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Do Firms Benefit from Complementarity Effect in R&D and What Drives their R&D Strategy Choices?*

U. Cantner^{†‡} and I. Savin^{† §}

Abstract

This paper analyzes whether firms conducting internal R&D and acquiring external high-tech equipment experience a complementarity effect. For German CIS data we conduct a complete set of indirect and direct complementarity tests refining the analysis by looking at various types of innovations and industries. Complementary effects are found in the indirect but not so in the direct approach. In contrast to previous literature, we find the distinct R&D strategy choices to be significant drivers of innovative activity and we identify contextual variables explaining the joint occurrence of the two strategies.

Keywords: *complementarity; equipment with embodied technology; innovation; internal R&D; Pavitt's sectoral taxonomy*

JEL Classification: O14, O31, O32, O33.

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1 Introduction

In the current competitive business environment, a firm's R&D activities are considered to create a competitive advantage. However, 'if you keep everything in-house, you will never generate as much' (Alexander and Young 1996). Rigby and Zook (2002) state that to develop innovations successfully firms cannot rely on internal R&D only, but also require knowledge and technologies from external sources. The question whether firms performing internal R&D and acquisition of external knowledge simultaneously demonstrate higher innovation performance than firms exploiting only one of the knowledge sources has received considerable attention in recent research on innovation.

Due to Cassiman and Veugelers (2006) firms can acquire external knowledge through licensing, R&D contracting, acquiring other firms or hiring qualified researchers that embody relevant knowledge. A further source is capital investment for technology acquisition as highlighted by many authors (e.g., Sakurai and Wyckoff (1996)), since many new technologies are in fact embodied in machinery and equipment. Quantitatively this external source is the second most important knowledge source, next to internal R&D (see Table 1). In this paper the joint implementation of internal R&D and acquisition of capital with embodied technology will be analyzed in terms of presumed complementarity effects between the two. As this relationship is not investigated yet, this paper can be considered as a further extension of research exploring complementarity effects¹ of internal and external innovation activities (see Grimpe and Hussinger (2013, p.689) and Catozzella and Vivarelli (2014, pp.180-182) for recent overviews). In doing so, we extend and go beyond that literature in taking on board *three* additional dimensions.

First, it is not clear whether the complementarity effect is present in all firms or whether that depends on the technological regime firms are operating in. Pavitt (1984) finds that supplier-dominated industries (SD), which include producers of personal goods and services (e.g., textile and food industries), are characterized by a lower technological content and a limited ability to develop new products and processes internally. Their dominant R&D strategy is typically based on acquisition of equipment with embodied technology, while they commonly lack the capability and resources to organize and maintain their own R&D. However, in specialized-supplier industries (SS), scale-intensive industries (SI) and science-based industries (SB),² which belong to technologically medium and higher advanced sectors, firms develop new technologies internally, while they also acquire machinery and equipment from suppliers (Castellacci 2008, Bogliacino and Pianta 2009). Therefore, we focus and distinguish between firms in SS, SI and SB industries, in which firms are more inclined to combine the two R&D strategies and potentially are subject to a stronger complementarity effect.

Secondly, in our analysis we furthermore look at different dimensions of the innovation performance and distinguish between different types of innovations, product innovations on the one hand and process innovations on the other. In case of product innovations, in turn, we consider radical or incremental only (depending on the degree of their novelty). Looking at process innovations we refer to Pavitt's sectoral taxonomy. There, in SI industries, users are more price sensitive, while in SB and SS industries users are rather both quality and price sensitive. The new contribution to the literature here is, whether and to

¹A *complementarity effect* shall be understood as an additional (i.e. complementary) positive effect to the marginal return of one activity given an increase in the intensity of use of the other (complementary) activity.

²The abbreviations are used henceforth in this paper.

what degree complementarity effects are prevalent when one considers and distinguishes these different types of innovations.

Third, by taking into account firms from the service sector we compare the difference in results obtained between manufacturing alone (on which the existing studies so far have been concentrating) and manufacturing with services together. By this we enrich the discussion of differences between manufacturing and services by the issue of complementarity.

We apply a two-step analytical approach to representative data drawn for Germany from the Community Innovation Survey (CIS) in 2005 and 2007. The empirical strategy of the paper is divided in two steps. In the first step, the adoption approach offers an indirect test for complementarities between internal R&D and external equipment with embodied technology, which implies a positive correlation between the adoption of the activities. In the second step, the productivity approach, which is a direct test for super-modularity through the regressions of innovation performances, measures whether the effect of the combined strategy significantly outperforms the effects of any single knowledge source.

As result of the first (adoption) step we find an indirect indication on the presence of complementarity effects together with six different contextual variables explaining the joint occurrence of internal R&D and external technology sourcing: appropriability conditions, R&D cooperation, importance of information from market sources, distance from productivity frontier, human capital and firm size. Interestingly, while the first one is found to be significant for all data subsamples (manufacturing vis-à-vis manufacturing and services, SI, SB and SS vis-à-vis total sample), the other five are identified only for certain subsamples. In the second (productivity) step we do not find complementarity effects for any type of innovative activity under investigation and in none of the subsamples considered. However, the instruments being constructed in the second step are found to be significant for the innovative outcomes illustrating that firms doing internal R&D and combining the two knowledge sources benefit in creating incremental innovations, while firms relying only on external embodied knowledge and having none of the two knowledge sources suffer from a worse performance in almost all types of innovative activities and in all technological regimes considered.

An additional interesting focus of the present paper is devoted to methodological aspects being important for empirical studies conducted in this area. In fact, one must be very careful in proceeding with this analysis. Among most frequently faced problems are i) self-selection bias,³ ii) improper specification of a null hypothesis,⁴ iii) concentration on the adoption approach only⁵ and iv) ignorance of possible endogeneity between R&D strategy choices of firms.⁶

The paper proceeds as follows. The next section provides a literature review together

³While some studies try to account for that by, e.g., the Heckman correction (Cassiman and Veugelers 2006), others simply ignore this important problem leading to biased estimates (see, e.g., Schmiedeberg (2008) and Catozzella and Vivarelli (2014)).

⁴While empirical researchers acknowledge importance to control probability of making a false statement, many empirical studies are still subject to type II errors (accepting a false null hypothesis), where the probability of error is not directly measurable, simply because their null hypothesis asserts presence of the complementarity effects. In contrast, formulating the null hypothesis asserting no complementarities and then being able to reject it with only a small probability of error (5 or 1% as it is common in literature) is clearly preferable.

⁵However, as we discuss in due course, this is subject to type I and type II errors because of unobserved heterogeneity between firms (Athey and Stern 1998).

⁶A good example addressing this issue is again presented by Cassiman and Veugelers (2006).

with hypotheses to be tested. Section 3 presents the data and the empirical strategy. In Section 4 empirical results are presented. Section 5 concludes.

2 Literature review and hypotheses

2.1 Internal R&D and capital with embodied technology

In order to preserve and sustain competitiveness and in light of the increasing costs, speed and complexity of technological change, it is no longer sufficient for a firm to invest only into internal R&D. Firms performing internal R&D only lack familiarity with new technologies generated elsewhere (Cassiman and Veugelers 2006), and depending on the importance of the external technologies for own innovative activities those firms need more time to create innovations and experience high risks due to a lower probability of innovation success (Alexander and Young 1996). As an example, pharmaceutical firms buy external research equipment with embodied technology related to their own research in order to increase the probability of discovering new medical products (Narula 2001).

A major source of external knowledge are investments in capital equipment. The embodied technologies are commonly used by firms to reduce costs, to increase own flexibility, improve quality and enter new markets (Hussey and Jenster 2003, Kakabadse and Kakabadse 2005). Indeed, firms in metal, semiconductor and electronic industries prefer to buy equipment with embodied technology (e.g., entire assemble lines) to reduce costs and save time of creating innovations (Ganotakis and Love 2012).

However, relying entirely on external equipment with embodied technology is not sufficient to preserve and sustain competitiveness either for the following reasons. First, because through external sourcing firms are only able to obtain codified knowledge, not the entire accumulated technological knowledge. Secondly, firms lack understanding of up-to-date technologies. Therefore, they may not be able to reproduce and improve them, which negatively affects their invention capacity (Sakurai and Wyckoff 1996, Veugelers 1997). As a consequence of the lack of internal R&D competencies firm's revenues may be reduced on the one hand and, on the other hand, further investments in acquisition of external technology may be prohibited. Cohen and Levinthal (1989) argue that semiconductor firms invest in R&D to preserve an in-house technical capability to assimilate new technologies developed elsewhere. Thus, firms' own in-house R&D activities are often considered as an important element of absorptive capacity in the medium and high tech sectors, increasing efficiency associated with external knowledge and allowing to modify and improve its usage (Cassiman and Veugelers 2006, Narula 2001).

As a summary, the combination of external technology sources and internal R&D allows firms to benefit from complementarities through the use of internal R&D that exploit external technologies more efficiently. Thus, the combination R&D strategy is supposed to have an advantage compared to any of the one-side alternatives:

Hypothesis 1: Firms conducting internal R&D and buying equipment with embodied technology (pursuing the combination strategy) experience a complementarity effect in their innovation performance.

The analysis of *H1* shows two dimensions. The first one is obviously complementarity. Here, although this issue itself has been addressed by several studies (see, e.g., Arora and Gambardella (1990), Cassiman and Veugelers (2006) and Schmiedeberg (2008)) we offer a methodologically complete analysis. And furthermore, we attempt to clarify in which sectors (manufacturing only or also in services; for which sectors of the Pavitt's

taxonomy) and for which indicators of innovative performance (e.g., product or process innovation) this complementarity effect can be identified and is most pronounced.

The second dimension addresses that finding complementarity effects themselves is not sufficient from the policy perspective, because a relevant question in this context is then: how policy makers can stimulate firms to use the combination strategy and explore those benefits from complementarities. A very useful concept for this was suggested by Cassiman and Veugelers (2006), who suggest particular '*contextual variables*': significant drivers of the combination strategy which do not affect other exclusive choices (make R&D internally only and buying external equipment only). In more detail we discuss this in Sections 3.2 and 4.

2.2 Pavitt's taxonomy

Whether and to which degree different R&D strategies are combined may depend also on some industry specific features of the innovation process. Based on the database on firm's innovations in the UK manufacturing sector, Pavitt (1984) classifies industries in four groups on the basis of technological regimes, the features of their production processes, market structures and other characteristics.

A recent challenge to this literature was constituted by the extension of the taxonomy to services. Castellacci (2008) and Bogliacino and Pianta (2009) reconsider the original Pavitt's taxonomy and include service industries in the four classes on the basis of the evidence on their technological activities. The resulting '*revised*' Pavitt's taxonomy can be summarized as follows.⁷

- (a) *Science-based industries (SB)* include sectors (such as pharmaceuticals, electronics, computer services) where innovation is based on R&D advances with research laboratories being an important source of product innovation. At the same time, these firms also may acquire external knowledge through cooperation with universities (Castellacci 2008) or through buying of equipment with embodied technology (Bogliacino and Pianta 2009).
- (b) *Specialised-supplier industries (SS)* include sectors producing machinery and equipment for other industries. Average firm size of this type of firms is small, and innovation is carried out in close cooperation with customers. Although internal R&D is seen as the most important innovative input, those firms also acquire external knowledge either from advanced users of new technologies (those firms that actually buy the equipments and machinery) or through acquiring machinery from other firms in this sector (Castellacci 2008).
- (c) *Scale-intensive industries (SI)* include sectors (such as the automotive sector and financial services) characterized by large economies of scale and oligopolistic markets, where technological change is usually incremental. The knowledge sources include both, internal R&D and equipment with embodied technology (Castellacci 2008, Bogliacino and Pianta 2009).

⁷See detailed explanation of the industry classification in Table 8 in Appendix. Necessarily, for some industries (like coke and refined petroleum) alternative allocation in the classification is possible. We try to follow the arguments from the literature (Pavitt 1984, Castellacci 2008, Bogliacino and Pianta 2009) and set up a classification serving best our needs.

- (d) *Supplier-dominated industries (SD)* include producers of final goods and services, characterized by a lower technological content compared to other three patterns and a limited ability to develop new products and processes internally. Their dominant innovation strategy is typically based on the acquisition of machinery and equipment to obtain new technologies, while firms in these industries commonly lack the capability and resources to organize and maintain their own R&D. Thus, they rely on the external acquisition of knowledge from their suppliers (Castellacci 2008, Bogliacino and Pianta 2009).

Based on this classification, among the four technological regimes described, in SB, SS and SI sectors firms are inclined to choose between four R&D strategies: internal R&D only, acquisition of equipment with embodied technology only, the combination strategy of the two knowledge sources and none of them. In the following we also distinguish between these three sectors together and the total sample.

2.3 Radical and incremental product innovations

To measure a firm's innovative performance related to new products and services, we distinguish between two types of innovations, radical and incremental ones. They basically differ with respect to their degree of novelty.

Incremental innovation is defined as a new product for a firm, which is also called as firm's novelty. Incremental innovations focus on existing products and services with the aim to improve their ability to create value for the firm or to improve and exploit existing technological trajectories (Sofka *et al.* 2009, Cantner and Meder 2007). In contrast, radical innovations are more disruptive and risky. They present major changes of products leading to obsolescence of existing designs and technologies and introducing new technological trajectories (novelty for a market).

Because of higher technological dynamics and rapid changes in user needs in the SB and SS industries, firms in those sectors are expected to have a high degree of novelty of their products, which implies that more radical innovations should be observed in those two sectors. In contrast, firms in the SI industries may have a lower level of novelty in their products resulting in more incremental innovations (Castellacci 2008).

Taking into account the complementarity effect of performing both internal R&D and acquisition of external equipment with embodied technology (the combination R&D strategy) discussed earlier and distinguishing between radical and incremental product innovations, the following hypotheses are suggested:

Hypothesis 2a: Firms using the combination R&D strategy in SI industries experience a higher performance in producing incremental innovations than firms exploiting only one of the knowledge sources.

Hypothesis 2b: Respectively, firms employing the combination R&D strategy in SB and SS industries experience a higher performance in creating radical innovations than firms exploiting only one of the knowledge sources.

2.4 Quality innovation and cost reducing innovation

As discussed above, firms using the combination R&D strategy might demonstrate a higher innovation performance than firms using only one of the knowledge sources. As innovative performance includes new products and processes, the combination strategy

may also affect success in process innovations. Rammer *et al.* (2009) argue that a successful introduction of new processes (by means of new technologies) can basically yield to two different types of outputs: a decrease in unit costs of production (cost reduction) or an increase in the quality of production processes (quality improvement).

According to Pavitt's taxonomy, requirements of users are different in SI, SB and SS industry patterns. In the SI industries, users are more price sensitive, which implies price competition and a higher attention to cost reducing process innovations. Thus, plastic, automobile and metal manufacturing firms give more attention to costs attracting more price sensitive customers. Contrary, in the SB and SS industries, users are both quality and price sensitive, which leads to quality and price competition on the market. For example, firms in electronic and pharmaceutical industries intensively compete on both, quality and prices (Pavitt 1984). Thus, we propose the following hypotheses:

Hypothesis 3a: In the SI industries, firms using the combination strategy demonstrate a higher cost reducing performance than firms using only one of the knowledge sources.

Hypothesis 3b: In the SB and SS industries, firms employing the combination strategy demonstrate both a higher quality and a higher cost reducing performance than firms using only one of the knowledge sources.

3 Data and empirical strategy

3.1 Data

We use data from the Mannheim Innovation Panel (MIP), which is a project of the Centre for European Economic Research (ZEW) and focuses on German firms that have at least five employees. The dataset covers a representative sample of the German manufacturing sector and business-related services. MIP is a part of the Community Innovation Survey (CIS) of the European Union. Thus, the MIP methodology fully complies with the CIS standards and follows Oslo manual (2005).

In our study, only the surveys for 2005 and 2007 are employed, which provide information on firms' innovation activities during the three years preceding the survey. We investigate the R&D activities (internal R&D and acquisition of capital with embodied technology) reported in 2005 and innovation performance from the survey in 2007 in order to reduce the problem of the simultaneity bias.⁸ In contrast to existing literature (Schmiedeberg 2008, Cassiman and Veugelers 2006), we neither restrict our sample only to those firms, which innovated in the respective period, nor to the manufacturing sector alone. The motivation for this choice is twofold. First, we avoid the self-selection bias⁹ by investigating the complementarity effect not only for those firms which innovated in the subsequent period, but for all firms with data available. Second, we can gain a valuable insight on whether the complementarity effect is present for the service sector, which to our knowledge is not analyzed yet.

⁸Unfortunately, due to i) small portion of firms repeatedly surveyed in MIP and ii) changes in the questions included into the surveys from other years, it is not yet possible to construct a panel suitable for a more comprehensive empirical analysis.

⁹The self-selection bias is a severe problem for many empirical studies assessing the complementarity effect. Although some approaches have been developed to address this problem, e.g., Heckman correction, those are efficient only under certain circumstances and are always inferior to estimations conducted on a full sample, i.e. without self-selection (Puhani 2000).

After excluding observations with missings, the pooled cross-sectional dataset contains 786 firms (446 for manufacturing and 330 for services, respectively). It includes 170 firms from SD industries (e.g., textiles, clothing, food, wood, wholesale trade), 237 firms from SS industries (machinery, equipment and their renting), 170 firms from SI industries (metals, motor vehicles, financial intermediation) and 134 firms from SB industries (chemicals, computers, telecommunication services). The remaining 75 firms are not attributed to any sector (not elsewhere specified, n.e.s. henceforth).

Table 1 shows shares of different types of R&D expenditures in sales indicating that firms spend about 90% of their overall R&D spending on internal R&D and acquisition of (external) equipment and machinery, while other posts (external R&D and external knowledge) together constitute the remaining. This allows us to exclude those two knowledge sources with the lowest budget shares from further considerations.

Table 1: Share of different types of R&D expenditure in sales (2005)

Variable	Mean	Standard deviation
Internal R&D	3.23%	0.39%
External R&D	0.35%	0.05%
External equipment and machinery	1.91%	0.24%
External knowledge	0.17%	0.04%

The two core variables, internal R&D and equipment with embodied technology, being binarized as explained later (the *Make* R&D strategy and the *Buy* R&D strategy) are positively and significantly (at the 5% significance level) correlated (Tetrachoric correlation equals 0.66 versus 0.18 by Cassiman and Veugelers (2006)), which is consistent with our expectation on the complementarity effect between them.

Table 2 summarizes information about the firms' R&D activities according to the Pavitt's taxonomy. In particular, it indicates which type of companies performs internal R&D and/or acquisition of capital with embodied technology. The variables listed are constructed on an *exclusive* basis (e.g., internal R&D only) and will be later referred to as exclusive choice variables (*MakeOnly*, *BuyOnly*, *Make&Buy*, *NoMake&Buy*). Clearly, in SS, SI and SB industries the option *Make&Buy* belongs to the most preferred strategy (between 45% and 70% of firms use it), while in SD industries, firms are almost equally distributed between using external equipment only, both or none of the knowledge sources. This finding supports our argument in Section 2.2 and in the following we distinguish between SS, SB and SI industries together on the one side and the entire dataset on the other one.

Table 3 provides information on the firms' success rates in different product and process innovation directions, again according to Pavitt's taxonomy. In particular, it summarizes proportions of firms which introduced respective product and/or process innovations in 2007 (the subsequent period). One can see that radical innovations have been mostly generated by firms in SS and SB industries, while incremental innovations being the most frequent innovation activity are very common for all four Pavitt's sectors. As for process innovations, firms from SS and SB sectors in fact tend to introduce both quality and cost reducing innovations, while there is no clear indication that firms from SI sector generate more cost reducing than quality innovations, rather the opposite.

Table 2: Frequency of R&D strategies (2005)

	SD industries	SS industries	SI industries	SB industries	N.e.s
No internal R&D/No acquisition of capital with embodied technology (<i>NoMake&Buy</i>)	33%	25%	31%	10%	44%
Internal R&D only (<i>MakeOnly</i>)	7%	9%	9%	10%	4%
Acquisition of capital with embodied technology only (<i>BuyOnly</i>)	28%	20%	15%	10%	25%
Combination strategy (<i>Make&Buy</i>)	32%	46%	45%	70%	27%
Number of firms	170	237	170	134	75

Table 3: Frequency of different types of innovations (2007)

	SD industries	SS industries	SI industries	SB industries	N.e.s
Radical innovation	32%	40%	38%	51%	19%
Incremental innovation	59%	63%	66%	80%	36%
Quality innovation	48%	50%	54%	69%	27%
Cost reducing innovation	52%	49%	47%	62%	28%

3.2 Empirical strategy

The test on the presence of a complementarity effect includes two steps: adoption approach and productivity approach, which have been implemented before in Arora and Gambardella (1990), Cassiman and Veugelers (2006) and Schmiedeberg (2008).

Adoption approach and contextual variables

The adoption approach uses variables indicating the *non-exclusive* choice of knowledge sources (internal R&D \equiv 'Make' or acquisition of capital with embodied technology \equiv 'Buy') as dependent variables in a bivariate probit model regressed conditionally on controlling factors, given by vector W_i . The adoption of the respective R&D strategy is¹⁰

$$\text{Make} = \alpha_1 W_i + u_i^{\text{int}}, \quad (1)$$

where

$$\text{Make} = \begin{cases} 1 & \text{if Internal R\&D} > 0 \\ 0 & \text{if Internal R\&D} = 0 \end{cases}$$

$$\text{Buy} = \alpha_2 W_i + u_i^{\text{ext}}, \quad (2)$$

¹⁰An alternative way to assign the two binary variables a positive value would be by selecting firms surpassing a certain threshold of spending their R&D budget on internal R&D or acquiring external equipment (see for an illustrative example Catozzella and Vivarelli (2014)). Particularly for the former case this could be justified by certain minimum level of absorptive capacity required to exploit advantages of external (embodied) technologies. However, a clear problem in such a case becomes to identify such a threshold value based on the underlying data. So far we leave this question for further research.

where

$$\text{Buy} = \begin{cases} 1 & \text{if Acquisition of capital} > 0 \\ 0 & \text{if Acquisition of capital} = 0. \end{cases}$$

Complementary activities according to this approach should be positively and significantly correlated via the error terms, $\text{Corr}(u_i^{\text{int}}, u_i^{\text{ext}}) > 0$. However, unobserved heterogeneity between firms may bias the result and lead either to false positives (accepting the hypothesis when there is no complementarity) or false negatives (rejecting the existence of complementarity when it is present) (Athey and Stern 1998, Cassiman and Veugelers 2006). For this reason a second step in testing complementarity, namely the productivity approach, is necessary (see below).

Furthermore, using the words of Cassiman and Veugelers (2006), we are also interested to find the so called '*contextual variables*': significant drivers of the combination strategy which do not affect other exclusive choices (MakeOnly and BuyOnly). In addition, those variables shall be significant in both bivariate probit regressions (1 and 2) indicating their indirect effect on adoption of the complementary activity (Cassiman and Veugelers 2006, p. 71). This investigation is additional to identifying the complementarity effect itself, as it helps to draw specific policy implications - what external factors may stimulate firms to combine the two knowledge sources and (potentially) benefit from it?

For testing these relationships, a multinomial logit model with a categorically distributed dependent variable *R&D Strategy*:

$$\text{R\&D Strategy} = \begin{cases} 0 & \text{if NoMake\&Buy (Make=0 \& Buy=0),} \\ 1 & \text{if MakeOnly (Make=1 \& Buy=0),} \\ 2 & \text{if BuyOnly (Make=0 \& Buy=1),} \\ 3 & \text{if Make\&Buy (Make=1 \& Buy=1)} \end{cases}$$

is estimated on a set of the firms' characteristics (W_i).¹¹ Multinomial logit is chosen due to less restrictive parameter assumptions imposed in comparison to a bivariate probit model. In particular, parameters affecting the combination strategy and exclusive knowledge sources can be different which is not the case in the bivariate probit, where only two non-exclusive outcomes are assessed (Cassiman and Veugelers 2006). Finally, the contextual variables identified will be included into the baseline bivariate probit model (with a minimum of explanatory controls) in order to reduce the observed positive correlation $\text{Corr}(u_i^{\text{int}}, u_i^{\text{ext}})$ and to validate their goodness in explaining the joint occurrence of innovation strategy choices (Make and Buy).

Productivity approach

The second step is the productivity approach, which is a direct test for supermodularity through regressions of innovation performance. Here $\text{Innovation}_{i,t}$ stands for either incremental, radical, quality or cost reducing innovation.

$$\text{Innovation}_{i,2007} = \beta_1 \text{MakeOnly}_{i,2005} + \beta_2 \text{BuyOnly}_{i,2005} + \beta_3 (\text{Make\&Buy}_{i,2005}) + \beta_4 (\text{NoMake\&Buy}_{i,2005}) + \beta' W_{i,2005} + \epsilon_i \quad (3)$$

¹¹The notation employed in the present study is largely in line with Cassiman and Veugelers (2006) to ease their comparison and understanding of results.

As many companies do not produce any innovations, the variable $Innovation_{i,t}$ is censored at zero. To overcome this problem, we estimate a tobit model.

In this model of innovation success we account for exclusive combinations of innovation activities (MakeOnly) and acquisition of equipment with embodied technology (BuyOnly) as well their interaction terms (NoMake&Buy and Make&Buy). The approach postulates that the complementarity effect is present *iff*

$$\beta_3 - \beta_1 \geq \beta_2 - \beta_4, \quad (4)$$

i.e. employing one source of knowledge acquisition while already using another one (here it is capital with embodied technology) should have a larger impact on the specific innovation performance than using only one source of knowledge (internal R&D) (Cassiman and Veugelers 2006, Schmiedeberg 2008). (4) is implemented by a one-sided Wald test of no complementarity, i.e. the null hypothesis postulates $\beta_3 - \beta_1 < \beta_2 - \beta_4$, which being rejected automatically leads to the conclusion on the presence of complementarity effects.¹²

The productivity approach requires that the explanatory variables on the right side in (3) are uncorrelated with the error term ϵ_i . This, however, may be a very strong assumption as the choice of the knowledge sources is an endogenous decision of firms in the context of their innovation strategy (see, e.g., Hammerschmidt (2009) and Egbetokun and Savin (2014)). Firm heterogeneity captured by ϵ_i may drive the choice of the knowledge sources, and therefore, as Cassiman and Veugelers (2006) suggest, it is more efficient to construct predictions of the innovation strategy (choice of knowledge sources) from the first step and employ those instruments in the productivity equation (3) naturally correcting the potential bias in the results (two-step approach).¹³

Variables description

As stated earlier, in the adoption approach the dependent variable is a binary choice variable between performing internal R&D ('Make') and performing acquisition of capital with embodied technology ('Buy'). While for the bivariate probit models these variables are non-exclusive, for the multinomial logit they are exclusive ones.

The explanatory variables we attribute into several groups, such as competition, innovation input, innovation conditions, a summary of which is also provided in Tables 9 and 10 in Appendix.

Competition. As an independent variable in the adoption approach we model the *productivity gap* to account for a potential existence of a catching up process in productivity levels. The issue is important at the micro level, where imitation may lead to convergence in productivity among competing firms. In order to find an accurate measure of this catching up process, we calculate the distance of firm's labor productivity to the highest productivity level in the respective industry (at 2-digit NACE level) in Germany:

¹²Note at this point that (4), testing whether buying equipment becomes more productive if one already does internal R&D, is equivalent to $\beta_3 - \beta_1 - \beta_2 + \beta_4 \geq 0$, which makes the approach also applicable for testing whether internal R&D as innovation strategy becomes more productive if one already buys equipment. Stating the null hypothesis with an opposite inequality sign would have created a problem to control the probability to incorrectly accepting it.

¹³For this to hold the models constructing predictions should have a good explanatory power, while the quality of predictions is of crucial importance, as remained noise may bias the results of the productivity approach. If, however, after employing the instruments results in (3) pass the test in (4), this may signal the actual complementarity between the two knowledge sources.

$$\text{Productivity gap}_{i,j} = \left(1 - \frac{a_{ij}}{\max(a_{ij})}\right) \in [0, 1], \quad (5)$$

where a_{ij} is a labor productivity of firm i in industry j .

To measure the level of *competition* on the market, we use the number of competitors in the main market as indicated by firm i . Facing a larger number of competitors on the market, the firm is expected to face more pressure to perform innovation activities. This variable is a categorical one, which is scaled between 1 and 4 (1 - no competitors, 2 - 1 to 5 competitors, 3 - 6 to 15 competitors, 4 - more than 15 competitors).¹⁴

Klomp and van Leeuwen (2001) find that firms which are involved in innovation cooperation demonstrate a significantly higher share of sales due to new products. *Cooperation* is measured by a binary variable equaling one in case the firm has an innovation cooperation and zero otherwise.

Innovation conditions. The surveyed firms had to rate the importance of several factors as obstacles to innovation. The variables are scaled between 0 (no) and 3 (high). Using component factor analysis and afterwards an orthogonal varimax rotation, we assign those variables into three groups of obstacles for innovation and combine in two factors, where the values have been added up.¹⁵ The first one is constituted by only one factor indicating *economic risk* ('economic risk too high'); the second one is related to *financial barriers* and includes factors 'innovation cost too high', 'lack of suitable internal sources of funding' and 'lack of suitable external sources of funding'; the third factor contains *organizational barriers*: 'organizational problems within firms', 'internal resistance', 'lack of skilled personnel', 'lack of information on technology', 'lack of information on market' and 'customers unresponsive to new products and process'. The resulting variables control for differences in the innovative conditions of firms and are suggested to influence innovation activities (Schmiedeberg 2008).

Appropriability conditions are measured by the success of knowledge protection (including patent, registered design, ornamental design, industry design, trademark, copyright, secrecy, complex design and head start). The surveyed firms were asked about the mechanism of protection, and their answers are scaled between 0 (low) and 3 (high). Laursen and Salter (2014) discuss the role of the appropriability strategies of firms in detail and, among others, argue for a strong and positive relation between firms' appropriability strategies and their openness in innovation search efforts (i.e. openness to external innovation sources such as suppliers, competitors and universities). However, as also indicated by Laursen and Salter (2014), this relationship is not linear but concave, and from a certain point strong appropriability strategies may lead to decline of openness to those external innovation sources. In this study we expect that good appropriability conditions should have a positive impact on the firms' innovation activities, particularly the external ones (equipment with embodied technology), but also the combination of internal and external strategies (see, e.g., Schmiedeberg (2008)).

Innovation input. The information sources of innovations are grouped into two variables (also based on component factor analysis): *market information* and *scientific information*. The surveyed firms had to rate the importance of eight potential informa-

¹⁴We acknowledge that the variable does not necessarily account for the actual level of competition on the market. However, other measures of competitiveness, such as the Lerner or Herfindahl indices are not available.

¹⁵Results are not included for the sake of brevity but may be obtained on request.

tion sources on a four-point scale ranging from 'not used' to 'high'. Each one of eight potential information sources is coded as a binary variable zero for 0-1 scale and one for 2-3 scale. The market information variable includes clients, suppliers, trade fairs and exhibitions, specialist journals and literature. The scientific information variable includes consultancy firms, universities and public, non-profit-making and private research institutions. To create these variables, the values of the information sources are added up for each information variable, respectively. Cassiman and Veugelers (2006) consider the rating of information sources as an indicator of the importance of incoming spillovers, which are expected to increase the probability of external innovation strategies.

The variable *human capital* is used as an indicator of absorptive capacity, which is measured by the share of employees having a university degree (Schmiedeberg 2008). *Innovation intensity* measures the share of total innovation expenditure (i.e. current innovation costs plus investment for innovation projects).

Further firm characteristics. It is important to control for presence of *public funding*. This is done by checking whether a firm received funding from at least one of the sources: Federal Region, Federal State, Federal Ministry of Economics and Technology, Federal Ministry of Education and Research, EU, European Commission and others.

Export intensity indicating the share of export in the firm's turnover and firm size (measured by number of employees¹⁶) are also included in our analysis.

Constants. Location, service and industry dummies (standing for the four sectors according to the Pavitt's taxonomy) are basic control variables, which are used in both, the adoption and the productivity approaches. We take into account differences between East and West Germany. East German firms have achieved less innovation output than West German firms, since they started from rather a lower technological level and need more time to build up innovative capabilities.

Regarding the second step of the analysis which measures the impact of innovation activities (Make and Buy decisions) on innovation performance, four innovation indicators of two groups (product innovation and process innovation) are used as dependent variables. *Incremental innovation* variable is measured by share of firm's sales from new products for the firm. *Radical innovation* variable is measured by share of firm's sales from new products for a market. *Quality innovation* variable is measured by share of firm's sales from products with quality improved by process innovations. *Cost reducing innovation* variable is measured by share of unit costs reduced through process innovations.

Central independent variables in the second step are predicted values of the firms' innovation strategies ('MakeOnly', 'BuyOnly', 'Make&Buy' and 'NoMake&Buy'). Control variables in the second step are the same as in the adoption approach.

4 Results

4.1 Adoption approach (indirect test)

Table 4 contains the results on the contextual variables related to the R&D strategies. In the multinomial logit model for different data subamples, the exclusive R&D strategy choices (Make, Buy and Make&Buy) are the dependent variables (NoMake&Buy is a benchmark). Among the variables tested appropriability conditions are consistently found to have a significant effect on the combination strategy (Make&Buy), while be-

¹⁶One could also use the firm's turnover instead, but this is a too volatile measure.

ing insignificant for the alternatives.¹⁷ Those conditions measuring the efficacy of firms' strategies in protecting own R&D in fact can stimulate firms to develop own technologies (which they can later turn into profits) and buy those technologies on the existing market. Interestingly, considering the manufacturing and services sectors together we also find those conditions to have a weakly significant effect on MakeOnly decision which, as also Cassiman and Veugelers (2006) find, indicates that firms favour internal R&D strategy under efficient intellectual property policy. Considering manufacturing industries alone the latter effect vanishes indicating that appropriability conditions stimulate firms to choose the combination R&D strategy and benefit from the complementarity effect. In both cases this is telling us that firms experiencing strong IP protection explore both sources of knowledge for their innovation activities.

Another three variables which seem to have a strong relation to the combination R&D strategy but which are not necessarily identified to be significant in all subsamples are *cooperation* (whether a firm has a cooperation partner in its R&D activity), *importance of market information* and *productivity gap*.¹⁸ The first variable is significantly associated with the combination strategy if we consider manufacturing and services together, while for manufacturing alone it is not always the case. Furthermore, cooperation is also significantly associated with MakeOnly decision indicating that a firm having an R&D partner tends to develop a new technology in its alliance more often than buying equipment with already embodied technology.

Importance of market information (from clients, suppliers, competitors), in contrast, tends to have a significant relation to combination strategy once we restrict our sample to most innovative Pavitt's sectors (SS, SB and SI). More specifically, for manufacturing alone this variable is also positively related to the BuyOnly decision: manufacturing firms valuing information from their suppliers tend to buy (potentially also from them) machines with embodied technologies, while in manufacturing and services together firms obtaining information from the market tend to develop technologies on their own.

Finally, evidence is found for firms in SS, SB and SI industries in manufacturing that being closer to the productivity frontier in their respective industries those firms tend to implement the combination strategy more often. Thus, we observe quite an opposite to a catching up process we have been assuming.

Overall, our findings demonstrate importance of a more detailed data analysis and that for different technological regimes and different sectors also different contextual variables, which stimulate them to choose the combination R&D strategy and exploit the complementarity between internal and external knowledge sourcing, can be found.

Next, in Table 5 we test the complementarity between the two innovation strategies by means of the adoption approach (weak test). While in Models 5.1, 5.3, 5.5 and 5.7 only a limited number of controls is included (firm size, innovation intensity, location and

¹⁷Another condition for 'contextual variables' being mentioned requires them to be also significant for both, Make and Buy, in the respective bivariate probit model in Table 5. To inform ahead, one can say that this condition holds in our study.

¹⁸Testing a subsample of firms from service sector only one finds appropriability conditions, human capital and firm size as contextual variables (all positively affecting adoption of the combination strategy). Considering SI, SB and SS sectors only firm size and appropriability conditions are also positively related to exclusive internal R&D strategy (i.e. the larger a firm is and the more secure it is in IP protection, the more R&D it does internally), while looking on all Pavitt's sectors in services one finds that human capital is not only positively related to the combination strategy, but also to the *BuyOnly* decision: the more absorptive capacity one has, the more likely it will try to source new knowledge from external equipment. More detailed results are available on request.

Table 4: Multinomial logit.

	Manufacturing only												Manufacturing and Service industries					
	SI, SB and SS industries 4.1				Total sample 4.2				SI, SB and SS industries 4.3				Total sample 4.4					
	MakeOnly	BuyOnly	Make&Buy	Yes	MakeOnly	BuyOnly	Make&Buy	Yes	MakeOnly	BuyOnly	Make&Buy	Yes	MakeOnly	BuyOnly	Make&Buy	Yes		
Productivity gap	-5.88	-3.47	-7.40**	Yes	-0.25	-0.62	-0.65	Yes	-1.95	-1.46	-1.99	Yes	-0.56	-0.49	-0.48	Yes		
Cooperation	1.30	0.81	1.37	Yes	2.48*	1.71	2.54**	Yes	2.61**	1.70	2.80**	Yes	1.32**	0.54	1.67***	Yes		
Competition	0.20	0.48	0.37	Yes	-0.03	0.31	0.08	Yes	-0.20	0.19	0.06	Yes	-0.09	0.11	-0.02	Yes		
Market information	0.07	0.34**	0.37***	Yes	-0.12	0.11	0.15	Yes	0.23*	0.08	0.36***	Yes	0.32***	0.23***	0.21***	Yes		
Scientific information	0.41	0.13	0.15	Yes	0.58	0.55	0.44	Yes	0.05	0.10	-0.08	Yes	0.29	0.23	0.20	Yes		
Public funding	2.59**	2.32***	1.79**	Yes	2.59***	2.88***	1.98***	Yes	3.16***	2.48***	2.02***	Yes	2.86***	2.72***	1.87***	Yes		
Appropriability	0.17	0.03	0.24**	Yes	0.10	-0.01	0.18**	Yes	0.15*	0.01	0.21***	Yes	0.11*	0.01	0.19***	Yes		
Economic risk	-0.34	-0.09	-0.16	Yes	-0.09	0.23	0.04	Yes	0.10	0.29	0.25	Yes	0.12	0.27	0.18	Yes		
Financial barriers	0.06	0.06	0.12	Yes	0.14	-0.11	-0.03	Yes	0.06	-0.08	-0.04	Yes	0.08	-0.04	-0.03	Yes		
Organizational barriers	0.05	0.06	0.12	Yes	0.02	0.05	0.10*	Yes	-0.05	-0.03	0.01	Yes	-0.01	-0.01	0.05	Yes		
Innovation intensity	48.29***	52.63***	57.44***	Yes	48.98***	51.89***	58.59***	Yes	11.20***	9.35**	12.54***	Yes	18.69***	18.71***	19.62***	Yes		
Export intensity	-0.61	-1.23	-0.80	Yes	0.45	-0.86	0.02	Yes	-0.08	-0.37	0.42	Yes	0.14	-0.31	0.59	Yes		
Human capital	0.01	-0.07***	-0.03	Yes	-0.01	-0.06***	-0.04***	Yes	0.02**	-0.01	0.01	Yes	0.01*	-0.01*	0.01	Yes		
Firm size	0.01	0.01	0.01	Yes	0.01	0.01	0.01*	Yes	0.01	-0.01	0.01**	Yes	0.01***	0.01	0.01***	Yes		
East Germany	0.03**	0.01	0.11	Yes	-0.06	0.32	0.07	Yes	-0.67**	-0.24	-0.33	Yes	0.40	0.07	-0.20	Yes		
Service sector				Yes				Yes	-1.42**	0.31	-0.86*	Yes	-1.13**	0.68*	-0.51	Yes		
Industry dummies				Yes				Yes				Yes				Yes		
Constant	-0.07	-1.19	1.67	Yes	-4.59**	-5.08***	-4.96***	Yes	-3.20	-5.27**	-2.33	Yes	-4.41***	-3.94***	-2.91***	Yes		
Pseudo R ²		0.39				0.37				0.36				0.34				
N		345				446				541				786				
χ ²		χ ² (51)=293.57***				χ ² (51)=376.05***				χ ² (54)=471.87***				χ ² (60)=667.23***				

***, **, * Statistically significant, respectively, at the 1, 5 and 10% level

industry dummies – variables which belong to more general factors explaining firms' R&D strategy choices¹⁹), in Models 5.2, 5.4, 5.6 and 5.8 the full set of explanatory variables (including the contextual variables identified by multinomial logit models) is applied. Relevant for complementarity is a positive significant correlation between the error terms of the Make regression and the Buy regression. We state that correlation $Corr(u_i^{int}, u_i^{ext})$ in the bottom of Table 5. As expected, the inclusion of additional variables reduces the correlation between the error terms, though it stays positive and significant.²⁰

Considering closer the reduction in the observed correlation, we see that this decrease is substantial in size but not significant.²¹ Overall, one can argue that the contextual variables identified explain a substantial portion in the co-occurrence of the two innovation strategies (conducting internal R&D and buying capital with embodied technology) but one might think of further instruments which could help to resolve this puzzle and be included in the future in the MIP questionnaire, such as characteristics of R&D teams, their past experience with alternative R&D strategies.

To sum up results from Table 5, we find a weak evidence of the complementarity effect between internal R&D (Make) and capital with embodied technology (Buy) for all data subsamples. As the contextual variables identified are also found to be significant for both R&D strategy choices and reduce the correlation in the error terms, it further supports our argument on their goodness.

4.2 Productivity approach (direct test)

Next, to apply the productivity approach we exogenize innovation strategy decisions (Make, Buy, Make&Buy and NoMake&Buy) by constructing their predictions from the adoption approach's full model specification and include those into the tobit models. We try both probit and logit model estimations with the same set of variables to see which alternative is more attractive. One of the problems we encountered is that by classifying forecasts generated into the categories with the predicted values $Pr(.)$ larger than the sample average $\bar{Pr}(.)$, we get a very large number of predictions (about 1400 which as about twice larger than number of actual cases) with a fairly low predictive power (about 40%), which is only marginally above random choice.²² To overcome this difficulty we apply the same models to the non-exclusive R&D strategy choices (*Make* and *Buy*) and after constructing predictions classify cases into categories based on a slightly different rule. In particular, the case is classified to be, e.g., *MakeOnly* if not only the forecasted probability of *Make* is above the sample's average, but also the probability of the opposite innovation strategy choice²³ is below its average:

¹⁹This limited set of variables is chosen well in line as done by Cassiman and Veugelers (2006).

²⁰Applying this exercise to the service sector only also reveals a positive and highly significant correlation in the error terms falling after including contextual variables: from 0.601 to 0.425.

²¹One should note at this point, however, that given the large confidence intervals for the correlation coefficients the reduction must have been very large (about two times higher) to become significant, which is hard to achieve given the limited number of explanatory variables in our study.

²²This is despite an even larger explanatory power of some of our models compared to Cassiman and Veugelers (2006) and mostly due to a large 'overshooting' in forecasting cases with the combination strategy (Make&Buy).

²³For this purpose we assume that *Make* is the opposite of *Buy* while *Make&Buy* is a coincidence of *Make* and *Buy*, and *NoMake&Buy* - is a coincidence of no *Make* and no *Buy*, see Section 3.2 on how exclusive R&D strategies have been formulated.

Table 5: Bivariate probit.

	Manufacturing only															
	SI, SB and SS industries				Total sample				SI, SB and SS industries				Manufacturing and Service industries			
	5.1		5.2		5.3		5.4		5.5		5.6		5.7		5.8	
Make	Buy	Make	Buy	Make	Buy	Make	Buy	Make	Buy	Make	Buy	Make	Buy	Make	Buy	
Productivity gap																
Cooperation																
Competition																
Market information																
Scientific information																
Public funding																
Appropriability																
Economic risk																
Financial barriers																
Organizational barriers																
Export intensity																
Human capital																
Innovation intensity																
Firm size																
East Germany																
Service sector																
Industry dummies																
Constant																
N	345	345	446	446	446	446	446	446	541	541	541	541	786	786	786	786
$Corr(u_i^{int}, u_i^{ext})$	0.513***	0.373***	0.519***	0.519***	0.519***	0.519***	0.519***	0.519***	0.551***	0.551***	0.396***	0.396***	0.579***	0.579***	0.407***	0.407***
Δ in $Corr(u_i^{int}, u_i^{ext})$		0.140		0.148		0.148		0.148		0.155		0.155		0.172		0.172

***, **, * Statistically significant, respectively, at the 1, 5 and 10% level

$$\begin{aligned} \text{MakeOnly} &= \begin{cases} 1 & \text{if } \Pr(\text{Make}) > \bar{Pr}(\text{Make}) \ \& \ \Pr(\text{Buy}) < \bar{Pr}(\text{Buy}), \\ 0 & \text{otherwise.} \end{cases} \\ \text{BuyOnly} &= \begin{cases} 1 & \text{if } \Pr(\text{Buy}) > \bar{Pr}(\text{Buy}) \ \& \ \Pr(\text{Make}) < \bar{Pr}(\text{Make}), \\ 0 & \text{otherwise.} \end{cases} \\ \text{Make\&Buy} &= \begin{cases} 1 & \text{if } \Pr(\text{Make}) > \bar{Pr}(\text{Make}) \ \& \ \Pr(\text{BuyOnly}) > \bar{Pr}(\text{Buy}), \\ 0 & \text{otherwise.} \end{cases} \\ \text{NoMake\&Buy} &= \begin{cases} 1 & \text{if } \Pr(\text{Make}) < \bar{Pr}(\text{Make}) \ \& \ \Pr(\text{MakeOnly}) < \bar{Pr}(\text{Make}), \\ 0 & \text{otherwise.} \end{cases} \end{aligned}$$

Thanks to this classification approach the number of predicted cases coincides with actual number of firms,²⁴ while percentage of correctly predicted cases rises to about 61% for both, logit and probit models with logit models providing marginally better results.²⁵ In Table 6 we report results of forecasts produced on the total sample only (manufacturing and services, all four Pavitt’s sectors), while further results are available on request. Clearly, the relatively good prediction results are mainly due to good identification of the combination R&D strategies and the absence of any R&D activity, while exclusive choices (*MakeOnly* and *BuyOnly*) are still poorly predicted. However, although the quality of forecasts remains a subject for further improvement (e.g., through inclusion of additional explanatory variables mentioned before), it shall be preferred to the alternatives and be used as predictions of exclusive R&D strategy choices in the tobit models.

Table 6: Real versus Forecasted R&D Strategy Choices

		Forecasts			
		<i>NoMake&Buy</i>	<i>MakeOnly</i>	<i>BuyOnly</i>	<i>Make&Buy</i>
		(260)	(29)	(141)	(356)
Probit	<i>NoMake&Buy</i> (215)	158	5	33	19
	<i>MakeOnly</i> (66)	10	5	10	41
	<i>BuyOnly</i> (153)	49	1	62	40
	<i>Make&Buy</i> (353)	43	18	36	256
		Forecasts			
		<i>NoMake&Buy</i>	<i>MakeOnly</i>	<i>BuyOnly</i>	<i>Make&Buy</i>
		(262)	(35)	(141)	(348)
Logit	<i>NoMake&Buy</i> (215)	161	6	32	16
	<i>MakeOnly</i> (66)	12	5	9	40
	<i>BuyOnly</i> (153)	49	2	63	38
	<i>Make&Buy</i> (353)	40	22	37	254

In Table 7 results of the two-step productivity approach with only predicted instruments as explanatory variables being included are provided (results of models where instruments and all control variables included are presented in Table 11 in Appendix), where the upper panel contains models tested for the manufacturing sector only, while the

²⁴So that the four constructed variables in sum form a vector of ones and allow us not to include a constant in the productivity approach estimations.

²⁵If one would concentrate only on SI, SB and SS industries or only on manufacturing, the goodness of forecasts rises to 65-70%.

lower one - for manufacturing and services together.²⁶ The reason why we concentrate on those parsimonious models is that the effects from the other control variables is already captured by the instruments and inclusion of the controls leads to severe multicollinearity problems. This is also evident from the regression coefficients of the distinct R&D strategy choices in Table 11, which often remaining still significant turn into large negative values.

First of all, one has to admit that no significant complementarity effects are identified from our two-step approach. One also does not find the combination strategy to have a significant complementary effect on any type of innovative activity in SB, SS and SI sectors – something we were expecting by formulating our hypotheses *H2a-H3b*.²⁷ This may be due to still some weak instrumental variables we use (though their goodness is better than in past literature (Cassiman and Veugelers 2006)), but also due to general problem of identifying the complementarity effects and realize benefits from innovation within such a short time frame (2-3 years in our case). The former reason can be illustrated by the type of bias our constructed forecasts (Table 6) demonstrate. In particular, it is clear that the *MakeOnly* strategy choice is not only underestimated in comparison to its actual frequency, but in the majority of cases this strategy choice is attributed to firms which in reality have been using the combination *Make&Buy* strategy. Due to this reason, the β_3 coefficient of the combination strategy may be underestimated (biased downwards), while β_1 coefficient of the *MakeOnly* strategy may be overestimated (biased upwards).²⁸ Hence, our results in Table 7 tend to be biased in direction of type I error (incorrect rejection of a true null hypothesis).²⁹ In our opinion, however, it is better that the bias present is this direction than in the one of type II error (accepting a false hypothesis), since the latter is already the dominant one in economic literature leading to adverse effects on policy making (see Bruns (2013) and Doucouliagos and Stanley (2001) for a discussion).³⁰

Comparing our study with past literature in this area, a distinct advantage of our application is the fact that the instrumental variables are found to be significant for the different innovative outputs and different subsamples.³¹ In particular, we find that

²⁶Here we report results obtained based on forecasts from logit models only, while results for probit models are very similar and can be obtained on request. Also we applied the same procedure on firms from the service sector only. Again, results are very similar and are available upon request.

²⁷Note that it is meaningless to compare the resulting regression coefficients between models in Table 7 since the samples analysed are not random and, therefore, variance in the samples is different making such analysis impossible. The only meaningful approach would have been to find a significant complementarity effect in one of the samples analysed and compare it versus the other samples. However, this is not the case in our study.

²⁸This conjecture holds conditional that the complementarity effects are in fact present and there are synergies from using the two R&D sources together, so that one shall expect $\beta_3 > \beta_1$.

²⁹To substantiate this we run an alternative set of regressions in which we use instead of the forecasted values of the R&D strategies the actual ones. The results are provided in Table 12 in Appendix. There we find for β_1 when significant some lower values, especially when considering manufacturing only, indicating the upward bias in case of using the instruments. Taking into account the difference between β_3 and β_1 measured in the complementarity test in (4), this supports the claimed downward bias of this test in Table 7.

³⁰Important to note at this point that we also tested our data set with a null hypothesis asserting presence of complementarity effects. In that case in five out of 26 models the null hypothesis was not rejected. However, this result cannot be considered as evidence signalling presence of the complementarities for the reasons stated earlier.

³¹Remember that Cassiman and Veugelers (2006) in their study do not find any significancies, while Schmiedeberg (2008) uses not instruments but R&D choices themselves which makes her findings vulnerable to sample selection bias discussed by Cassiman and Veugelers (2006, p. 29).

Table 7: Productivity Regressions by Tobit models and Two-Step Approach

	SI, SB and SS industries			Total sample			SI, SB and SS						
	7.1 Increm.	7.2 Radical	7.3 Quality	7.4 Cost	7.5 Increm.	7.6 Radical	7.7 Quality	7.8 Cost	7.9 Increm.	7.10 Radical	7.11 Cost	7.12 Cost	7.13 Quality
Manufacturing only													
MakeOnly	21.46***	-4.55	-7.34	0.84	26.35***	1.06	-8.94	4.75	23.00*	-5.28	6.31	-0.85	-9.37*
BuyOnly	13.38**	-20.98***	-8.91*	-7.56*	10.24*	-27.52***	-9.62**	-4.50	-6.84	-11.59	-8.16*	-2.88	-9.26
Make&Buy	25.55***	-0.95	-0.67	-0.51	24.65***	-1.15***	-1.05	0.39	24.54***	-0.32	2.07	-2.34	-2.02
NoMake&Buy	-5.83	-29.21***	-15.43***	-15.75***	-7.44**	-28.12***	-16.20***	-15.65***	-9.52*	-22.90	-10.75***	-18.75***	-14.90***
<i>N</i>	300	303	210	223	393	392	279	295	125	176	113	110	104
Complementarity													
<i>F</i> test	2.24	0.18	0.00	0.22	5.09	0.09	0.03	8.07	0.00	0.19	0.45	2.47	0.03
Services													
MakeOnly	25.36***	-3.72	-4.91	-1.69	13.61***	-10.49*	-14.51**	-5.00	10.71	0.15	-3.64	-0.47	-9.64
BuyOnly	-10.55**	-34.92***	-12.97***	-13.26***	-9.96***	-29.62***	-14.96***	-12.24***	-10.18	-30.44***	-11.17**	-14.28***	-13.64***
Make&Buy	25.32***	-3.69*	-3.08	-4.06***	23.63***	-3.98**	-3.26*	-2.44*	22.26***	-3.09	-1.80	-5.22**	-4.90*
NoMake&Buy	-15.24***	-40.00***	-21.97***	-19.96***	-16.49***	-42.41***	-26.26***	-19.45***	-11.56**	-42.56***	-13.37***	-27.05***	-26.61***
<i>N</i>	468	468	356	372	681	683	536	557	142	324	131	241	234
Complementarity													
<i>F</i> test	0.63	0.22	0.99	0.21	0.22	0.60	0.01	0.08	0.30	1.45	2.14	4.43	0.68

***, **, * Statistically significant, respectively, at the 1, 5 and 10% level. Note also that the sample size *N* is varying for the four types of innovations depending on the number of observations available. Thus, for example, incremental and radical innovations have been indicated in the MIP questionnaire from 2007 clearly more often than process innovations. In order not to reduce the sample size too much and allow for subsequent verification of hypotheses *H2a-H2b* we include all those observations available provided that the set of explanatory variables (from the year 2005) is balanced.

the combination strategy has a consistently positive and significant effect on incremental innovations. An exclusive internal R&D choice also in most of subsamples considered has a positive and significant effect on incremental innovations. An exclusive external equipment strategy choice, in contrast, has mostly a negative effect not only on incremental but also radical innovations, while for process innovations this is only the case when considering manufacturing and services together. An exclusion from this rule is the case of incremental innovations in manufacturing only where firms seem to experience a positive impact on their innovative activity from buying external equipment as the only R&D strategy. Finally, absence of any R&D strategy (*NoMake&Buy*) has a consistently negative effect on all types of innovations and in almost all subsamples. However, while in certain cases the combination strategy has a larger effect on innovative activity than the exclusively internal R&D strategy choice (e.g., incremental innovations in manufacturing and services together), in other subsamples (like incremental innovations by manufacturing firms only) this is not the case.

Overall, based on the findings obtained one has only an indirect sign of the complementarities present between internal R&D and capital with embodied technology in the adoption approach, but one cannot reject the null hypotheses of no complementarity effects present (opposite of the test in (4)) in the two-step productivity approach in any of the subsamples we have investigated in this study. Nevertheless, distinguishing between manufacturing and services and also between different technological regimes according to the Pavitt's taxonomy one finds a considerably richer set of so-called contextual variables which drive firms preferring either the combination R&D strategy or an exclusive source of knowledge (see Section 4.1).

5 Conclusion

In this paper we have been investigating the presence of the complementarity effect between internal R&D and acquisition of equipment with embodied technology on firms' innovative performance. Doing this we were distinguishing between underlying technological regime (according to revised Pavitt's taxonomy) and the type of innovative performance recorded: radical, incremental, quality improving and/or cost reducing innovation. In addition, we have been comparing results for manufacturing sector alone and manufacturing and services taken together. The complementarity test applied consists of the adoption and productivity approach.

The present study has several important findings. First, by a more detailed analysis of firms (whether they belong to manufacturing or services and to which technological regime) we find a broader list of indicators which may stimulate firms to prefer the combination R&D strategy sourcing knowledge from internal R&D and buying it embodied in external equipment elsewhere. These are firms' efficiency of IP protection, R&D cooperation, importance of information from market sources, distance from productivity frontier, human capital and firm size. While the first one is consequently identified for all data subsamples considered, the significance of others is dependent on the type of firm we are analyzing.³²

³²For example, considering the service sector alone, two variables (firm size and human capital) have been identified as contextual while being insignificant in the total sample or manufacturing and services being pooled together. Thus, one finds differences between firms producing goods and services. However, when it comes to the identification of complementarity effects, the two sectors have shown similar results: presence of those effects demonstrated by the indirect adoption approach and no complementarities

Second, the presence of complementarity effects being indicated by a weak test from adoption approach is not confirmed for any type of innovations by the productivity approach. This, as discussed in previous section, may be due to overidentification of the combination strategy in cases where firms in fact were applying internal R&D strategy.

In addition, despite the insignificances identified, the instruments being constructed in the second step are found to be significant for the innovative outcomes illustrating that firms doing internal R&D and combining the two knowledge sources benefit in creating incremental innovations, while firms relying only on external embodied knowledge or having none of the two knowledge sources suffer from a worse performance in almost all types of innovative activities and in all technological regimes considered.

Overall, we believe that our results not only indicate the presence of different contextual variables, but - maybe even more importantly - the importance to conduct the quite particular complementarity analysis but also the more general empirical analysis by looking more accurately on what type of firms and what type of innovations are considered. Pooling all the data into one model (as it was done before in literature) may not provide such detailed findings. Another important methodological aspect of the present paper is that one must be very careful in proceeding with this type of empirical analysis. As it has been stated before, the indirect complementarity test is insufficient since it is subject both to type I and type II errors. Important, however, to keep in mind is that also the productivity approach relying on instruments constructed may be a subject for those two types of errors. Based on a comparison of the actual vs. forecasted strategy choices, in the current study we argue that the type I error is more likely to be present. Despite all the drawbacks related to this, it is in our view still better to rather reject a true null hypothesis than accept a false one in order not to produce an adverse picture for policy makers, who are expected to be main beneficiaries of our research.

As for further research, one can think of inclusion of additional indicators explaining the correlation between internal R&D and acquisition of capital with embodied technology (possible contextual variables) like, e.g., characteristics of R&D teams and their past experience with the alternative R&D strategies.³³ One could also explore possible presence of the complementarity effects once a certain threshold of internal R&D has been reached (similar to what was done in Catozzella and Vivarelli (2014)). Another important extension of analysis is to exploit advantages of a panel data structure with multiple time periods.

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identified by the direct productivity approach.

³³Inclusion of those controls shall also contribute to further improvement of instruments in the productivity approach helping to identify presence of complementarity effects.

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6 Appendix

Table 8: Revised Pavitt's sectoral taxonomy

Pavitt's sector	Industry	NACE 2-digit
Science-Based	Coke, refined petroleum products and nuclear fuel	23
	Chemicals and chemical products	24
	Office machinery and computers	30
	Electrical machinery and apparatus n.e.c.	31
	Radio, television and communication equipment	32
	<i>Post and telecommunications</i>	64
	<i>Computer and related activities</i>	72
	<i>Research and development</i>	73
Scale-Intensive	Rubber and plastic products	25
	Other non-metallic mineral products	26
	Basic metals	27
	Fabricated metal products, except machinery and equipment	28
	Motor vehicles, trailers and semi-trailers	34
	Other transport equipment (ships, railway, aircraft, spacecraft)	35
	<i>Financial intermediation, except insurance and pension funding</i>	65
	<i>Insurance and pension funding, except compulsory social security</i>	66
	<i>Activities auxiliary to financial intermediation</i>	67
Specialized-Supplier	Machinery and equipment n.e.c. (including weapons, ammunition, domestic appliances)	29
	Medical, precision and optical instruments, watches and clocks	33
	<i>Real estate activities</i>	70
	<i>Renting of machinery, equipment, personal and household goods</i>	71
	<i>Other business activities (incl. legal, accounting, book-keeping)</i>	74
Supplier-Dominated	Food products and beverages	15
	Tabacco products	16
	Textiles	17
	Wearing apparel; dressing and dyeing of fur	18
	Leather and leather products	19
	Wood and wood products	20
	Pulp, paper and paper products	21
	Publishing, printing and reproduction of recorded media	22
	Furniture, jewellery, musical instruments manufacturing n.e.c.	36
	Recycling	37
	<i>Sale, maintenance and repair of motor vehicles and motorcycles</i>	50
	<i>Wholesale trade and commission trade, except of motor vehicles</i>	51
	<i>Retail trade, except of motor vehicles, repair of personal and household goods</i>	52
	<i>Hotels and restaurants</i>	55
	<i>Land transport, transport via pipelines</i>	60
<i>Water transport</i>	61	
<i>Air transport</i>	62	
	<i>Supporting and auxiliary transport activities</i>	63

Note: NACE classification is verified with the German Classification of Economic Activities, Edition 2003, used in MIP database. Service industries are in italics.

Table 9: Description of the variables used

Innovation	Incremental innovation	Share of sales from new products for the firm (in relation to total turnover) in the MIP survey in 2007
	Radical innovation	Share of sales from new products for the market (in relation to total turnover) in 2007
	Quality innovation	Share of sales from quality improvement innovation (in relation to total turnover) in 2007
	Cost reducing innovation	Share of cost reduction by process innovation (in relation to total turnover) in 2007
R&D strategy	Internal R&D (<i>Make</i>)	Binary (1 if a firm performed internal R&D activities) in 2005
	Acquisition of capital (<i>Buy</i>)	Binary (1 if a firm performed acquisition of equipment with embodied technology) in 2005
	Internal R&D only (<i>MakeOnly</i>)	Binary (1 if a firm performed <i>only</i> internal R&D activities) in 2005
	Acquisition of capital only (<i>BuyOnly</i>)	Binary (1 if a firm performed <i>only</i> acquisition of equipment with embodied technology) in 2005
	Combination strategy (<i>Make&Buy</i>)	Binary (1 if a firm performed <i>both</i> , internal R&D activities and acquisition of equipment with embodied technology) in 2005
	No R&D Strategy (<i>NoMake&Buy</i>)	Binary (1 if a firm performed <i>neither</i> internal R&D activities nor acquisition of equipment with embodied technology) in 2005
Competition	Productivity gap	Percentage difference between the firm's labour productivity and productivity frontier in the respective NACE 2-digit industry in 2005
	Cooperation	Binary (1 if the firm has innovation cooperations) in 2005
	Competition	Number of main competitors (1 if no, 2 if 1-5, 3 if 6-15, 4 if more than 15) in 2005
Innovation input	Market information	Importance of information from market sources (clients, suppliers, competitors, trade fairs and exhibitions, specialist journals and literature) in 2005
	Scientific information	Importance of information from scientific sources (consultancy firms, universities, public, non-profit-making and private research institutions) in 2005
	Human capital	Share of employees holding a university degree (in relation to total number of employees) in 2005
	Innovation intensity	Share of innovation expenditure in the turnover in 2005
Innovation conditions	Appropriability	Efficiency of mechanisms protecting intellectual property (including patent, registered design, ornamental design, industry design, trademark, copyright, secrecy, complex design and head start) in 2005
	Economic risk	'High economic risk' to innovation in 2005
	Financial barriers	Importance of financial barriers (include categories 'innovation costs too high', 'lack of suitable internal and external sources of funding') to innovation in 2005
	Organizational barriers	Importance of organizational barriers (includes categories 'organizational problems within firms', 'internal resistance', 'lack of skilled personal', 'lack of information on technology', 'lack of information on market' and 'customers unresponsive to new products and process') to innovation in 2005
Further firm characteristics	Public funding	Binary (1 if at least one of the sources of public funding is present: Federal Region, Federal State, Federal Ministry of Economics and Technology, Federal Ministry of Education and Research, EU, European Commission and n.e.s.)
	Export intensity	Export share in relation to total turnover in 2005
	Firm size	Number of employees of the firm in 2005
Constants	East Germany	Binary (1 if a firm is located in East Germany) in 2005
	Service sector	Binary (1 if a firm belongs to the service sector)
	SB industries	Binary (1 if a firm belongs to the science-based industries)
	SI industries	Binary (1 if a firm belongs to the scale-intensive industries)
	SS industries	Binary (1 if a firm belongs to the special-supplier industries)
	SD industries	Binary (1 if a firm belongs to the supplier-dominated industries)

Table 10: Variables' descriptive statistics

	Total sample		Make=1		Buy=1		MakeOnly		BuyOnly		Manufacturing only	
	Mean	(Std)	Mean	(Std)	Mean	(Std)	Mean	(Std)	Mean	(Std)	Mean	(Std)
Incremental innovation	16.2%	(22.3%)	24.2%	(24.3%)	20.5%	(23.4%)	21.9%	(28.8%)	10.4%	(20.0%)	20.0%	(23.3%)
Radical innovation	4.3%	(12.5%)	6.8%	(15.0%)	5.5%	(13.4%)	6.4%	(17.8%)	2.1%	(9.1%)	5.5%	(13.7%)
Cost innovation	2.3%	(9.4%)	5.7%	(11.8%)	4.7%	(11.1%)	2.8%	(6.1%)	2.3%	(5.8%)	3.7%	(8.7%)
Quality innovation	3.3%	(7.2%)	4.7%	(8.8%)	4.1%	(8.2%)	2.2%	(4.5%)	2.0%	(7.3%)	3.9%	(7.9%)
Productivity gap	0.88	(0.16)	0.86	(0.15)	0.87	(0.14)	0.86	(0.17)	0.90	(0.13)	0.84	(0.15)
Competition	2.49	(0.81)	2.44	(0.74)	2.48	(0.78)	2.41	(0.74)	2.56	(0.87)	2.5	(0.72)
Scientific information	0.44	(0.76)	0.63	(0.88)	0.55	(0.83)	0.60	(0.94)	0.36	(0.67)	0.48	(0.82)
Market information	3.13	(2.21)	3.81	(1.78)	3.83	(1.84)	3.41	(1.86)	3.71	(2.02)	3.3	(2.1)
Economic risk	1.48	(1.08)	1.71	(0.95)	1.66	(1.00)	1.71	(0.92)	1.56	(1.11)	1.6	(1.0)
Financial barriers	4.03	(2.94)	4.62	(2.68)	4.40	(2.72)	4.98	(4.80)	4.04	(2.86)	4.4	(2.8)
Organizational barriers	4.93	(3.83)	5.76	(3.42)	5.53	(3.55)	5.33	(3.60)	4.84	(3.85)	5.4	(3.7)
Appropriability	3.16	(4.13)	5.04	(4.48)	4.05	(4.48)	3.91	(3.75)	1.27	(2.62)	4.4	(4.6)
Innovation intensity	0.07	(0.16)	0.10	(0.18)	0.09	(0.18)	0.08	(0.18)	0.06	(0.15)	0.06	(0.10)
Export intensity	0.16	(0.24)	0.24	(0.27)	0.19	(0.25)	0.20	(0.27)	0.07	(0.17)	0.26	(0.27)
Cooperation	0.23	(0.42)	0.39	(0.49)	0.31	(0.46)	0.30	(0.46)	0.08	(0.27)	0.29	(0.45)
Human capital	21.4	(24.7)	25.9	(26.3)	22.7	(25.1)	27.6	(27.2)	16.0	(21.2)	16.6	(18.1)
Public funding	0.80	(0.40)	0.94	(0.23)	0.94	(0.23)	0.97	(0.17)	0.96	(0.20)	0.85	(0.35)
East Germany	0.35	(0.48)	0.32	(0.47)	0.34	(0.47)	0.32	(0.47)	0.39	(0.49)	0.33	(0.47)
Firm size	371	(2983)	603	(4068)	388	(2268)	1123	(8161)	115	(222)	353	(2280)
Service sector	0.43	(0.50)	0.29	(0.45)	0.40	(0.49)	0.26	(0.44)	0.64	(0.48)	—	—
Sample size N	786		419		505		66		215		446	

Table 11: Productivity Regressions by Tobit models and Two-Step Approach

	SI, SB and SS industries				Total sample				SI, SB and SS				SB and SS				
	7.1 Incremental	7.2 Radical	7.3 Quality	7.4 Cost	7.5 Incremental	7.6 Radical	7.7 Quality	7.8 Cost	7.9 Incremental	7.10 Radical	7.11 Cost	7.12 Cost	7.13 Quality	7.14 Incremental	7.15 Radical	7.16 Quality	7.17 Cost
Manufacturing only	MakeOnly	-23.10	-17.92	-28.88*	-6.92	-23.66***	-25.77	-5.99	-20.19	-18.91	4.45	-18.51	-41.71**	-13.19	-15.03	-30.97**	-19.64
	BuyOnly	-15.93	-16.37	-30.01*	-12.08	-30.98	-30.01*	-15.36	-40.11	-7.47	-12.05	-26.57	-34.08	-17.74	-22.05	-35.05**	-23.16**
	NoMake&Buy	-21.53	-6.52	16.50	-0.83	-19.01*	6.25	-0.74	-18.77	-4.15	-11.08	4.94	-43.50**	1.59	10.80***	0.98*	-1.09
	Cooperation	0.41	-3.07	0.65	1.75	-1.55	9.26**	3.85	-0.43	6.13	6.06	3.82	2.07	0.75	0.66	1.49	1.13
	Market information	0.75	-0.66	-0.17	-0.32	1.32	0.22	-0.13	0.28	0.21	0.29	-1.51	-0.50	1.01	-0.07	3.28*	1.68
	Scientific information	1.01	-0.07	3.28*	1.68	1.15	0.47	1.67	3.61	-0.75	-5.42**	4.87*	2.28	31.66***	17.54*	13.86***	4.23
	Public funding	31.66***	17.54*	10.51**	13.86***	22.12***	15.11**	11.24**	48.47***	17.71	7.79*	20.20*	2.66	0.70	0.37	0.53	0.08
	Appropriability	0.70	0.37	0.53	0.08	0.89**	0.82*	0.29	0.14	0.71	1.01**	-0.51	0.62	1.73	-1.80	-1.17	-2.42
	Economic risk	1.73	-1.80	-1.17	-2.42	1.17	-0.74	-2.20	-2.81*	-0.69	0.05	-2.19	-0.04	0.05	0.03	0.44	0.38
	Financial barriers	0.05	-0.03	0.44	0.38	0.71	0.16	0.38	0.65	0.15	0.16	0.57	0.80	-0.29	-0.13	0.03	-0.41
	Organizational barriers	-0.29	-0.13	0.03	-0.41	-0.31	-0.04	-0.22	-0.24	0.40	-1.00	-0.87	0.28	22.81	48.80**	16.52	29.37**
	Innovation intensity	22.81	48.80**	16.52	29.37**	24.49	32.13	31.69**	16.29	17.99	37.19**	23.21	22.98	14.95**	13.17*	14.00**	4.23
	Export intensity	14.95**	13.17*	14.00**	4.23	15.35**	10.93*	8.50	0.06	-14.75	18.06**	9.24	19.44**	0.29**	0.12	-0.16	-0.16
	Human capital	0.29**	0.12	-0.16	-0.16	0.16	0.13	-0.06	-0.04	0.14	0.01	-0.17	-0.11	-0.01	0.01	-0.03***	-0.01
Firm size	-0.01	0.01	-0.03***	-0.01	-0.01	0.01	-0.01	-0.01	0.01	-0.01	0.01	-0.01	4.63	-12.25***	1.40	0.01	
East Germany	4.63	-12.25***	1.40	0.01	5.65	-12.00***	0.87	-0.96	6.82	-9.16*	-2.85	-0.20	Yes	Yes	Yes	Yes	
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
N	300	303	210	223	393	392	279	295	125	176	113	110	104	300	303	210	223
Complementarity <i>F</i> test	0.07	0.25	0.01	1.46	0.49	0.21	0.16	3.74	0.78	0.75	0.14	1.15	0.10	0.07	0.24	0.02	1.26
Manufacturing and Services	MakeOnly	0.22	-18.74	-35.80***	-16.62	-25.02**	-36.17***	-19.67**	-19.50	-17.83	-30.71**	-9.46	-61.35***	-34.08**	-28.27*	-47.03***	-29.57**
	BuyOnly	-14.46	-22.22	-41.22***	-24.92**	-34.41**	-40.37***	-27.92***	-37.89	-25.08	-33.30**	-21.86	-70.00***	-17.10	-30.17**	-42.70***	-28.52***
	NoMake&Buy	-16.48	-6.93	9.97	-1.25	-6.83	12.80	-1.37	-32.84	3.41	-9.11	3.44	-66.35***	4.35	11.70***	3.38	-0.12
	Cooperation	4.35	11.70***	3.38	-0.12	3.52	11.25***	-2.11	4.87	8.17*	3.85	-0.57	-0.07	-1.13	-2.37	1.04	1.41
	Market information	2.62***	-0.84	1.15	0.54	2.18***	-0.53	0.24	2.21	-0.40	2.72	0.95	2.34	2.62***	-0.84	1.15	0.54
	Scientific information	-0.49	0.82	1.18	-0.12	0.63	0.48	0.20	0.20	2.33	0.99	1.31	1.11	-0.49	0.82	1.18	-0.12
	Public funding	24.29***	18.21**	16.69***	13.46***	18.94**	13.84**	13.03***	11.63***	41.42***	16.54	15.62***	8.20	17.96**	24.29***	18.21**	16.69***
	Appropriability	0.83*	0.60	0.72	0.44	1.23***	0.85**	0.50	0.59**	0.60	0.70	1.64***	0.56	0.83*	0.60	0.72	0.44
	Economic risk	2.62	0.27	0.69	-2.54	1.83	-0.53	-0.55	-3.35***	-1.44	2.91	-1.99	-1.55	2.51	2.62	0.27	0.69
	Financial barriers	-0.21	0.08	0.24	0.95	0.37	0.28	1.01	1.14	-0.23	0.14	0.36	1.05	0.33	-0.21	0.08	0.24
	Organizational barriers	0.22	-0.15	0.10	0.17	0.13	-0.11	0.07	0.06	0.38	-0.68	0.97*	-0.36	0.22	-0.15	0.10	0.17
	Innovation intensity	35.66***	30.32***	18.33**	15.78*	27.61***	19.36***	18.21**	4.05	33.80	32.49***	55.75***	10.72	22.48**	35.66***	30.32***	18.33**
	Export intensity	12.45*	16.63**	12.17*	1.32	13.85**	15.01**	7.38	0.61	-2.20	20.97***	6.19	3.86	19.50**	12.45*	16.63**	12.17*
	Human capital	0.01	0.01	-0.11	-0.09	0.02	0.06	-0.07	-0.07	0.15	-0.01	-0.14	-0.06	-0.07	0.01	0.01	-0.11
Firm size	-0.01	-0.01	-0.01	0.01	-0.01	-0.01	0.01	-0.01	-0.01	-0.01	-0.01	0.01	-0.01	-0.01	-0.01	0.01	
East Germany	2.41	-12.18***	1.71	-0.09	1.37	-13.25***	0.41	-0.32	1.02	-10.00*	5.53	-2.41	0.81	2.41	-12.18***	1.71	
Service sector	-1.38	-6.74	6.03	-3.20	-0.57	-5.74	4.34	-1.90	0.77	-7.15	10.863**	-7.14	4.87	-1.38	-6.74	6.03	
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
N	468	468	356	372	681	683	536	557	142	324	131	241	234	468	468	356	372
Complementarity <i>F</i> test	0.05	0.24	0.02	1.26	0.19	2.64	0.20	0.62	2.15*	1.49	0.91	3.54	0.01	0.05	0.24	0.02	1.26

***, **, * Statistically significant, respectively, at the 1, 5 and 10% level. Note also that the sample size *N* is varying for the four types of innovations depending on the number of observations available. Thus, for example, incremental and radical innovations have been indicated in the MIP questionnaire from 2007 clearly more often than process innovations. In order not to reduce the sample size too much and allow for subsequent verification of hypotheses *H2a-H3b* we include all those observations available provided that the set of explanatory variables (from the year 2005) is balanced.

Table 12: Productivity Regressions by Tobit models and Actual R&D Strategy Choices

	SI, SB and SS industries				Total sample				SI, SB and SS				
	7.1 Increm.	7.2 Radical	7.3 Quality	7.4 Cost	7.5 Increm.	7.6 Radical	7.7 Quality	7.8 Cost	7.9 Increm.	7.10 Radical	7.11 Cost	7.12 Cost	7.13 Quality
Manufacturing only													
MakeOnly	15.20***	-4.87	-15.65**	-11.08**	14.32***	-7.79*	-14.95***	-8.19**	16.71*	-1.44	-3.28	-0.85	-16.47**
BuyOnly	15.49***	-17.70***	-4.24	-5.92	10.39**	-18.85***	-12.39***	-5.15*	11.56	-18.76**	-4.89	-4.23	-5.24
Make&Buy	25.69***	-2.64	-0.41	-0.08	24.51***	-3.30	0.06	0.43	22.94***	-1.05	-0.16	0.13	-2.58
NoMake&Buy	-16.79***	-33.11***	-20.86***	-21.11***	-18.66***	-33.28***	-22.37***	-19.91***	-29.34***	-17.31*	-15.27***	-26.41***	-14.18***
<i>N</i>	300	303	210	223	393	392	279	295	125	176	113	110	104
Complementarity													
<i>F</i> test	5.22	1.62	0.01	0.36	5.84	1.33	0.52	1.19	4.95	0.02	0.85	0.23	0.20
Manufacturing and Services													
	SI, SB and SS industries				Total sample				SI, SB and SS				
	7.14 Increm.	7.15 Radical	7.16 Quality	7.17 Cost	7.18 Increm.	7.19 Radical	7.20 Quality	7.21 Cost	7.22 Increm.	7.23 Radical	7.24 Cost	7.25 Cost	7.26 Quality
MakeOnly	18.77***	-9.36*	-9.90**	-12.93***	15.74***	-13.02***	-13.94***	-10.86***	15.82*	-6.41	-7.51	-15.73***	-14.30**
BuyOnly	-2.17	-30.01***	-16.86***	-14.01***	-4.60	-30.27***	-19.19***	-11.93***	-9.32	-33.33***	-9.00**	-16.78***	-18.73***
Make&Buy	24.67***	-4.40**	-0.58	-2.09	21.87***	-6.33**	-2.13	-2.24	20.75***	-3.09	-1.77	-2.18	-1.88
NoMake&Buy	-21.36***	-42.27***	-27.78***	-24.89***	-22.66***	-39.22***	-28.97***	-22.31***	-25.70***	-39.56***	-17.41***	-33.33***	-33.04***
<i>N</i>	468	468	356	372	681	683	536	557	142	324	131	241	234
Complementarity													
<i>F</i> test	2.76	0.65	0.06	0.00	3.40	0.10	0.11	0.14	4.56	0.07	0.09	0.11	0.04

***, **, * Statistically significant, respectively, at the 1, 5 and 10% level. Note also that the sample size *N* is varying for the four types of innovations depending on the number of observations available. Thus, for example, incremental and radical innovations have been indicated in the MIP questionnaire from 2007 clearly more often than process innovations. In order not to reduce the sample size too much and allow for subsequent verification of hypotheses *H2a-H3b* we include all those observations available provided that the set of explanatory variables (from the year 2005) is balanced.