Paper to be presented at the DRUID Academy Conference 2016 in Bordeaux, France on January 13-15, 2016

# Innovation as an Initiator of Fixed Capital Investment

**Andrin Spescha**
**ETH Zürich**
**D-MTEC**
**spescha@kof.ethz.ch**

## Abstract

Innovation as an Initiator of Fixed Capital Investment Andrin Spescha, ETH Zürich (in cooperation with Martin Wörter, ETH Zürich) Year of enrollment: October 2013, Expected final date: Summer 2017 E-mail: spescha@kof.ethz.ch 1) State-of-the-art: Since the financial crisis of 2008, low economic growth rates in advanced economics 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. Providing insights into an alternative, probably more important determinant of fixed capital investment, this paper argues that for firms to be willing to undertake fixed capital investments, they first need to have profitable growth opportunities in the form of a promising innovation at their disposal. Without such an opportunity, firms will, irrespective of the cost of capital, not be willing to extent their existing capacities. The paper at hand contributes to this discussion by empirically measuring the impact firms' research and development expenditures (R&D), eventually resulting in innovation success, have on fixed capital investment. Existing empirical literature applies VAR analysis, targeted to uncover the direction of causality between R&D and investment, but finds rather ambiguous results. 2) Research gap: Contrasting this existing empirical literature only based on VAR analysis, the paper at hand applies Two Stage Least Squares (2SLS) to identify whether there is indeed a causal link between firms' R&D and their subsequent investment into fixed capital. 3) Theoretical arguments: The central challenge to estimation will be that R&D expenditures and fixed capital investment are both subject to the same idiosyncratic shocks affecting the availability of financial resources. A fall in demand by, for example, actions of competitors will make funds scarcer, which is likely to simultaneously lower both R&D and investment. In order to obtain an instrument exogenous to the firm's contemporaneous financial resources, the paper exploits shocks to the basic scientific knowledge outside of the firm (technological potential). The central characteristic of technological potential is that it is accessible to everyone, but not yet ready for commercial purposes. To make it useful for the firm, it has 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. 4) Method: The paper applies 2SLS on a panel of Swiss firms ranging from 1994 to 2014, obtained from merging the Swiss Innovation Survey and the Swiss Investment Survey, both carried out by the KOF Swiss Economic Institute. The combined data set provides information on R&D expenditures, fixed capital investment, as well as a suitable proxy for technological potential. 5) Results: Results display coefficients in a similar order of magnitude as those previous studies finding a positive link from R&D to investment, the most robust specifications show that one additional Swiss Franc of R&D expenditures leads to an increase in fixed capital investment of about three Swiss Francs. 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.

Jelcodes:O33,-

# Innovation as an Initiator of Fixed Capital Investment

Andrin Spescha* and Martin Woerter**

Abstract:

This paper contributes to the empirical literature on the causal relationship between firms' research and development expenditures (R&D) and their investment 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, by contrast, holds that it is the firm's fixed capital investment that causes R&D expenditures, as R&D becomes necessary to find solutions to fit existing products and processes to newly acquired equipment from suppliers. Using panel data of Swiss firms ranging from 1990 to 2014, this 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 suppliers of capital goods. Results show that firms' R&D expenditures are causally related to fixed capital investment, whereas we do not find evidence for reverse causation. Moreover, when 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, Innovation, Technological Opportunities, Complementarity

---

* ETH Zürich, KOF Swiss Economic Institute; spescha@kof.ethz.ch

** ETH Zürich, KOF Swiss Economic Institute; woerter@kof.ethz.ch

# 1. Introduction

Since the financial crisis of 2008, low economic growth rates in advanced economics 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 capital, not be willing to extent 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 investment. It is therefore key for politicians and academics alike to gain a good understanding of the factors causing investment into fixed capital. In this paper we argue, vindicating Schumpeter's controversial thinking, that R&D expenditures are such a causal factor behind movements in fixed capital investment.

The aim of the paper at hand is threefold. First, it investigates whether firms' R&D expenditures, which are expected to 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 the economy. Second, the paper investigates whether the reverse effect also holds true, whether fixed capital investment causes R&D expenditures, which are, according to this perspective, necessary to find solutions to fit existing products and processes to the newly acquired equipment and machinery. Third, and very much related to the first two points, the paper investigates whether R&D activities, when looking at innovation performance, are complementary to fixed capital investments, in the sense that R&D activities, because the higher degree of novelty they imply, increase the expected return from fixed capital investments.

The central problem every econometric estimation of a causal relation between R&D expenditures and fixed capital investment faces are the many idiosyncratic components affecting a firm's liquidity situation, caused by a rise or fall in demand resulting from, for example, changing consumer tastes, regulation, or actions of competitors. A decrease in the availability of cash is likely to simultaneously lower both R&D expenditures and fixed capital investment. For a successful empirical investigation, the joint variation between contemporaneous cash-flow and investment into R&D and fixed capital has to be removed. In the paper at hand, contrasting the existing empirical literature only based on VARs, we address this problem by using a Two-Stage Least Square framework (2SLS). In order to provide exogenous variation, we use technological opportunities to instrument for R&D expenditures and sales of novel capital goods to instrument for fixed capital investment. The variable technological opportunities measures the availability of the worldwide scientific knowledge than can be accessed by the respective firm, whereby these opportunities can stem from 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 first be taken up by the firm's R&D department and converted into blueprints for the production of commercially valuable products or technologies. The variable sales of novel capital goods in the market, on the other hand, describes actions of capital goods producers, which should be exogenous to the individual firm but be correlated with the firms' investment into equipment such as machinery. The value of using technological opportunities and sales of novel capital goods as instruments lies in that they are not correlated with the firm's contemporaneous cash-flow, which enables identifying the (long-term) causal impact of R&D expenditures on fixed capital investment and vice-versa. After solving the issue 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. Although the literature provides comprehensive empirical studies addressing various types of complementarities (Milgrom and Roberts 1995), 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 empirical investigation, we can make use of a unique dataset based on a representative panel of Swiss firms and consisting of data from two matched surveys; the Swiss Innovation Survey and the Swiss Investment Survey. Together these two surveys yields a 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 technological opportunities given to a firm. The Swiss Investment Survey delivers, on a yearly basis, information of firms' fixed capital investments. Because of a partial overlap of the sample of firms these two surveys are based on, they can be merged together into a comprehensive firm-year dataset. Results from our 2SLS estimations show that R&D expenditures indeed cause fixed capital investments, whereas we do not find evidence for the reverse effect. Moreover, when looking at innovation performance, there is substantial complementarity between R&D and fixed capital investment, as fixed capital investment based on products developed by R&D shows a higher return than investment extending capacities for only marginally modified products. Thus, the paper shows that R&D activity not only stimulates fixed capital investment via the implementation of inventions, but, due to the higher returns provided by R&D, also via an increase in the firms' incentives to invest. From a policy perspective, increasing R&D expenditures could therefore, by accelerating fixed capital investment, 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 be true as well. 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 investment into intangible capital, fixed capital investment 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 leads to 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 investment outweigh any complementary interactions between them, as investment crowds out R&D spending but does 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 depart in this paper from this view by first giving arguments for a causal impact of R&D on fixed capital investment and, vice versa, for a causal impact of fixed capital investment on R&D, while only then discussing complementary between them.

*R&D investments cause fixed capital investments*

From a Schumpeterian perspective, innovations brought forward by firms are the fundamental driving force that set 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 is thereby the driving force behind an ongoing renewal of the economy's production structure, in the sense that the economy has to constantly adapt to these 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 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, with the data available to the authors they cannot 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 orginating from suppliers has a positive effect on the respective firm's fixed capital investment. New equipment that, for instance, let's you produce 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 investment. He suggests a step-wise relation between R&D expenditures and fixed capital investment. An R&D success leads, as set out before, to fixed capital investment. 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 investment. Consequently, there should be a positive long-term relation between R&D expenditures and fixed capital investment. 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 investment; fixed capital investment, on the other hand, does not guarantee success of the products in the market and can therefore also not be the cause of once again increasing R&D activities. Seen this way, the proposed long-term relation is solely driven by the success of the firm's R&D activity.

The results of these empirical studies suggest that R&D expenditures are indeed a vital factor in determining fixed capital investment. 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, from fixed capital investment to R&D investments, to which we turn now.

*Fixed capital investments cause R&D investment*

Schmookler (1966) describes the possibility that within a firm the number of technical problems recognized depends upon the extent of the firm's economic activity. When a firm extends its existing capacities and invests in additional fixed capital, there usually arise problems during the process of installing the new machines or setting up the new factories or buildings; the employees will start to recognize shortfalls of in the newly introduced technology. In order to solve these shortfalls, the firm will look for appropriate solutions and, to this end, increase its R&D expenditures. The number of technical problems recognized during the implementation of new fixed capital thereby determines the extent of R&D expenditures. Given a certain level of complexity of an investment, a higher amount of fixed capital investment will lead to the recognition of more problems and thus to higher R&D expenditures to solve these problems. Alternatively seen, implementation of fixed capital will lead to "learning by doing"; resulting ideas about how to further improve the production process can provide valuable stimuli for research expenditures.

In a similar vein, Toivanen and Stoneman (1998) argue that technological novelties emerging from other firms, universities, or other industries drive a firm to include these novelties into its fixed capital investments. The authors argue that such novelties do not directly find their way in the firm's R&D; only after having implemented the improved new fixed capital, firms increase their R&D expenditures, as they need solutions that enable adaption of the existing products and facilities to the new machinery. Both Schmookler's (1966) and Toivanen and Stoneman's (1998) arguments rest on the idea that an increase in fixed capital investment leads an increase in the number of problems recognized, which then have to be solved by additional R&D activities.

Note that Schmookler (1966) actually refutes the above argument and argues that it is the value of a solution to a problem and not simply its recognition that determines inventive activity. He argues that inventive activity follows from the expected profits that can be realized with an invention, the better the prospects, the higher the effort invested into inventive activity. Thus, an increase in a firm's fixed capital investment will only be followed by intensified research activity when the economic value of the respective solution to fix the problem is high. But, ceteris paribus, a higher level of fixed capital investment also means that the costs of not using it are higher, as the unused new equipment could meanwhile produce a large amount of new products. These higher opportunity costs imply that for large investment projects incentives to find a solution through research activities are higher. From a theoretical viewpoint, the channel that an increase in investment causes an increase in research activity is therefore very well possible. Indeed, Toivanen and Stoneman (1998) find the exact opposite empirical result of the above studies, fixed capital investment Granger-causes R&D and not vice versa.

We argue that these two contradicting arguments on the direction of causality between R&D and investment can be reconciled by looking at how the two arguments differ in their view about how investment into fixed capital is implemented. Lach and Schankerman (1989) consider an integrated process within the firm, invention by the firm is followed by the construction of means to produce the respective products. Toivanen and Stoneman (1998), on the other hand, emphasize the importance of the purchase of novel capital goods from suppliers, which on their own already enable the production of innovative goods. R&D becomes only necessary to fit the new capital goods to the firm's existing products and processes. In the empirical part, we will add to this unresolved discussion about the direction of causality between R&D and fixed capital 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 investment is the result of successful innovation activities, then an increase in fixed capital investment should be followed by an increase in innovative output, as the final result in this chain of causation. In this section, we extend this one-dimensional view by introducing the idea of complementarity between R&D and fixed capital investment. 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 performance. Ordering causal effects is important information to economists, as they like to know which button they have to press to set the whole engine in motion. We will assess 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 investment based on products emerging from R&D has a higher expected return than fixed capital investment based on products similar to the existing ones. There are two contrasting perspectives in this discussion.

According to the first perspective, we assume that both R&D and fixed capital are planned simultaneously, which makes fixed capital investment dependent upon R&D success, as it cannot take place before the new product has been developed. Since R&D is a risky activity with uncertain outcomes, this dependency makes ex-ante planned fixed capital investments uncertain as well. The firms could instead choose the conservative strategy and rely on fixed capital investments enlarging the capacity to produce goods similar to existing ones. The riskiness of R&D thereby mainly stems from the fact that the development of new products or processes does not necessarily result in innovation success. Hence, when firms make simultaneous investment decisions, the risk inherent in performing R&D activities also affects fixed capital investments, and the return on fixed capital investments based on R&D inventions could therefore be lower than the return on fixed capital investments that are not based on the firm's R&D activities.

According to the second perspective, we assume that investments in both R&D and fixed capital are taken step-by-step (Chiao 2001). This means that fixed capital investments will be planned not until the R&D step has been successfully completed. Only then, when the blueprint for the new product or process is available, the investments into the respective fixed capital will be realized. Since fixed capital investment will not take place until innovation success, it rules out a large part of the risk of simultaneous planning. In addition, products or processes resulting from R&D tend to have a greater degree of novelty than new products not based on R&D. This novelty increases the risk of commercialization, as it confronts consumers with beforehand unknown product characteristics and can turn out either way, in astonishing success or in complete failure. 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. Provided that firms follow a step-by-step investment approach, we obtain a high degree of complementarity between R&D and fixed capital. Whereas the step-by-step approach rules out the risk of obsolete fixed capital investment, the higher degree of novelty emerging from R&D inventions provides the firms' fixed capital investments with a higher expected return as compared to fixed capital investments only based on extending the capacities for products more similar to the existing ones.

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, in that participating in export markets raises the return 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 do not further comment on this for us interesting observation.

# 4. Data, models, and econometric procedures

*Data*

The data underlying this paper is obtained by merging 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 in three years steps between the years 1990-2014. The Swiss Investment Survey has been carried out on a yearly basis between the years 1988-2011. 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 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. 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 (Tovanen 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).

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

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

first stages:

$$\boldsymbol{r_{it-1}} = \boldsymbol{\delta_1} + \boldsymbol{\theta_1}\mathbf{z}_{\boldsymbol{it-1}} + \boldsymbol{\pi_1}\boldsymbol{x_{it-1}} + \boldsymbol{\mu_{1}}_{\boldsymbol{it}} \quad (1a)$$

$$\mathbf{i}_{\boldsymbol{it-1}} = \boldsymbol{\delta_2} + \boldsymbol{\theta_2}\mathbf{w}_{\boldsymbol{it-1}} + \boldsymbol{\pi_2}\boldsymbol{x_{it-1}} + \boldsymbol{\mu_{2}}_{\boldsymbol{it}} \quad (2a)$$

We first turn to model (1). The variable *i* represents fixed capital investment, *r* represents R&D expenditures, *x* refers to the control variables (sales, employees with tertiary education, capital stock), and *z* refers to the instrument.[1] 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

[1] The simultaneity issues of R&D expenditures and fixed capital investment weigh especially strong when considering funding of the two activities. Both activities 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 much more subject to longer-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.

ordinal scale with five categories, ranging from "very low" to "very high". The technological potential of a firm is defined as: (i) basic scientific knowledge, (ii) knowledge about key technologies, (iii) technological or organizational knowledge specific to your area of activity; whereby this definition explicitly refers to technological potential *outside of the surveyed firm*. The central characteristic of technological potential is that it is accessible to everyone, but not yet ready for commercial exploitation. Thus, the only channel via which technological potential can influence investments is via research activities, since the research department has first, to convert this basic scientific knowledge into knowledge usable for the creation of new products and technologies. Consequently, we argue that an increase in the technological potential will entail an increase in the firm's research expenditures, because the firm will need additional capabilities to absorb and make use of such a shock in external knowledge (this corresponds to the first stage in 1a), but 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, which implies that $Cov(z, \varepsilon) = 0$. We additionally extend this reasoning by arguing that the technological potential is more valuable for firms 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, in the case of a large stock of applied knowledge, enable more technological combinations and recombinations that help 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.[2] In order to look at the robustness of the results we run model (1) by applying random effects, fixed effects, and system GMM (GMM-SYS).

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 investment, 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, from "not relevant" to "very important". We argue that an increase in the technical knowledge about new capital goods is likely to lead the firm to invest on its own 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

[2] 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.

investments (this corresponds to the first stage in 2a) and only then translates, in order to fix upcoming problems and to adapt existing goods to the new technical requirements, 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 affects fixed capital investment. Both instruments thereby fulfill, we argue, the key requirement that they are independent of the firm's contemporaneous liquidity situation.

*Measurement of variables*

R&D expenditures are measured as the average R&D expenditures during the past three-year period the survey refers to; 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. Investment into fixed capital is measured by firms' gross investments, which are available in 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, because of this structural characteristic, be positively correlated with R&D expenditures and cross-sectional information will not be 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 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 how this variable interacts with increases in R&D and fixed capital investment. Last, the number of competitors should proxy for the omitted 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 investment into fixed capital, 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 settings tests whether in combination R&D activities and fixed capital investments exerts an extra performance premium.

$$\mathbf{inns_{it}} = \boldsymbol{\alpha_3} + \boldsymbol{\beta_3}\mathbf{rd_{it-1}} + \boldsymbol{\varphi_3}\mathbf{i_{it-1}} + \boldsymbol{\partial_3}(\mathbf{rd_{it-1}} * \mathbf{i_{it-1}}) + \boldsymbol{\gamma_3}\mathbf{x_{it-1}} + \boldsymbol{\tau_3}\mathbf{mills}_{it} + \boldsymbol{\varepsilon_3}_{it} \quad (3)$$

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. This captures the before outlined distinction between simultaneous and step-by-step planning, as the former would suffer from downward bias; a failure in innovation activities 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 product has already taken the hurdle of introduction. 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 investment, 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 increase their fixed capital investments, irrespective of the 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 extent 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 this into account and provide an answer to potential bias.

Table 3 presents the 2SLS specifications of model (1) with first stage (1a). The F-statistics for the instrument is in all of the four presented regressions well above the critical value of 10, that is, increases in our instrument for technological opportunity are highly correlated with increases in research and development expenditures. This is evidence for our argument that firms incorporate shocks to technological opportunities by their own R&D activities. 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 investment, 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 investment 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 investment in time "t" very well, after three years the sales variable has no more explanatory power. This means that cash-flow effects do not extent 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, therefore 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 Colum II very similar and both times not statistically significant. We can therefore say that there is no empirical evidence in our sample that increases in firm's fixed capital leads to increases in research activities of firms.

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.[3] 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 indeed significantly positively related to innovative sales. In fact, the positive relation between fixed capital investment and innovative sales seems to stem entirely from 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 performance premium. The higher expected returns from such R&D based investments will encourage firms to further increase their investment activities. 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 relation 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.

[3] We have to know whether R&D drives fixed capital investments or whether the effect is vice versa in order to get the marginal performance effect of –in this case– fixed capital investment. If the causality run from fixed capital investment to R&D, then we would have to derive by fixed capital investments and not by R&D.

## 6. Conclusion

The paper at hand has pursued two goals. It has, first, investigated the direction of causality between R&D investment and fixed capital investment and, second, investigated potential complementarity between R&D and fixed capital investment in terms of 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. 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) measures that solely focus on 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 are mirroring 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 that there is no significant effect in the opposite direction. Moreover, we see a complementary relation between the two investment decisions in terms of the commercial success of innovative products.

From a policy point of view, this result has far-reaching 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 investment into fixed capital. Hence, policy measures that increase research at universities or other public research institutions can stimulate firms to increase their R&D investments, with the target to absorb such newly discovered technologies and use these technologies to develop innovative products. Second, since Europe's economies 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 policies to strengthen R&D activity could not only impact the economy through higher TFP growth but also give the economy a head start to end the investment crisis. Hence, we suggest that the currently observed investment crisis in Europe is actually 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 activity. 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 limited to 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.

## Bibliography


Aghion, P, Howitt, P. (1990): “A Model of Growth Through Creative Destruction”, *NBER Working Paper* No. 3223

Arvanitis, S., Lokshin, B., Mohnen, P. & Woerter, M. (2015): “Impact of External Knowledge Acquisition Strategies on Innovation: A Comparative Study Based on Dutch and Swiss Panel Data”, *Review of Industrial Organization* 46: 359-382

Aw, B., Roberts, M., Yi Xu, D. (2008): “R&D Investments, Exporting, and the Evolution of Firm Productivitiy”, *The American Economic Review* 98(2): 451-456

Baussola, M. (2000): “The Causality between R&D and Investment”, Economics of Innovation and New Technology 9(4): 385-399

Ballot, G., Fakhfakh, F., Taymaz, E. (2006): “Who Benefits from Training and R&D, the Firm or the Workers?”, *British Journal of Industrial Relations*: 473-495

Chiao, C. (2001): “The Relationship between R&D and physical investment of firms in science-based industries”, *Applied economics* 33(1): 23-35

Cohen, W., Levinthal, D. (1990): “Absorptive Capacitiy; A New Perspective on Learning and Innovation”, *Administrative Science Quarterly*, 35(1): 128-152

Cohen, W. (2010): “Fifty Years of Empirical Studies of Innovative Activitiy and Performance”, *Handbook of the Economics of Innovation 1*: 129-213

Crépon, B., Emmanuel D., Mairessec, J. (1998): "Research, Innovation And Productivity: An Econometric Analysis at The Firm Level." *Economics of Innovation and new Technology*: 115-158.

Eisner, R. (1978): “Factors in Businesss Investment”, *NBER*

Grabowski, H., Mueller, D. (1972): “Managerial Stockholder Welfare Models of Firm Expenditures”, *The Review of Economics and Statistics* 54(1): 9-24

Lach, S., Rob, R. (1996): “R&D, Investment, and Industry Dynamics”, *Journal of Economics & Management Strategy* 5(2): 217-249

Lach, S., Schankerman, M. (1989): “Dynamics of R&D and Investment in the Sientific Sector.”, *Journal of Political Economiy* 97(4): 880-904

Lucas, R., Prescott, E. (1971): “Investment under Uncertainty”, *Econometrica* 39(5): 659-681

Nickell, S., Nicolitsas, D. (2000): “Does Innovation Encourage Investment in Fixed Capital”, Centre for Economic Performance, LSE

Polder, M., van Leeuwen, G., Mohnen, P., Raymond, W. (2010): „Product, Process and Organizational Innovation: Driver, Complementarity and Productivity Effects“, *CIRANO Scientific Publications*

Romer, P. (1990): “Endogenous Technological Change”, *Journal of Political Economy* 98(5): 71-102

Rosenberg, N. (1974): “Science, Invention and Economic Growth”, *The Economic Journal* 84(333): 90-108

Schmookler (1966): “Invention and Economic Growth”, *Harvad University Press*

Schumpeter, J. (1934): “The Theory of Economic Development”, *Harvard University Press*

Schumpeter, J. (1939): *“*Business cycles: a theoretical, historical, and statistical analysis of the capitalist process*”, NBER*

Toivanen, O., Stoneman, P. (1998): “Dynamics of R&D and Investment: UK Evidence.”, *Economic Letters* 58: 119-126

Woerter, M. (2014): “Competition and Persistence of R&D”, *Economics of Innovation and New Technology*23: 469-489

**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(Capital_stock)_ lag | 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" to "t"; 0 otherwise | 9805 | 0.36 | .48 | 0 | 1 |
| ln(R&D_expenditures) | 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 *outside of the firm* (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 |
| Number_of_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 | Qualitiative variable with 4 categories, "low" to "high" innovation constraints by govern. regulation | 8299 | 2.35 | 1.06 | 1 | 4 |

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

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

| | I | II | III | IV |
|---|---|---|---|---|
| DV: ln(Investment)$_t$ | RE | RE | GMM-SYS | FE |
| ln(R&D_exp)$_{avg(t-2,t-1,t)}$ | 0.067*** | 0.044*** | 0.071*** | 0.043*** |
| | (0.010) | (0.013) | (0.016) | (0.013) |
| R&D$_{sum(t-2,t-1,t)}$ | -0.566*** | -0.481*** | -0.626*** | -0.420*** |
| | (0.122) | (0.173) | (0.203) | (0.157) |
| ln(CapStock)$_{t-1}$ | | 0.552*** | | |
| | | (0.018) | | |
| ln(Investment)$_{t-1}$ | | | 0.136** | |
| | | | (0.060) | |
| ln(Sales)$_t$ | 0.878*** | 0.410*** | 0.776*** | 0.546*** |
| | (0.011) | (0.021) | (0.056) | (0.035) |
| Constant | -1.818*** | -2.376*** | -1.780*** | 3.972*** |
| | (0.179) | (0.252) | (0.339) | (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*

| | I | II | III | IV |
|---|---|---|---|---|
| DV: ln(Investment) in: | „t“ | „t“ | „t+3“ | „t+3“ |
| | 2SLS-RE | 2SLS-FE | 2SLS-RE | 2SLS-FE |
| $\ln(\text{R\&D\_expenditures})_{avg(t-2,t-1,t)}$ | 0.180*** | 0.237* | 0.209*** | 0.310* |
| | (0.048) | (0.125) | (0.055) | (0.186) |
| $\text{R\&D}_{sum(t-2,t-1,t)}$ | -1.893*** | -2.649* | -2.268*** | -3.476 |
| | (0.569) | (1.438) | (0.661) | (2.114) |
| $\ln(\text{Sales})_t$ | 0.851*** | 0.506*** | 0.815*** | 0.044 |
| | (0.018) | (0.043) | (0.024) | (0.066) |
| Constant | -1.513*** | 4.445*** | -0.672* | 12.343*** |
| | (0.306) | (0.687) | (0.387) | (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 Fixed Capital Innovations as an instrument*

| | I | II |
|---|---|---|
| DV: ln(R&D_expenditures) in: | „t“ | „t+3“ |
| | 2SLS-RE | 2SLS-RE |
| $\ln(\text{Investment})_t$ | 0.635 | 0.677 |
| | (0.542) | (0.822) |
| $\ln(\text{Sales})_t$ | 0.345 | 0.353 |
| | (0.500) | (0.775) |
| $\text{Tert\_educ\_share}_t$ | 0.053*** | 0.056*** |
| | (0.006) | (0.009) |
| $\text{Past\_demand}_t$ | 0.034 | 0.182* |
| | (0.078) | (0.099) |
| $\text{Number\_of\_competitors}_t$ | -0.221*** | -0.110* |
| | (0.042) | (0.059) |
| Constant | -12.191*** | -13.497*** |
| | (1.741) | (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(Inno_sales) in „t+3“ | I<br>RE | II<br>RE | III<br>RE | IV<br>Heckman | V<br>Heckman | VI<br>Heckman |
|---|---|---|---|---|---|---|
| $\ln(\text{Investment})_t$ | 0.047** | 0.045** | 0.009 | 0.047** | 0.045** | 0.000 |
| | (0.019) | (0.019) | (0.024) | (0.019) | (0.020) | (0.024) |
| $R\&D_{sum(t-2,t-1,t)}$ | | 0.168*** | -0.505 | | 0.166*** | -0.539 |
| | | (0.056) | (0.338) | | (0.056) | (0.341) |
| $R\&D_{sum(t-2,t-1,t)}*\ln(\text{Investment})_t$ | | | 0.050** | | | 0.053** |
| | | | (0.025) | | | (0.025) |
| $\ln(\text{Sales})_t$ | 0.864*** | 0.860*** | 0.862*** | 0.864*** | 0.860*** | 0.866*** |
| | (0.025) | (0.025) | (0.025) | (0.025) | (0.025) | (0.025) |
| $\text{Tert\_eudc\_share}_t$ | 0.008*** | 0.008*** | 0.008*** | 0.008*** | 0.007*** | 0.008*** |
| | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| $\text{Past\_demand}_t$ | 0.044** | 0.042* | 0.040* | 0.044** | 0.041* | 0.039* |
| | (0.021) | (0.021) | (0.021) | (0.021) | (0.021) | (0.021) |
| $\text{Number\_of\_competitors}_t$ | -0.007 | -0.005 | -0.008 | -0.008 | -0.005 | -0.007 |
| | (0.018) | (0.018) | (0.018) | (0.018) | (0.018) | (0.018) |
| Inverse_Millsratio | | | | 0.000 | 0.000 | 0.000 |
| | | | | (0.000) | (0.000) | (0.000) |
| Constant | -0.528 | -0.497 | -0.030 | -0.515 | -0.484 | 0.002 |
| | (0.347) | (0.347) | (0.416) | (0.348) | (0.347) | (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