint variation of both variables with the contemporaneous liquidity situation of the firm.

In order to instrument for the firm's R&D expenditures, we use the variable technological opportunities. This variable measures the availability of the worldwide scientific knowledge base that can be accessed by the respective firm, whereby this knowledge can be provided by such external sources as universities or other public research institutes. The central characteristic of technological opportunities is that they are open to everyone but not yet ready for commercial purpose. To make technological opportunities useful for the firm, they have to be first taken up by the firm's R&D department and converted into blueprints for the production of commercially valuable products or technologies. In order to instrument for the firm's fixed capital investments, we use the variable sales of novel capital goods. As this variable measures actions of capital goods producers, it should be exogenous to the focal firm but be correlated with the firms' investment into new equipment. We argue that both instruments, technological opportunities and sales of novel capital goods, identify relevant and clearly ordered causal mechanisms that are at the same time not correlated with the firm's contemporaneous liquidity situation. After solving the question about the direction of causality between R&D and investment, we can order the effects and investigate their complementarity in terms of the commercial success of innovative products, whereby we argue that R&D increases the return on fixed capital investments. Although the literature provides comprehensive empirical studies addressing various types of complementarities (e.g., Milgrom and Roberts 1995; Arvanitis et al. 2015; Polder et al. 2010), the complementary relationship in terms of the commercial success of innovative products between R&D and fixed capital has not been investigated so far.

For our quantitative analysis, we can make use of a unique dataset based on a representative panel of Swiss firms and consisting of data from two surveys; the Swiss Innovation Survey and the Swiss Investment Survey. Because both surveys are conducted on the same panel of Swiss firms, they can be merged and together they yield a comprehensive dataset of over 9000 firm-year observations, covering in three year steps the years 1990 to 2014. The Swiss Innovation Survey includes various variables measuring firms' innovativeness as well as drivers and obstacles of innovativeness, such as a valuable proxy for the technological opportunities given to a firm. The Swiss Investment Survey delivers information of firms' fixed capital investments on an annual basis.

Results from our 2SLS estimations show that R&D expenditures indeed cause fixed capital investments. We do not, however, find evidence for the reverse effect. Referring to innovation performance, we find substantial complementarity between R&D and fixed capital investments; fixed capital investments combined with R&D expenditures show a higher return than capacity enhancing investments that are not driven by R&D results. Thus, the paper shows that R&D activities stimulate fixed capital investments in two ways; directly via the implementation of inventions and indirectly via the higher expected returns from R&D based fixed capital investments. From a policy perspective, measures increasing R&D expenditures could therefore—by accelerating

fixed capital investments—provide a valuable stimulus for the growth perspectives of an economy in times of an ongoing economic downturn.

The paper is organized as follows. Section 2 presents the literature about the causal relationship between R&D and fixed capital investment, where we find arguments for both views; R&D could cause fixed capital investment but the reverse effect could also be true. Section 3 deals with the relevant literature regarding complementarity. Section 4 presents data, model and the econometric procedures. Section 5 shows the results and Section 6 concludes and provides some policy implications.

2. The relationship between R&D and fixed capital investment

Lach and Rob (1996) argue that, traditionally, the difference between R&D expenditures and fixed capital investment has only been one of labelling. R&D expenditures concern investments into intangible capital, fixed capital investments into tangible capital, whereby both are supposed to affect output in a similar fashion. In accordance with this view, Grabowski and Mueller (1972) state that an increase in contemporary R&D expenditures causes a decrease in contemporary fixed capital investments, as they both withdraw resources from each other, in the form of, for example, cash, employees, or managerial talent; the authors argue that substitutive interactions between R&D expenditures and fixed capital investments outweigh any complementary interactions between them, as investments crowd out R&D spending but do not encourage any further research. However, in line with more recent research (Lach and Schankerman 1989; Toivanen and Stoneman 1998; Nickell and Nicolitsas 2000; Baussola 2000), we first depart from this view by giving arguments describing a causal impact of R&D on fixed capital investments and, vice versa, arguments describing a causal impact of fixed capital investments on R&D, while only then discussing complementarity between them.

R&D investments cause fixed capital investments

From a Schumpeterian perspective, innovations brought forward by firms are the fundamental driving force that sets the capitalist engine in motion (Schumpeter 1939; 1934). New goods, new methods of productions, new supply sources, or new forms of organization move the economy away from its equilibrium position and cause, through the unfolding of the business cycle, the economy to grow. The introduction of new inventions thereby constantly renews the economy's production structure, in the sense that the economy has to constantly adapt to the new inventions. However, inventions are not necessarily exogenous to the economy, they can be the outcome of the firm's R&D activities (Romer 1990), its accumulated knowledge (Aghion and Howitt 1990), or its ability to benefit from the steady advance of basic scientific knowledge (Rosenberg 1974; Cohen and Levinthal

1990). In this paper we argue that for a firm to be able to profit from its inventions, it has first to invest into fixed capital, which will in turn allow production and commercialization of the product or technology that the invention describes. A prototype of a new robot, for instance, is just a necessary first step towards a marketable product. In order to commercialize the prototype, the firm needs to first invest into machines and factories that allow serial production. For Schumpeter, it was clear that without inventive activity resulting in new technologies, investment opportunities would dry up and economic growth would come to an end. This perspective of R&D causing fixed capital investment has been taken up by several empirical papers, all of them using VAR (Vector Autoregressive) analysis to isolate the direction of causality between the two factors.

Lach and Schankerman (1989) use data from the US science-based manufacturing sector (assembled by NBER) for the period 1973-1981. The 191 firms in their sample are on average larger and they are more R&D and fixed capital intensive than the average firms in the manufacturing sector. The paper explores the interaction between R&D expenditures and fixed capital investments applying a dynamic factor analysis, where the three endogenous variables R&D expenditures, fixed capital investment, and the market rate of return are determined by three unobserved stochastic factors. Since they can show that past R&D expenditures and past fixed capital investments do not affect the market rate of return, their analysis mainly results in a test about the interaction between R&D investments and fixed capital investments. They find evidence that R&D investments Granger-cause fixed capital investments, but not vice versa. However, the data available to the authors does not provide evidence for any particular interpretation of these unobserved shocks.

Nickell and Nicolitsas (2000) use a sample of about 100 UK manufacturing firms over the period 1976 to 1994. Controlling for firm fixed effects, the authors find that R&D does encourage investment in fixed capital in most industries and that there is no positive effect in the other direction. Moreover, they also find that R&D originating from suppliers has a positive effect on the focal firm's fixed capital investments. New equipment that allows for a production that is twice as fast clearly increases the incentives for firms to buy and apply it.

Baussola (2000) also finds evidence that R&D Granger-causes investment in both the short and long-run and that the reverse only holds in the long-run. Chiao (2001) puts forward an explanation for this long-run correlation between R&D and fixed capital investments. He suggests a step-wise relation between R&D expenditures and fixed capital investments. An R&D success leads, as set out before, to fixed capital investments. Commercial success of the new product can then induce further R&D expenditures, with the target to improve or diversify the existing product, which, in the case of R&D success, again initiates new fixed capital investments. Consequently, there should be a positive long-term relation between R&D expenditures and fixed capital investments. However, it is crucial to see that this long-term relationship explanation rests on a one-way causal relation only, from R&D to fixed capital investments; fixed capital investments, on the other hand, do not guarantee success of the products in the market and can therefore also not be the cause of once again increasing R&D activities.

The results of these empirical studies suggest that R&D expenditures are indeed a vital factor in determining fixed capital investments. However, as implied by the model of Lach and Schankerman (1989), there is a lack of data that would identify the unobserved shocks initiating these causal relationships; the existing papers do not provide such insights. Moreover, despite the above results, there are also arguments and empirical evidence in favor of a reversed relationship; that fixed capital investments cause R&D activity, to which we turn now.

Fixed capital investments cause R&D investments

So far we have looked at fixed capital investments as an integrated process within the firm. The firm makes an invention of a new product and then, by itself, constructs the means necessary to produce the respective new products for the market. Novel capital goods, however, can also be purchased in their entirety from external capital goods suppliers. Against this background, Toivanen and Stoneman (1998) describe the idea that such investment activities of a firm can provide valuable stimuli for the firm's research activities. When a firm extends its existing capacities and purchases additional fixed capital goods from suppliers, the process of installing and first using these new machines will provide the firm with valuable inputs for the development of new products and processes; the new equipment, for example, could allow the firm to combine materials in ways that were not possible before or allow adding new features to the product. In that sense, new capital goods can provide the respective firm's researchers with a whole range of new production possibilities and, in combination with the new capital goods, may also encourage researchers to even think of entirely new products. The added value for the firm thereby lies in the novelty of the purchased capital good, as this newly introduced element can spur the innovative imagination of the firm's researchers, in the sense of "what else could we improve based on this new machine?". The described process of implementation and subsequent use of new fixed capital goods is a process of "learning by using". The research department thereby provides solutions to upcoming problems and, more important, new opportunities that emerge while using the new fixed capital equipment for production.

Consequently, from a theoretical point of view, it is very well possible that higher levels of (purchased) fixed capital investments can increase the level of research activities. A large amount of fixed capital investments will, *ceteris paribus*, also allow for more production possibilities, which will in turn translate into more intellectual stimuli for researchers and thus to higher research expenditures. Indeed, Toivanen and Stoneman (1998) find the exact opposite empirical result as compared to the studies presented in the previous section, that fixed capital investment Granger-causes R&D and not vice versa.

In this paper we argue that the views of Lach and Schankerman (1989) and Toivanen and Stoneman (1998) are not contradictory and can be reconciled by looking at how they differ in their perspective of where fixed capital investment originates from. Lach and Schankerman (1989) consider fixed capital investment to naturally follow from inventions made by the R&D department, whereby the whole process takes place within the focal firm. Toivanen and Stoneman (1998), on the other hand, emphasize the importance of the purchase of capital goods from external suppliers, which will translate into stimuli for the firm's research activities. In the empirical part,

we will incorporate both views, by exploiting exogenous variation in the sense of, first, Lach and Schankerman (1989) and, second, Toivanen and Stoneman (1998).

3. Innovation performance: Complementarity between R&D and fixed capital investments

Given that fixed capital investments are the result of successful inventive activity, then an increase in fixed capital investments should be followed by an increase in innovative output (sales), as the commercialization of new products or services is the final step in the described production chain. In this section, we extend this unidimensional view by introducing the idea of complementarity between R&D and fixed capital investments. When understood in the terms of Edgeworth, the question of complementarity between R&D and fixed capital is directly related to the issue of causality as outlined in Section 2: doing more of one thing increases the returns of doing more of the other (Milgrom and Roberts 1995), but essential is the ordering between the two factors. A higher level of the exogenous variable leads to a higher level of the endogenous variable, but only together they can increase (innovation) performance. Ordering causal effects is important information for economists, as they like to know which button they have to press to set the whole process in motion. We will therefore consider whether the joint occurrence of fixed capital investment and R&D leads to superior innovation performance, and, given that R&D is the exogenous variable, whether fixed capital investments based on successful R&D activities have a higher expected return than fixed capital investments not based on R&D activities, where a firm only produces goods similar to the existing ones.

R&D is essentially a risky activity with uncertain outcomes. Products or processes resulting from R&D tend to have a greater degree of novelty than new products not based on R&D or products that are only improvements on existing products. This novelty increases the risk of commercialization, as it confronts consumers with beforehand unknown product characteristics and can turn out either way, in success or failure. The firms could instead choose the conservative strategy and rely on fixed capital investments enlarging the capacity to produce goods more similar to existing ones. On average, however, we expect the higher degree of novelty of R&D inventions to pay off and therefore to result in a higher amount of newly introduced products. We therefore see a high degree of complementarity between R&D and fixed capital, in the sense that R&D raises the expected returns from investing into fixed capital. Extending the capacities for the production of goods that are based on R&D will on average be subject to higher returns than extending the capacities for production of products similar to existing ones. Thus, following our arguments in Section 2, R&D does not only initiate fixed capital investment via the implementation of inventions, but also via the higher expected returns of R&D based products. That is, firms with R&D activities will invest more into fixed capital because they can expected to grab a larger market share with their newly launched products.

Moreover, we argue that R&D and fixed capital investments should not be seen as strictly sequential, either one factor leading to the other, but instead as achieving a higher performance when conducted simultaneously. The firm should already plan and start clearly necessary investments steps before the final prototype is built, otherwise there will be a considerable lag between the firm's research output and serial production of the new products and the prototype will stay unused, which gives competitors an unnecessary advantage. We thus see simultaneous running of R&D and fixed capital investments as having a clear performance advantage compared to only sequential planning of the two activities.¹

There is a rich empirical literature on complementarities between the firm's innovation activities and various economic phenomena. For instance, Polder et al. (2010) find that ICT investment is an important driver of organizational innovation, which itself complements product and process innovations in achieving higher TFP growth. Arvanitis et al. (2015) find complementarities between external knowledge acquisition strategies such as "buy" and "cooperate" and the firm's own innovation activities. Aw et al. (2008) find a positive interaction effect between R&D and export activities in terms of firms' productivity; participating in export markets raises the returns on R&D. However, empirical contributions on the complementarity of R&D and fixed capital investments is scarce. One rare exception is the investigation from Ballot et al. (2006) about the effects of training, R&D, and fixed capital investments on labor productivity. The authors observed 100 French firms and 250 Swedish firms over the period 1987-1993. Their sample consist of mainly very large firms; they cover about 10% and 50% of the employment in the manufacturing sector in France and Sweden, respectively. They find, only as a side effect, complementarity in terms of labor productivity between fixed capital investment and the number of R&D employees in both countries, but they do not further comment on this for the paper at hand interesting observation.

4. Data, models, and econometric procedures

Data

For our empirical investigation, we merged two datasets: the Swiss Innovation Survey and the Swiss Investment Survey. The Swiss Innovation Survey is the Swiss equivalent of the Community Innovation Survey (CIS) of the European Union and has been carried out every third year during the period 1990-2014. The Swiss Investment Survey has been carried out on a yearly basis during the peroid1988-2011. Both surveys rest on the same panel of firms and can therefore be matched together into a comprehensive dataset containing various qualitative and quantitative measures regarding innovation and investment activities. Due to the three year lag structure of the

¹ A description of the risk implications of step-by-step planning and simultaneous planning of R&D and fixed capital activities can be found in Chiao (2001).

Innovation Survey, information on innovation activities is only available in three year steps and usually refers to the yearly average (or cumulative activity) of the respective three years before the survey has taken place. The last five waves of the Innovation Survey already contain information about the gross investment expenditures of firms in the year before the survey. The Investment Survey additionally provides yearly investment data for the first three Innovation Survey waves as well as for the years in-between the three year steps of the Innovation Survey. This will make it possible to incorporate an adequate measure of the firm's capital stock. The response rates for the two surveys vary between 32% and 45%. The combined dataset, as it remains after including the relevant variables in our regression models, provides us with an unbalanced panel of 9805 firm-year observations. The descriptive statistics as well as information about the construction of the variables relevant for our analysis can be seen in Table 1.

The relationship between investments in fixed capital and R&D

Lach and Schankerman (1989) and Toivanen and Stoneman (1998) use the framework of a theoretical investment model (Lucas and Prescott 1971) in which the firms invest in fixed capital and R&D in order to maximize their expected value of cash flow. Against the background of this model, they investigate the causal relationship between R&D expenditures and investment into fixed capital. They are posing different exclusion restrictions on their set of models, which can be related to particular orderings of Granger-causality. It is important in this model that the value of a firm is determined by current factors only and, by contrast, fixed capital investments and R&D investments are determined by the evolution of such unobservable factors as technological opportunities generated by scientific advances (Lach and Schankerman 1989) or new offerings of capital goods from suppliers (Toivanen and Stoneman 1998). In the paper at hand, we are able to measure such factors and can thus solve the simultaneity issue of the investment decisions in R&D and fixed capital with a standard instrumental variable (2SLS) approach (all variables are in natural logarithm). Moreover, we argue that our instruments are also robust to omitted variable bias in the form of financial funding of R&D and fixed capital investments.²

$$i_{it} = \alpha_1 + \beta_1 r_{it-1} + \gamma_1 x_{it-1} + \varepsilon_{1it} \quad (1)$$

$$r_{it} = \alpha_2 + \beta_2 i_{it-1} + \gamma_2 x_{it-1} + \varepsilon_{2it} \quad (2)$$

² Both activities do not only draw financial resources from each other but are also subject to common shocks in the form of, for example, a fall in consumer demand, which tightens the firm's liquidity. R&D expenditures are generally subject to long-term engagement and fluctuate decidedly less than investments into fixed capital, on firm as well as on industry level (Lach and Rob 1996; Nickell and Nicolitsas 2000). For example, Lach and Schankermann (1989) show that the growth rate of R&D expenditures is about four times less volatile than the growth rate of fixed capital investment. A possible explanation for this observation is that R&D facilities require continuous engagement over longer time periods to be able to generate successful innovations (Coad and Rao 2010). Hiring and firing as a reaction to external shocks might severely restrict successful innovation outcomes. However, although R&D seems to be less effected by external shocks, we still cannot rule out an endogeneity issue. Hence, we need to apply an instrumental variable approach.

first stages:

$$r_{it-1} = \delta_1 + \theta_1 z_{it-1} + \pi_1 x_{it-1} + \mu_{1it} \quad (1a)$$

$$i_{it-1} = \delta_2 + \theta_2 w_{it-1} + \pi_2 x_{it-1} + \mu_{2it} \quad (2a)$$

We first turn to model (1). The variable i represents fixed capital investment, r represents R&D expenditures, x refers to the control variables, and z refers to the instrument. The instrument z represents, as described by Lach and Schankerman (1989, p. 887), shocks in technological opportunities and is operationalized by the concept of “technological potential”, which has an ordinal scale with five categories, ranging from “very low” to “very high”. The technological potential of a firm is defined as the worldwide available technological knowledge that can be used for innovation activities in the firm’s market environment. More specifically, it is defined as: (i) basic scientific knowledge, (ii) knowledge about key technologies, (iii) technological or organizational knowledge specific to your area of activity; whereby the definition explicitly refers to technological potential *outside of the surveyed firm*. Technological potential is an objective measure in the sense that it refers to the amount of knowledge that can be used by anyone in the firm’s market environment and is therefore independent of the firm’s own knowledge base. Intensified research activity by the individual firm will not increase the technological potential available to the firm. But, and this is the core of our identification strategy, we argue that technological potential has a causal impact on the extent of the firm’s research activities. Technological potential is defined as knowledge accessible to everyone, but not yet ready for commercial purposes. Thus, an increase in technological potential will lead to a subsequent increase in the firm’s research activities, since the research departments has first to convert this basic scientific knowledge into knowledge usable for the creation of new products and technologies. The firm needs additional capabilities to absorb and make use of such a shock in external knowledge (this corresponds to the testable first stage in 1a). We argue that at the same time also the key requirement for a valid instrument is fulfilled; this means that the technological opportunity is related to fixed capital investments only through R&D.

We extend this reasoning by arguing that a given base of technological potential is more valuable for the firm’s innovation activities when operating in an industry that disposes of a large stock of applied knowledge. A novel insight from, for example, university research will interact with the already existing applied knowledge in the respective industry, and, a large stock of applied knowledge allows for more technological combinations helping a firm to develop commercially valuable products and technologies. We therefore multiply the variable technological potential with the average R&D expenditures in the firm’s industry (the industry average of R&D expenditures is calculated without including the R&D expenditures of the respective firm); the average R&D expenditure of the industry should thereby reflect the stock of applied knowledge present in an industry.³ In

³ It can be the case that a firm faces high technological potential, but the applied research activities within the industry are very low. This is to say that scientific knowledge is too advanced for the technological capabilities of the industry. Nanotechnology, for instance, significantly increased the technological potential for a textile firm. However, average R&D expenditures of the industry can remain on a low level, when the applied potential is low.

order to look at the robustness of the results, we run model (1) by applying both random effects and fixed effects estimation.

In order to test for the reverse case, whether fixed capital investments cause investments into R&D, we refer to model (2) and the instrument w . The instrument w represents, as described by Toivanen and Stoneman (1998), shocks in the form of sales from new capital goods in the market. It is operationalized by the average innovative sales of the three industries: i) machines, ii) electrical engineering, and iii) electronic instruments. The underlying idea is that an increase in the economy-wide offerings of novel capital goods is likely to stimulate a firm's fixed capital investments, as, for example, the additional offering of a new machine, which allows the firm to significantly enlarge its production, raises the probability that the firm invests into fixed capital by buying this machine. In order to allow for firm specific variation, we multiply the sales of capital goods suppliers with a variable measuring the knowledge inflow from capital goods suppliers on a four point ordinal scale ranging from "not relevant" to "very important". We argue that an increase in the technical knowledge about new capital goods is likely to cause the firm to invest into additional fixed capital capacities, by, for example, improving the original production process or even by constructing entirely new capacities. Hence, we argue that new capital goods offerings, coupled with technical information from suppliers, lead to an increase in the firms' fixed capital investments (this corresponds to the testable first stage in 2a) and only then translate, via the research stimuli provided by the availability of new equipment, into rising R&D expenditures.

The central difference between (1a) and (2a) is the way in which novel ideas are incorporated into the production process. Whereas in (1a) we look at an external technology shock that has first to be processed by the R&D department, in (2a) we look at an external technology shock that first translates into additional fixed capital capacities. Thus, we argue that by using the two described instruments we can successfully solve the simultaneity issue between the two variables. Note that by using 2SLS we are only identifying Local Average Treatment Effects (LATE), that is, we cannot for example rule out a causal effect of R&D on investment via other factors than technological opportunities. The same holds for the reverse channel; an insignificant result would not rule out any other causal effects operating in this direction. However, by applying our instruments we directly test the causal stories described in the theoretical background and if we find insignificant results, we will be able to clearly reject these stories. Finally, we argue that the two applied instruments are also robust to omitted variable bias, as they are both independent from the firm's contemporaneous liquidity situation. Both instruments proxy for the knowledge base firms can draw on and do not themselves influence the available amount of knowledge.

Measurement of variables

R&D expenditures are measured as the average R&D expenditures during the past three-year period covered by one wave of the survey; for instance, the 2010 survey, average yearly R&D expenditures refer to the years 2008-2010, that is, the period " $t-2$ " up to " t ". As can be seen in Table 1, only 36.6% of the firm-year observations in our sample actually have positive R&D expenditures. In order to control for the many zero observation, we

additionally add a binary variable showing whether the firm has positive R&D expenditures or not, which allows separating the extensive and intensive margin. Investments into fixed capital is measured by firms' gross investments, which are available in the triannual Swiss Innovation Survey as well as in the annual Swiss Investment Survey.

Of central importance for the cross-sectional dimension of our panel data analysis is an adequate measure of the firm's capital stock. Often, research intensive firms are also capital intensive firms, such as, for example, the automotive industry or the pharmaceutical industry. Without a variable measuring the firm's capital stock, investments will be positively correlated with R&D expenditures because of this structural characteristic and cross-sectional information will not be very informative. Using the yearly observations from the Investment Survey, the paper applies the perpetual inventory method to construct a measure for the capital stock. The initial capital stock (period t_0) is calculated by dividing the first positive fixed capital investment value by the interest rate (5%) and the depreciation rate (15%). For the following years, the capital stock is depreciated by the usual 15%, whereas at the same time the respective yearly gross investments are added to the capital stock (perpetual inventory method). In order to avoid a correlation between the growth of the capital stock and the contemporaneous investment activities, the capital stock enters the regression one year lagged. Due to the unbalanced nature of our panel dataset, the construction of the capital stock will lead to a substantial drop of observations used in the regression analysis.

All models include other important control variables. Firm size is measured by the natural logarithm of the firm's sales. It controls for the fact that larger firms tend to simultaneously invest more in fixed capital and in R&D. In addition, since an increase in contemporaneous sales usually affects investments via an increase in profits or the availability of cash (Eisner 1978), the sales variable will also take up a certain part of the omitted variable bias inflicted by liquidity shocks. To further distinguish between tangible and intangible assets, the firm's human capital is added, which is measured by the share of employees with a tertiary education. Past demand development is incorporated into the regression to give an indication about how this important variable associates with increases in R&D and fixed capital investments. Last, the number of competitors should proxy for the factor that competition lowers the incentives to invest into both, tangible and intangible assets.

The performance effects of fixed capital investments and R&D investments

In order to identify the complementary effects of R&D and fixed capital investments, we follow a standard innovation equation, inserting a "Schumpeterian" control vector comprising variables for competition, past demand development, and firm size (Cohen 2011; Crépon et al. 1998) and add fixed capital investments and the interaction between fixed capital investments and R&D. This setting tests whether in combination R&D activities and fixed capital investments exerts an extra performance premium.

$$\text{inns}_{it} = \alpha_3 + \beta_3 \text{rd}_{it-1} + \varphi_3 \text{i}_{it-1} + \theta_3 (\text{rd}_{it-1} * \text{i}_{it-1}) + \gamma_3 \text{x}_{it-1} + \tau_3 \text{mills}_{it} + \varepsilon_{3it} \quad (3)$$

The dependent variable *inns* represents the natural logarithm of sales from innovative products. *rd* is a dummy variable indicating whether the individual firm has R&D activities or not. The estimation carries with it the issue that we observe innovative sales only for firms that succeeded in their innovation activities, which would imply a downward bias; a failure to innovate would lower the return to fixed capital investment. Hence, we estimate a Heckman selection bias correction, whereby we use governmental regulation of innovation activities as an instrument (measured on a 4 point Likert-scale ranging from “not relevant” to “highly relevant”). Governmental regulation of innovation activities is correlated with the probability to bring forward a new product, as regulation might delay or even prohibit the introduction of a new product. But once a product is introduced to the market, governmental regulation should not constrain sales anymore; the new product has already taken the crucial hurdle. We then insert the resulting inverse mills ratio (*mills*) from every cross-section in model (3). Note that *rd* is a binary variable and shows little variation across time, as has been documented by Woerter (2014). Consequently, a within-effects (fixed effects) estimator would largely erase the *rd* effect and we would miss an important piece of information. Hence, we only run random effects estimations.

6. Results

As a baseline, Table 2 presents four estimated versions of model (1) without instrumenting; thus, it presents simple correlations between R&D expenditures and fixed capital investments, given the respective covariates. Column I of Table 2 uses Random Effects (RE) estimation and shows that R&D expenditures are significantly positively related to fixed capital investment. Moreover, the negative R&D dummy, in combination with the continuous variable on R&D expenditures, shows that on average firms selecting into R&D have higher levels of fixed capital investment, though the difference is not significant. Column II of Table 2 shows that these results are robust to the inclusion of the variable measuring the firms’ capital stock, despite the markedly reduced sample size. Thus, Column I and II show that firms investing more into R&D also invest more into fixed capital, irrespective of their capital intensities. Column III of Table 2 shows that the positive relation between R&D expenditures and investment also extends to the system GMM (GMM-SYS) estimation including the lagged dependent variable. The coefficient on the lagged dependent variable thereby shows that we look at a stationary process with not very persistent shocks; only about 10% of the unobserved shocks extend to more than three years. Column IV of Table 2 presents result from the Fixed Effects (FE) estimation. Again, the coefficient on R&D expenditures is very similar in magnitude to the previous three estimations, which means that time persistent unobserved heterogeneity does obviously not imply a large bias upon our estimates. Given this similarity of results, we will drop the capital stock variable in later estimations, since it markedly reduces the number of observations. Because firms’ capital intensities have low variation across time, the 2SLS fixed effects specifications will take account of this problem and will provide an answer whether there is any bias.

Table 3 presents the 2SLS specifications of model (1) with first stage (1a). The F-statistics for the instrument is in all four presented regressions well above the critical value of 10, showing that increases in our instrument for technological opportunities are highly correlated with increases in research and development expenditures. This is evidence for our argument that firms incorporate shocks to technological opportunities through a rise in their R&D expenditures. Column I and III of Table 3 present results from the 2SLS-RE regressions with contemporaneous and three-year forwarded values of investment. The coefficients are in both cases close to 0.2 and highly significant, despite the large differences in sample size. Column II and IV of Table 3 present the 2SLS-FE results, focusing on the within dimension only and thereby eliminating all remaining time-invariant unobserved firm specific effects such as the capital intensity. The results confirm our theoretical notions; the impact of R&D expenditures on fixed capital investment is positive and still significant on the 10 percent level, both for contemporaneous and for three year forwarded fixed capital investment. An increase in research activities triggered by shocks in technological opportunities therefore leads to an increase in fixed capital investments, both one and four years after the increase in research activities (recall that R&D expenditures refer to the yearly average between “t-2” and “t”). When considering that with respect to three year forwarded fixed capital investments the coefficient on the sales variable in the 2SLS-FE estimations shrinks to almost zero, the 2SLS-FE estimations gain additional credibility. Whereas in time “t” sales can explain fixed capital investments in time “t” very well, after three years the sales variable has no more explanatory power. This means that cash-flow effects do not extend over much more than one year, whereas an increase in research activities has a considerable long-term impact. Note that the 2SLS coefficients obtained in Table 3 are much larger than the simple RE coefficients found in Table 2. Interestingly, the 2SLS estimates roughly coincide with the elasticities of around 0.2 to 0.3 found in earlier studies (e.g., Lach and Schankerman 1989; Nickell and Nicolitsas 2000). Our estimations provides an exact causal effect: an increase in R&D expenditures in the order of 1% leads on average to an additional increase in fixed capital investment of about 0.2% to 0.3%.

Table 4 presents the 2SLS specifications of model (2) with first stage (2a). The F-statistic for the instrument is in both presented 2SLS-RE estimation well above the critical value of 10; not so, however, in the 2SLS-FE estimations. Whereas our instrument for new capital goods offerings, coupled with the knowledge transfer from suppliers, explains fixed capital investments quite well when comparing different firms, the instrument does a poor job when explaining variation in fixed capital investment within firms over time. We thus do not present the 2SLS-FE regressions, as they would suffer from weak instrument problems. However, when looking at Column I for contemporaneous and Column II for three year forwarded R&D expenditures, coefficients are despite the markedly reduced sample in Column II very similar and both times not statistically significant. We can therefore say that there is no empirical evidence in our sample for the causal story we presented above; novel capital goods and the associated knowledge inflow do obviously not encourage further R&D expenditures.

Table 5 shows results from model (3). It is a necessary precondition for this part of the investigation that the causality issue between R&D and fixed capital investment has been solved, since we have to know the ordering

of effects to identify complementarity.⁴ Table 5 shows the results from the complementarity tests, both the RE and the Heckman estimates. We find that fixed capital investments are significantly positively related to innovative sales (Column I). The size of the coefficient remains largely unchanged when we insert the R&D variable (Column II). In order to find out whether the two variables are complementary to each other, we have to look at Column III and the coefficient on the interaction term, which is significantly positively related to innovative sales. In fact, the positive relation between fixed capital investment and innovative sales is entirely driven by R&D active firms, as the coefficient on fixed capital loses its significance in the presence of the interaction term. The positive interaction term essentially says that the innovation performance effect of fixed capital investment is about 5% higher for firms with R&D activities than for firms without R&D activities. We therefore have evidence for that fixed capital investments based on R&D activities yield a considerable innovation performance premium. The Heckman estimates of Column IV to VI show that results do not really change as compared to the simple RE estimates. This means that the selection bias of only observing the relationship between fixed capital and R&D for successful innovators is negligible. The control variables show the expected signs and—with the exception of our proxy for competition—they are significantly related with the commercial success of innovative products. The size of a firm, the skill level, and past demand show a positive and significant sign, just as expected.

6. Conclusion

The paper at hand has pursued two goals. It has, first, investigated the direction of causality between R&D investments and fixed capital investments and, second, investigated potential complementarity between R&D and fixed capital investments in terms of the commercial success of innovative products. Without solving the causality question in the first place, complementarity in the sense of Milgrom and Roberts (1995; Edgeworth complementarity) is hard to address and to understand. Since economists and policy makers usually seek to order effects, it is important information for them whether we can expect larger performance effects from i) fostering R&D activities, or from ii) encouraging investment activities based on existing technologies and products.

Based on comprehensive firm-level data stemming from two surveys covering the period 1990 to 2014, we have used an instrumental variable approach (2SLS) to look at the direction of causality between R&D and fixed capital investment. The applied instruments thereby reflect the theoretical notions about the exogenous drivers behind investment decisions in R&D and fixed capital, as proposed by Lach and Schankerman (1989) and Toivannen and Stoneman (1998), respectively. Our estimations show that R&D investments cause fixed capital investments and

⁴ We have to know whether R&D drives fixed capital investments or whether the effect is the other way round in order to get the marginal performance effect of—in this case—fixed capital investment. If the causality ran from fixed capital investment to R&D, then we would have to derive by fixed capital investments and not by R&D.

that there is no significant effect in the opposite direction. Moreover, we see “complementarity” between the two investment decisions in terms of the commercial success of innovative products.

From a policy point of view, this result has considerable implications. First, technological opportunities, triggered by technological breakthroughs, cause firms to increase their R&D investments, which, in order to provide capacities for production of the products, increases private investments into fixed capital. Hence, policy measures that increase research at universities or other public research institutions are likely to stimulate private R&D activities, with the target to absorb such newly discovered technologies and use these technologies to develop innovative products. Second, since Europe’s economies currently suffer from low private investment activities, the European Central Bank has launched an investment incentive program of historical size, albeit with low success so far. At this point, we argue that instead of creating incentives to extend existing investment capacities, policies to strengthen R&D activity could turn out more favorable in giving the economy a head start to end its downturn. Hence, we suggest that the currently observed investment crisis in Europe is also an innovation crisis and not only a question of cheap money. This may also be one reason why quantitative easing works in the US –one of the most innovative countries in the world– and (so far) not in Europe.

We conclude from our results that R&D activities are of utmost importance in stimulating economic activities. Intensified research activity may not only contribute to persistent economic growth but may also be able to free the economy, via investment, from its lethargic state of stagnation or moderate economic growth in times of prolonged recessions. The investigation of this paper is on representative firm-level panel data for Switzerland, with its special characteristics of a technologically advanced and small economy with an internationally competitive education and public research sector. It will therefore be necessary to affirm our results for other countries as well.

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Table 1: Descriptive Statistics

Variable	Description	Obs	Mean	Std Dev	Min	Max
ln(Investment)	Natural logarithm of investment expenditures	9805	13.16	2.13	2.07	24.54
ln(Cap_stock)	Natural logarithm of capital stock, created by using perpetual annuity method	3804	15.85	1.94	7.22	24.75
R&D	Dummy variable, equals 1 when R&D activities in "t-2" up to "t"; 0 otherwise	9805	0.36	.48	0	1
ln(R&D_exp)	Natural logarithm of R&D expenditures	3488	12.74	2.29	1.79	22.10
ln(Sales)	Natural logarithm of Sales	9805	16.81	1.74	11.15	24.59
Instrument z	Branch specific average R&D expenditure multiplied with techn. potential <i>outside of the firm</i> (1-4)	9771	14.04	20.83	0	80.59
ln(Inno_sales)	Natural logarithm of average yearly revenues from innovative sales during "t-2" to "t"	3745	15.59	1.84	9.02	23.64
Tert_educ_share	Share of employees with tertiary education in "t"	8299	6.76	12.34	0	100
Past_demand	Qualitative variable with 5 categories, "very low" to "very high" past demand, "t-2" to "t"	8299	3.19	1.04	1	5
Competitors	Variable with 5 categories, "0-5", "6-10", "11-15", "16-50", and "over 50" principal competitors	8299	2.55	1.43	1	5
Instrument w	Average sales of capital goods multiplied with knowledge transfer from suppliers (1-5)	8299	38.34	16.09	15.00	62.07
Regulation	Qualitative variable with 4 categories, "low" to "high" innovation constraints by govern. regulation	8299	2.35	1.06	1	4

Note: The observations are restricted to the observations actually used in the regression.

Table 2: RE, GMM-SYS, and FE estimates

DV: $\ln(\text{Investment})_t$	I RE	II RE	III GMM-SYS	IV FE
$\ln(\text{R\&D_exp})_{\text{avg}(t-2,t-1,t)}$	0.067*** (0.010)	0.044*** (0.013)	0.071*** (0.016)	0.043*** (0.013)
$\text{R\&D}_{t-2:t}$	-0.566*** (0.122)	-0.481*** (0.173)	-0.626*** (0.203)	-0.420*** (0.157)
$\ln(\text{Cap_stock})_{t-1}$		0.552*** (0.018)		
$\ln(\text{Investment})_{t-1}$			0.136** (0.060)	
$\ln(\text{Sales})_t$	0.878*** (0.011)	0.410*** (0.021)	0.776*** (0.056)	0.546*** (0.035)
Constant	-1.818*** (0.179)	-2.376*** (0.252)	-1.780*** (0.339)	3.972*** (0.579)
Observations	9,805	3,804	4,799	9,805
R-squared				0.054
Time fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	No

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3: 2SLS RE and 2SLS FE estimation using *Technological Potential as an instrument*

DV: ln(Investment) in:	I „t“ 2SLS-RE	II „t“ 2SLS-FE	III „t+3“ 2SLS-RE	IV „t+3“ 2SLS-FE
$\ln(R\&D_exp)_{avg(t-2,t-1,t)}$	0.180*** (0.048)	0.237* (0.125)	0.209*** (0.055)	0.310* (0.186)
$R\&D_{t-2:t}$	-1.893*** (0.569)	-2.649* (1.438)	-2.268*** (0.661)	-3.476 (2.114)
$\ln(Sales)_t$	0.851*** (0.018)	0.506*** (0.043)	0.815*** (0.024)	0.044 (0.066)
Constant	-1.513*** (0.306)	4.445*** (0.687)	-0.672* (0.387)	12.343*** (1.060)
Observations	9,771	9,771	5,744	5,744
Time fixed effects	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	No	No

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4: 2SLS RE estimation using *Sales of Fixed Capital Goods as an instrument*

DV: ln(R&D_exp) in:	I „t“ 2SLS-RE	II „t+3“ 2SLS-RE
$\ln(Investment)_t$	0.635 (0.542)	0.677 (0.822)
$\ln(Sales)_t$	0.345 (0.500)	0.353 (0.775)
$Tert_educ_share_t$	0.053*** (0.006)	0.056*** (0.009)
$Past_demand_t$	0.034 (0.078)	0.182* (0.099)
$Competitors_t$	-0.221*** (0.042)	-0.110* (0.059)
Constant	-12.191*** (1.741)	-13.497*** (2.740)
Observations	8,299	4,100
Time fixed effects	Yes	Yes
Industry fixed effects	Yes	Yes

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5: RE and Heckman estimation of innovative sales on investment

DV: $\ln(\text{Inno_sales})$ in „t+3“	I RE	II RE	III RE	IV Heckman	V Heckman	VI Heckman
$\ln(\text{Investment})_t$	0.047** (0.019)	0.045** (0.019)	0.009 (0.024)	0.047** (0.019)	0.045** (0.020)	0.000 (0.024)
$\text{R\&D}_{t-2:t}$		0.168*** (0.056)	-0.505 (0.338)		0.166*** (0.056)	-0.539 (0.341)
$\text{R\&D}_{t-2:t} * \ln(\text{Investment})_t$			0.050** (0.025)			0.053** (0.025)
$\ln(\text{Sales})_t$	0.864*** (0.025)	0.860*** (0.025)	0.862*** (0.025)	0.864*** (0.025)	0.860*** (0.025)	0.866*** (0.025)
Tert_eudc_share_t	0.008*** (0.002)	0.008*** (0.002)	0.008*** (0.002)	0.008*** (0.002)	0.007*** (0.002)	0.008*** (0.002)
Past_demand_t	0.044** (0.021)	0.042* (0.021)	0.040* (0.021)	0.044** (0.021)	0.041* (0.021)	0.039* (0.021)
Competitors_t	-0.007 (0.018)	-0.005 (0.018)	-0.008 (0.018)	-0.008 (0.018)	-0.005 (0.018)	-0.007 (0.018)
$\text{Inverse_Millsratio}$				0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Constant	-0.528 (0.347)	-0.497 (0.347)	-0.030 (0.416)	-0.515 (0.348)	-0.484 (0.347)	0.002 (0.416)
Observations	2,013	2,009	2,006	2,011	2,007	2,000
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1