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Measuring Informal Innovation: From Non-R&D to On-line Knowledge Production

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Abstract

In this paper we explore the concept of informal innovation by investigating it both on the input (activities) and output (impact) side of the innovation process. Informal innovation is defined as innovation that is not explicitly planned and budgeted and therefore remains largely hidden in (aggregate) innovation data. We take a statistical approach to reveal the significant potential of informal innovation. We furthermore conceptualize and operationalize informal innovation as an activity taking place without R&D (in non-R&D firms). In general, on the input side, we show that around half of the innovative firms in our sample (of innovative firms in the Swiss Innovation Survey of 2002) develop innovations without any R&D. Moreover, on the output side, over one third of the innovative sales and production cost reductions can be attributed to informal innovation. Although the results appear to be rather pervasive, they are strongest for small firms, low-tech firms and firms in service industries. This leads us to conclude that informal innovation is not just an important complement to formal innovation – as scarcely acknowledged in literature – but that is largely takes place next to and as a substitute for formal innovation as well – which is largely neglected in literature to date. We furthermore explore the possible attributes of the process of informal innovation and develop a preliminary framework that needs to be investigated into further detail by future research. In particular, we argue that 'on-line' activities are a crucial part of the innovation process, although it has been largely neglected to date. It becomes clear that the literature on learning-by-doing and learning-by-using needs to be expanded by more explicitly focusing on the processes that are at the heart of the (informal) innovation process in order to clearly show the sources of innovation. In order to do this, we indicate some possible avenues for future research to improve the measurement of (informal) innovation.

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1. INTRODUCTION

Innovation is widely acknowledged to play an important role in the survival of many business firms (e.g., Schumpeter, 1942; Teece, Pisano and Shuen, 1997), or as a main driver for economic growth (e.g., Aghion and Howitt, 1998). Research on innovation to date investigates the determinants and effects of different kinds of innovation. A particular kind of innovation for which the above is shown is *technological* innovation. Dosi (1988) acknowledges that formalized R&D activities are an important input for this kind of innovation. However, other determinants of technological innovation have to be investigated as well (e.g., van de Ven, 1986; van de Ven, Polley, Garud and Venkataraman, 1999). Some non-R&D activities that are acknowledged to play an important role in a firm's innovation efforts and performance are for example marketing, design and engineering capabilities, training and learning (e.g., by doing), monitoring external sources of innovation, development new production facilities, acquiring of new technologies and technical information or know-how, and organizational investment and change (e.g., Dosi, 1988; e.g., Kline and Rosenberg, 1986; OECD, 1997; Rosenberg, 1976) where some activities such as engineering can still have significant informal attributes (e.g., King, 1999; Rosenberg, 1982; Vincenti, 1990). Dosi emphasizes that "such informal effort is generally embodied in people and organizations (primarily firms) (Pavitt, 1986; Teece, 1977, 1986), and its cost is hard to trace." (Dosi, 1988: 1125) Therefore, "this is a source of technological innovation [that] receives no direct expenditures" (Rosenberg, 1982: 121-122). It is in these lines that *informal innovation* is defined as innovation that is not explicitly planned and budgeted and therefore remains largely hidden in (aggregate) innovation data. In this sense, informal innovation can be contrasted to formal R&D activities that are traditionally considered as a systematic and organized activity by innovation or R&D surveys (cf., OECD, 1963, 1997, 2002).

In order to address this issue of informal innovation, the goal of this paper is to show how many firms are involved in it and what their impact is. More precisely, we use a statistical approach to reveal a part of the innovation process that is ordinarily missed or ignored. A more general objective therefore is to develop an indicator for informal innovation. We do this by using the Swiss Innovation Survey for which we make certain assumptions with regard to innovation and R&D. Within our definition, informal innovation is approximated by investigating innovations that do not derive from R&D. We investigate the characteristics of these firms with regard to size and technology intensity. While this shows the *input* side of informal innovation, it is also important to investigate the *output* side by revealing the weight of these informal innovators in the economy. Among the non-R&D sources of new knowledge in a firm, 'on-line' improvements deriving from the efforts of experienced employees on the work floor are claimed to be critical in the innovation system. Therefore, an important issue is to measure systematically this source of innovation that is still often ignored (cf., von Hippel, 2005).

The paper is structured as follows. We first review the literature on the measurement of innovation, by indicating some of its frontiers. We thereby develop a framework for the measurement of (informal) innovation that shows that an important part of the innovation process might typically be ignored (Section 2). In order to extend this boundary, we attempt to go beyond the existing literature by investigating informal innovation with an exploration of both its input (activities) and output (impact) side (Section 3).

We continue by exploring a possible framework that might explain a large part of this process of informal innovation (Section 4). In this section, we also give possible avenues for future research on the measurement of (informal) innovation. Finally, we conclude our study (Section 5).

2. THE MEASUREMENT OF INNOVATION: SOME FRONTIERS

2.1 Outputs Characteristics of Innovation

Although it is sometimes suggested that innovation is inherently impossible to quantify and to measure, this is true just for some aspects of innovation (Smith, 2005). The key dimensions of the innovation process as well as the input and output *can* be measured, and this has been done quite successfully, with some well-known caveats (see Godin, 2005 for an historical review). In the measurement of innovation, a few basic distinctions and typologies have been made in order to improve the conceptualization of innovation and to advance measurement of this concept.

First, *process* innovation is differentiated from *product* innovation. The distinction is always used among academics from a theoretical as well as from an empirical point of view (for example in CIS surveys) – the latter even if it is sometimes difficult for firms to make this distinction (Simonetti, Archibugi and Evangelista, 1995).

Second, in the different innovation surveys (for example, CIS for the European Community) *radical* innovation is considered as an innovation that is novel for the market while the weight of the innovation is also investigated (see CIS questionnaire on product innovation sales). However, radical innovations are not well identified especially by SMEs that are myopic on their potential or real potential markets. The smaller a firm, the more radical become its product or process innovations. The weakness of this qualitative distinction explains the complementary use of patent data to cope with the problem of the quality of innovation – see Archibugi and Pianta (1996) for a review on the measurement of innovation through patents and innovation surveys.

Third, a perhaps more useful distinction is a more recent one which separates *technological* from *non-technological* innovation. Aligned with the broad definition of Schumpeter (1934), the Oslo Manual, for example, acknowledges this kind of innovation in its Annex 2 (OECD, 1997). Building on this third issue, CIS questionnaires propose some techniques as “advanced management techniques”, “new or significantly changed organizational structures”, or “significant changes in the aesthetic appearance or design of at least one product” (European Commission, 2004) that could be extended by other complementary or more precise topics as done before with “innovation in packaging” or “marketing innovation” (Lhuillery, 2001). The scattered results in innovation studies may raise doubts about the common understanding of the underlying concepts. The distinction between non-technological and technological innovation may be also fuzzy for innovation in packaging, for example.

2.2 Input Characteristics of Innovation

Another important development in the measurement of innovation is an effort dedicated to widen the analysis of innovation that is usually based on inputs of innovation. While early attempts to measure innovation mainly relied on formal R&D data (OECD, 1963), more recently there is an attempt to get a better view of the knowledge production factors within a firm.

First, the recent version of the Frascati Manual defines R&D as "creative work undertaken *on a systematic basis* in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications."[1] (OECD, 2002: 30, emphasis added) The idea here is to extend R&D activities to the production of new knowledge that use social sciences (e.g., law, psychology, or even mathematics) that are used in services or to shape new services.

Second, the Frascatian definition insists on the fact that the knowledge production has to be creative work undertaken "*on a systematic basis*." A important extension of the literature attempts to clarify what activities are hidden in R&D (e.g., Kleinknecht, 1987; Kleinknecht and Reijnen, 1991; Lhuillery and Templé, 1994; Santarelli and Sterlacchini, 1990). In line with these articles, R&D is a concept that incorporates six different boundaries which are to be removed in order to get a better picture of (the full spectrum of) R&D activities:

- a threshold effect where firms with less than one full-time equivalent researcher are not considered (see OECD, 2002);
- a delimitation effect where firms that only sub-contract R&D are not included in R&D data-sets;
- a discontinuity effect; that is, firms with discontinuous activities are less likely to be over the threshold;
- an organizational effect that sometimes makes it difficult to indicate to what extent an engineer is dedicated to R&D when participating in an innovation project;
- a specialization aspect when firms create a task dedicated to R&D and when non-specialized units are in charge of such an activity;
- an accountancy affect when R&D expenditures are not known or computed by firms doing R&D when required in a non-planned or decentralized manner.

With regard to the empirical evidence of this 'hidden' informal R&D, Kleinknecht (1987; 1989) found that the official innovation survey (in the Netherlands) only captured about one third of the R&D performed by small firms (based on man-years). Similar results were found in an Italian survey (Archibugi, Cesaratto and Sirilli, 1987). Kleinknecht, Poot and Reijnen (1991) showed that only one third of industrial firms which conduct R&D implement a dedicated R&D department. More precisely, Santarelli and Sterlacchini (1990) report that on average 17.5% of their sample of manufacturing firms performs R&D in other (than R&D) departments *only*. This result is even stronger for service firms (Kleinknecht, et al., 1991). Interesting to note here however is that these figures are even greater for larger

[1] In the Frascati Manual, the term R&D covers three activities: basic research, applied research and experimental development (OECD, 2002).

firms. Moreover, a significant share of firms (about one third) declared to have less than one researcher – that is, more that one man year – conducting R&D (Kleinknecht, *et al.*, 1991; Kleinknecht and Reijnen, 1991). This share is even higher for small manufacturing and service firms, of which over 50% report less than one R&D man year.

2.3 Informal technological Innovation: Departing from R&D Activities

Despite these studies, there are still some important issues which are not dealt with. In particular, when non-technological innovation is considered, non-R&D innovation is still poorly addressed in the literature. It is in fact a paradox to see that the Oslo Manual does criticize the usual view of the innovation process where the R&D activities take a central place but subsequently does not consider it in that much more detail. An explanation for this could be institutional. The Oslo Manual (OECD, 1997) is developed at the OECD and has to be articulated in line with the Frascati Manual (OECD, 2002) and thus rather insists on outputs than on inputs at the source of technological invention and innovation. Hence, non-R&D activities are considered here as complementary to R&D activities rather than substitutes.

In contrast, the definition of innovative activities complementary to R&D is extended. In the CIS4 questionnaire, for example, activities that are considered besides the intramural and extramural activities are: the acquisition of machinery, equipment and software, the acquisition of external knowledge, training expenditures, all forms of design costs, marketing expenditures. Here, non-R&D costs are introduced or even extended but are still not exhaustive since items as standardization and normalization costs, or patent costs could be proposed. These activities do not include inventive activities that could be substitute for the R&D activity that remain at the core of the innovation process. The suggested firm strategy to innovate is therefore: to choose to invest in R&D or not, outside or inside, to buy external knowledge or not, and to choose whether or not to invest in complementary assets that raise the likelihood of success of the innovation.

However, there is still no place in this literature for two other inventive activities such as:

- an innovation process without any R&D;
- an individual technological innovation not planned in an R&D activity.

Table 1: Activities considered in innovation (measurement) literature.

		R&D activities	
		Yes	*No*
Inventive activities without R&D	*Yes*	Complementary to R&D: Yes (Oslo Manual) Next to or substitute for R&D: Not considered	Not considered
	No	Standard conception (Frascati Manual)	Non-innovative firms

This brings us to the development of a specific framework for the different innovation activities that are considered in the measurement of innovation (Table 1). From Table 1 it becomes clear that there is little misconception in the bottom part of the table. That is to say, if there are no internal inventive activities *without R&D* while there are (formal) R&D activities (aimed at the development of innovation), firms are assumed to be innovative according to the ordinary definition of the Frascati Manual (OECD, 2002).

Furthermore, if the are no (formal) R&D activities and no non-R&D inventive activities, a firm is considered to be non-innovative. However, problems arise in the two top cells of Table 1 where there exist inventive activities *without R&D*. Even if complements to R&D activities are considered by the Oslo Manual (OECD, 1997), the literature ignores technological inventive activities without R&D that take place as a stand-alone activity – that is, next to or as a substitute for R&D – while there are ongoing R&D activities. In addition, inventive activities without R&D in non-R&D firms are ignored as well. This article tries to investigate the two last difficulties and makes a first measurement attempt. We argue that technological invention made by non-R&D firms can be measured by using innovations surveys (next section) even if stand-alone inventive activities occur in R&D and non-R&D firms require to be addressed in more detailed as we will see in Section 4.

3. FROM INFORMAL R&D TO INFORMAL INNOVATION

3.1 Innovative Firms and Their Commitment to R&D: The Potential of Informal Innovation

In line with the concepts and definitions described in the previous sections, we focus on innovative firms that introduce product and/or process innovations without conducting any R&D (see Appendix). We thereby particularly address the upper right quadrant of Table 1. As already indicated before, an innovative firm can also innovate in processes or products without any declared R&D. We therefore broadly define an informal innovation as a technological innovation that does not require any R&D activities – neither continuous nor discontinuous – within the firm.

Table 2 shows that 57% of Swiss *innovative* firms does not invest in internal R&D activities whereas 20% are involved in continuous R&D. The weight of informal innovators using the sales of innovators is restricted to 46% since informal innovation is more dedicated to SMEs and micro firms (Table 2). It shows that a majority of firms may be ignored when one focuses mainly on R&D activities[2].

Table 2: Innovative firms and their commitment to R&D, by classes of employees.

Size	*No R&D* [b]		*Discontinuous R&D* [b]		*Continuous R&D* [b]	
	NW	W	NW	W	NW	W
10 to19	66%	70%	21%	19%	13%	11%
20 to 249	54%	55%	24%	22%	22%	23%
250 and more	40%	36%	14%	7%	46%	57%
Total	57%	46%	23%	14%	20%	40%

NW=Not weighted; W=Weighted; Weighted stands for weighted by 2001 sales

[2] Only 2% of innovative firms without R&D do patent their innovation whereas this share rises to 36% for continuous R&D firms.

Table 3: Innovative firms and their commitment to R&D, by sectors.

Sectors	*Rank*		*No R&D*		*Discontinuous R&D*		*Continuous R&D*	
	NW	W	NW	W	NW	W	NW	W
Transportation/ telecommunication	1	17	76%	32%	18%	5%	6%	63%
Retail	2	1	74%	85%	25%	9%	1%	6%
Building	3	4	72%	72%	14%	14%	14%	14%
Printing & Publishing	4	6	70%	65%	25%	29%	5%	6%
Banking/ insurance	5	13	70%	45%	11%	16%	19%	39%
Automotive	6	5	66%	71%	9%	7%	25%	22%
Wood	7	14	63%	44%	30%	43%	7%	13%
Paper	8	11	63%	51%	22%	10%	15%	39%
Energy	9	3	61%	79%	23%	15%	16%	6%
Metal products	10	12	59%	48%	22%	26%	19%	26%
Hotel and restaurant industry	11	9	59%	54%	38%	44%	3%	1%
Information technology services/ R&D	12	7	59%	59%	8%	11%	33%	30%
Services for enterprises	13	2	59%	80%	24%	9%	17%	11%
Food	14	22	53%	19%	35%	20%	12%	61%
Textile	15	10	52%	52%	22%	17%	26%	31%
Non-metallic minerals	16	8	49%	54%	31%	22%	20%	24%
Clothing	17	15	47%	38%	26%	28%	27%	34%
Other manufacturing	18	16	46%	38%	27%	32%	27%	30%
Electronics/ instruments	19	18	45%	30%	8%	3%	47%	67%
Electrical equipment	20	20	41%	20%	19%	7%	40%	73%
Machinery	21	23	40%	16%	17%	7%	43%	77%
Clock making	22	21	38%	20%	27%	8%	35%	72%
Rubber & Plastics	23	19	33%	28%	38%	35%	29%	37%
Chemicals	24	24	10%	0%	20%	3%	70%	97%
All			57%	46%	23%	14%	20%	40%

NW=Not weighted; W=Weighted; Weighted stands for weighted by 2001 sales

Table 3 shows that innovative firms belonging to the service sectors are more inclined to be informal innovators than manufacturing firms. High-tech industries moreover tend to formalize their production of knowledge through an R&D activity and are therefore less inclined to innovate informally. As shown in Table 3, R&D data in several service sectors hide more than two third of the innovative firms whereas very few are missing in a sector as the chemical industry. Pavitt's (1984) typology gives a more precise partition: scale intensive firms, which tend to develop their process technology themselves in-house, such as metal manufacturing, paper, automotive and food (although not if weighted by sales), are relatively highly ranked as informal innovators. While the same can be said about some supplier-dominated firms such as building and financial and commercial services, the converse is true (as also expected) for specialized suppliers as machinery and instruments as well as for science-based firms as electronics and (as already mentioned) chemicals. The results are furthermore largely in line with some of the expectations deriving from a taxonomy of innovation small firms (de Jong and Marsili, 2006).

Table 4: Types of output by type of input for innovative firms.

	No R&D		*Discontinuous R&D*		*Continuous R&D*		*Total*	
	NW	W	NW	W	NW	W	NW	W
Process	67%	76%	74%	85%	84%	72%	69%	80%
Product	83%	75%	94%	85%	97%	98%	87%	85%
Both	50%	51%	68%	70%	81%	70%	58%	65%
Product Innovation only	33%	24%	26%	15%	16%	28%	29%	20%
Process Innovation only	17%	25%	6%	15%	3%	2%	11%	15%

NW=Not weighted; W=Weighted; Weighted stands for weighted by 2001 sales

Informal innovation can be divided into two different kinds of technological innovation. 67% of firms without R&D implement *process* innovation, and 83% *product* innovation (Table 4). Half of informal innovators are both process and product innovators, while one third is involved in product innovation only. Thus, non-R&D innovation is associated with both product innovation and process innovation. The share of firms innovating only at the process level increases with decreasing R&D activity. If weighted by their sales, it appears that process innovators reach the level of product innovators (Table 4). Hence, even if fewer non-R&D firms are involved in process than product innovation, they are larger (by sales).

The results are in line with the results of Kleinknecht and others (Kleinknecht, 1987; Kleinknecht and Reijnen, 1991; Santarelli and Sterlacchini, 1990) on informal R&D because there is a similar effect of size and sectors. Nevertheless, it goes beyond the concept of informal R&D by showing that non-R&D innovative activities are ignored and represent a large bulk of technological innovation in the economy.

3.2 The Place of Informal Innovation in the Innovation Process: The Impact of Informal Innovation

The (relative) weight of informal innovative firms does not tell us what the weight of informal innovation in an economy is. A further step therefore is to weight the firms by the outcome of their technological innovative process. This shows the impact of informal innovation on the level of the economy.

Table 5: Process and product innovation impact, by classes of employees.

	Process				Product			
Size	No R&D	Discontinuous R&D	Continuous R&D	Total	No R&D	Discontinuous R&D	Continuous R&D	Total
10-19	2%	1%	1%	4%	3%	1%	1%	4%
20 to 249	26%	7%	15%	48%	22%	10%	16%	48%
250 and more	7%	3%	38%	48%	15%	1%	31%	48%
Total	35%	11%	54%	100%	40%	12%	48%	100%

All values are weighted by 2001 innovative sales for products and by 2001 cost reduction for process innovation

As far as *process innovation* is concerned, non-R&D firms account for more than one third of the total reduction of production costs due to process innovation – i.e., the measure for the impact of (informal) process innovation – while continuous R&D firms represent more that half of the progress here (see Table 5). Large firms innovating without R&D do not represent an important part of the progress with only 7% of the whole economized resources. The same remark applies to micro firms whereas SMEs gather more than a quarter of the whole economic progress due to process innovation. Table 6 furthermore shows that costs are especially reduced by non-R&D activities in service industries. The size of sectors is however important since automotive industries, information industries and wholesale represent near to 15% of the whole progress due to informal process innovation (see Table 6).

Table 6: Process and product innovation impact, by sectors.

Type of innovation	*Process*				*Product*			
	Industry weight	*Share of economized costs Between types of firms*			*Industry weight*	*Share of innovative turnover between types of firms*		
Sectors	*No R&D*	*No R&D*	*Discontinuous R&D*	*Continuous R&D*	*No R&D*	*No R&D*	*Discontinuous R&D*	*Continuous R&D*
Clothing	**0.0%**	**0%**	100%	0%	**0.5%**	**27%**	14%	59%
Chemicals	**0.1%**	**1%**	1%	98%	**0.0%**	**0%**	2%	98%
Clock making	**0.1%**	**2%**	2%	96%	**0.7%**	**19%**	10%	71%
Transportation/ telecommunication	**1.4%**	**9%**	1%	90%	**0.8%**	**15%**	4%	81%
Machinery	**0.6%**	**17%**	11%	71%	**0.4%**	**9%**	7%	84%
Electronics/ instruments	**2.0%**	**24%**	3%	73%	**0.7%**	**15%**	2%	83%
Rubber & Plastics	**0.7%**	**26%**	45%	29%	**0.2%**	**8%**	42%	50%
Electrical equipment	**1.0%**	**27%**	16%	57%	**0.8%**	**19%**	9%	72%
Textile	**0.9%**	**30%**	5%	65%	**0.9%**	**34%**	14%	52%
Food	**0.4%**	**31%**	19%	50%	**0.5%**	**17%**	19%	64%
Wholesale	**4.5%**	**39%**	9%	52%	**6.4%**	**59%**	20%	21%
Wood	**1.6%**	**46%**	54%	0%	**0.6%**	**33%**	21%	46%
Metal products	**1.7%**	**48%**	22%	30%	**0.6%**	**37%**	40%	23%
Other manufacturing	**0.6%**	**50%**	8%	42%	**0.9%**	**39%**	47%	14%
Paper	**1.3%**	**53%**	38%	9%	**0.7%**	**21%**	4%	75%
Banking/ insurance	**1.7%**	**58%**	27%	15%	**5.0%**	**33%**	1%	66%
Non-metallic minerals	**1.6%**	**58%**	20%	22%	**0.6%**	**39%**	15%	46%
Information technology services/ R&D	**5.2%**	**61%**	10%	29%	**7.3%**	**78%**	5%	17%
Building	**0.2%**	**65%**	35%	0%	**0.1%**	**47%**	43%	10%
Hotel and restaurant industry	**0.3%**	**77%**	23%	0%	**1.1%**	**37%**	63%	0%
Printing & Publishing	**1.5%**	**77%**	19%	4%	**0.4%**	**35%**	52%	13%
Services for enterprises	**1.2%**	**85%**	12%	3%	**1.4%**	**66%**	12%	22%
Automotive	**5.2%**	**87%**	0%	13%	**6.5%**	**78%**	4%	18%
Retail	**1.0%**	**100%**	0%	0%	**2.6%**	**74%**	19%	7%
Total	**35%**	**35%**	11%	54%	**40%**	**40%**	12%	48%

The same procedure applies to *product innovation*. However, instead of the contribution to cost reduction the weight is given by the turnover made by product innovation – i.e., the measure of the impact of (informal) product innovation. 40% of innovative sales are not considered if only R&D firms are considered (Table 5). This loss is higher with decreasing firm size. As it is the case for process innovation, within the group of informal innovators, SMEs capture the main amount of innovative sales. Combined with micro firms, 25% of the economic value of product innovation is produced by non-R&D innovators (Table 5). By sectors, the weight of non-R&D product innovation is also undermined in service industries such as bank and insurance (see Table 6). It could be noted that the interpretation of some sectors should be done cautiously because of their small size. This latter sector (bank and insurance) is namely relatively large in Switzerland and it is therefore overestimated compared to other countries. (Dividing this figure by two would give a good indication for other countries.)

4. AN EXPLORATION OF THE PROCESS OF INFORMAL INNOVATION

4.1 Characterizing Informal Innovation: On-line Inventions

While the above section gives a broad framework of the informal innovation process, more detailed mechanisms that underlie informal innovation still need to be explored. The idea that individual capabilities to invent new technological artifacts can exist without R&D activities is not unfamiliar to the innovation literature. Two interesting learning processes are usually considered in this context.

First, "*learning-by-doing*" that takes place for a given production (process) technology (Arrow, 1962). In Arrow's model, a better productivity is induced by the experience acquired exclusively when the employee is working on a new machine. In other words, "learning is the product of experience. Learning can only take place through the attempt to solve a problem and therefore only takes place during activity [and if it is] associated with repetition of essentially the same problem [, it] is subject to sharply diminishing returns." (Arrow, 1962: 155) Whereas the main motivation for engaging in the productive activity is the physical output, there is a relatively small additional gain in terms of information which yet reduces the cost of further production (Arrow, 1969). Furthermore, "Each new machine produced […] is capable of changing the environment in which production takes place, so that learning is taking place with continually new stimuli. This at least makes plausible the possibility of continued learning in the sense, here, of a steady rate of growth in productivity." (Arrow, 1962: 157) In this framework, progress is thus induced by the combination of an exogenous progress that is the acquisition of new machines with better performance with an endogenous learning process that the new machines induce. Indeed, the progress is individual and/or collective, endogenous and internal to the firms. However, there are no new technologies, produced neither at the level of the machine user nor at the level of the firm through R&D. Still, these two possibilities are implicitly acknowledged by Arrow (1962: see 156 and 172).

Second, following Rosenberg (1982), a distinction can be made between "gains that are internal to the production process (doing) and gains that are generated as a result of the subsequent use of that [technology] (using)." (Rosenberg, 1982: 122) However, the scope of this last type of learning – that will be named "*learning-by-using*" – is not well defined. According to Rosenberg, this kind of learning "overlaps with development. The learning involved requires participation in the production process. […] The point is that productive activities always involve specialized kinds of knowledge […]. There is typically a range of possible improvements that require intimate familiarity with the minutiae of the productive sequence." (Rosenberg, 1982: 122) Compared to Arrow (1962), the added value of the learning-by-using concept introduced by Rosenberg (1982) is ambiguous – in particular with regard to the locus of learning. Learning-by-using would be related to the active use of technology – e.g., the participation in the production process – compared to a passive view of learning. In order to clarify the concept, Rosenberg (1982) introduces a further distinction between *embodied* and *disembodied* learning-by-using. The embodied form of learning-by-using entails a feed back loop in the development stage – i.e., to optimize a design. It thus leads to actual changes in the technology that is being used. In the case of disembodied knowledge generated by learning-by-using, certain alterations in use take place without a need to modify the hardware design – that is, the technology. This in turn leads to new practices that increase the productivity of the hardware.

In this setting, and in contrast to the typical learning-by-doing studies that focus on (autonomous) learning curves, learning should not always be seen as just a (simple or automatic) by-product of or a windfall profit deriving from 'doing' because it can also be induced or deliberate, and thereby even managed, to some extent (see e.g., Adler and Clark, 1991; Argyris and Schön, 1978; David, 2003; Dutton and Thomas, 1984; Fiol and Lyles, 1985; Geroski and Mazzucato, 2002; Malerba, 1992; Zollo and Winter, 2002). In this vein, learning-by-using appears to be close to the process of informal innovation since it allows technological invention at the shop floor level without R&D – especially if it generates knowledge in an embodied way.

The contribution of von Hippel (1988; 2005) insists more than Arrow (1962) and Rosenberg (1982) on the ability to produce new knowledge by using technologies. He defined users as “firms or individuals that expect to benefit from *using* a product or a service. Users are unique in that they alone benefit *directly* from innovations.” (von Hippel, 2005: 3, original emphasis) He furthermore shows that users are often the ones that invent, because of their high need and expected benefit. The process can be seen as a trial-and-error (problem-solving or experimentation) process in which the (solution) knowledge that is generated is combined with the need of the user (see also Iansiti, 1998; Thomke, 1998; von Hippel, 2005; von Hippel and Tyre, 1995). Due to the sticky nature of knowledge, the user often has an advantage over the manufacturer and is therefore expected to innovate (von Hippel, 1994).

While this framework provides important indications for how users are able to innovate, it lacks a coherent view of the characteristics of and differences between different kinds of user. Von Hippel’s (2005) analysis holds important implications that allow us to study a firm’s internal users’ inventions. The internal use of technology seems to mainly refer to *process* technology (and thus innovation) and drive inventive activities within firms. In order to get a more precise view, a distinction between ‘off-line’ and ‘on-line’ (internal) users is required (cf., Foray, 2004; Nelson, 2003). Off-line work largely refers to R&D activities because it is isolated – at a distance – from the regular production of goods and services (cf., Pisano, 1994, 1996). On-line activities refer to learning during the course of production. This user learning is often related to the need to interrupt the ongoing activity – by a process of experimentation or problem-solving. As this could be in tension with the required pace of production, there is a trade-off between short-term loss due to the disruption of production by users and long-term gain in performance increase due to the users’ inventions (e.g., Carrillo and Gaimon, 2000). Furthermore, in Pisano’s (1997) framework, for example, the importance of off-line versus on-line process development (or innovation) depends on the characteristics of the underlying knowledge. The process of on-line innovation involves a continuing series of small experiments on the shop floor, designed to produce incremental gains in knowledge (Garvin, 1993) – in other words, on-line experimentation is a the heart of informal innovation (Foray, 2004), which remain hidden in other (non-formalized or non-R&D) activities of the firm (cf., Cooke, 2002a; Cooke, 2002b; le Bars, 2001; Tremblay, 1998, 1999).

4.2 Difficulties in Innovation Measurement: A Window for Future Research

The few studies that address this aspect of the innovation process indicate that informal innovation is derived from learning in the form of problem-solving and experimentation (cf., Leonard-Barton, 1992). Moreover, many studies remain vague as far as the empirical evidence and concrete managerial implications are concerned (Garvin, 1993). With regard to non-R&D technological innovation, the quantification of this on-line activity needs also to be addressed despite its hidden nature. By identifying more concrete aspects of the process below, we explore some possible strategies for future measurement.

The first solution to develop the measurement of (informal) innovation is the implementation of an *output* measure in a questionnaire. This can however be problematic in a qualitative questionnaire that starts by general inquiries on innovation (see CIS questionnaires) if it is considered as a process innovation because respondents will be unable to identify the on-line innovation. A better strategy would be to introduce such a question after the questions on resources devoted to innovations (innovation costs including R&D) because this explicitly asks for acknowledging the locus of innovation – in which on-line process invention does not require R&D costs, off-line expenditures or even planning. Another solution – which can be complementary – is to develop systematic technometric measures in firms where machinery improvements have been done on-line. The existing literature uses various statistical approaches in order to capture the output of the processes that we have termed learning, problem-solving, innovation and experimentation (e.g., Box, 1984). Moreover, there are already interesting attempts to measure the output of informal on-line learning (by experimentation) behavior (Box, 1966; Box and Draper, 1969). Such statistical attempts can be an important help to extend the frontiers of (on-line) innovation measurement (cf., Fine, 1986).

A second general measurement strategy is to focus on the *input* side of the informal innovation process. A potential measurement strategy is to approximate on-line (informal) innovation by the complementary assets it requires (e.g., number of engineers or level of skills). Furthermore, one may successfully explore the types of fields in which it is more pervasive (cf., Bohn, 1995) as well as the role of the employee – such as the role of the engineer in certain mechanical fields (cf., Vincenti, 1990). Using a usual distinction in labor economics, it might moreover not be a matter of degree but rather of experience since the knowledge is here often very specific to employees (cf., West and Iansiti, 2003). Questions can also be addressed to employees (see Mairesse and Greenan, 1999) by asking them about their individual characteristics with regard to their carrier and experience.

Third, once a technology is put into use, it may cause organizational changes (Leonard-Barton, 1988). Capabilities and routines in organizations – in contrast to the production or development thereof – can also significantly contribute to innovation and performance (Barney, 1991; Cohen and Levinthal, 1990; Henderson and Cockburn, 1994; Nelson and Winter, 1982; Teece, 1986). Therefore, there will be a lot of value in exploring the *practices* within firms that are (directly) related to the process of on-line innovation. For example, the appropriation practices implemented at the firm level may differ between on-line and off-line innovation. On-line innovations are often incremental process innovations that are hard to appropriate through usual intellectual property rights. Alternative appropriation routines such as secrecy or restricted communication policies might be used – see for example traditional industries (e.g., luxury watch industry) – which are not inconsistent with patent registration (used for major and/or non-tacit knowledge). The potential leakage of knowledge could be dealt with by long-life careers, retaining the best on-line innovators within the enterprise. This last practice leads us to a broader view on human resources management practices, used for both R&D and non-R&D employees (e.g., Foss and Laursen, 2005; Huselid, 1995; Ichniowski, Kochan, Levine, Olson and Strauss, 1997; Ichniowski, Shaw and Prennushi, 1997; Shaw, 2004). The reward structure can be especially designed for on-line inventions in order to stimulate knowledge creation and problem-solving capacity by productive workers, or even to encourage the diffusion of on-line innovations – e.g., idea boxes and/or financial rewards. In similar vein, a strategy might be adopted to permit or punish failure – an inherent part of on-line experimentation might (cf., Lee, Edmondson, Thomke and Worline, 2004).

Fourth, the difficulties relating to the measurement of on-line innovation may induce yet another possible research strategy that deals with a *ceiling* and *threshold*. If it appears impossible to identify the exact magnitude of the phenomenon of on-line innovation, a second-best inquiry can be to find levels on a sub-population that can be applied to the whole population of firms. This statistical approach might significantly increase the reliability of the investigations, especially if the measurement problems remain unresolved. Measures can afterward be used to give imputation values to the entire sample and get thresholds or ceilings by using the characteristics of the censored population.

Finally, a critical issue is the ability to filter the different *types of innovative activities*. Overlapping innovative activities introduce noise in the data and lower the likelihood to properly identify them. As already mentioned, the distinction between product and process technological innovation is critical. However, the distinction between technological and non-technological innovation – like the one between on-line and off-line – may be hard to make especially in SMEs and services. A first outlook should thus rather focus on large manufacturing firms with R&D activities to figure out what is the particular place of on-line innovation.

5. CONCLUSIONS

In the paper, we argued that, although innovation is considered to be a main driver for firm performance and economic growth, there are still important parts of its process that are unknown because of the inherent difficulties to measure it. While some of these limitations are taken away after the work on informal R&D (e.g., Kleinknecht, 1987) there is still an important gap in the literature with regard to non-R&D innovations. While a part of these non-R&D activities are considered as complementary to R&D activities (OECD, 1997), we argue that they can also take place next to or as a substitute for R&D-based innovation. Moreover, we contend that (technological) innovative activities without R&D that take place within non-R&D firms are almost completely ignored.

In order to test this idea we identify how many innovative firms in the Swiss economy introduce ‘informal innovation’ defined as technological innovation without conducting any R&D. Our results show that around half of all the (innovative) firms in the sample could be considered as being informal innovators, in line with our definition. In particular, service firms were confirmed to be mostly involved in this informal innovation whereas high-tech firms are less likely to be (exclusively) involved in non-R&D innovation. Furthermore, we show that non-R&D innovation is associated to product innovation as well as process innovation. The process innovation side is contended to rely on learning-by-doing or learning-by-using. Non-R&D (innovative) firms account here for more than one third of the total reduction of production costs due to process innovation, which in particular holds for smaller firms and service industries. Non-R&D innovations are thus important substitutes for R&D-based innovation. These results show that a large part of the economy is not considered by Science and Technology (S&T) policy makers, as they focus on one side of the knowledge production in enterprises.

An important next step is to explore the characteristics of the informal innovators and innovations. The literature on learning-by-doing and learning-by-using – as well as experimentation and problem-solving – gives some indications but needs to be extended in order to investigate the "factory as a learning laboratory." (Leonard-Barton 1992) As we described, the concept of on-line innovation raises significant challenges for measurement efforts. However, in addition to studying the actual behavior of on-line workers, in the form of experimentation or problem-solving, there might be several complementary activities to on-line innovation that could be investigated. The possibilities we put forward are largely tantamount to exploring the antecedents of on-line innovative behavior – in other words, what determines innovative on-line behavior? In this sense, the economics of on-line innovation need to be explored by investigating the benefits and costs of these activities, which might be embedded in (organizational) incentive (or punishment) systems. This exploration should show that informal (on-line) innovation is not just a complement to formal (R&D) innovation but can be an important substitute or stand-alone activity as well. This is still an open issue that needs to be accepted by innovation (measurement) scholars and implemented in statistical questionnaires. We proposed a few avenues to do so.

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APPENDIX I: DATA AND ASSUMPTIONS

The core data set used in this paper is the Swiss Innovation Survey of 2002[3], originally launched in 1990, by the Konjunkturforschungsstelle (KOF) or Swiss Institute for Business Cycle Research at the Eidgenössische Technische Hochschule Zürich (ETHZ) in order to investigate the Swiss firms' capability to innovate (see Arvanitis and Hollenstein, 2004 for more information on the Swiss Innovation Survey and its data and statistical background). The survey is conducted every three years and covers a three year period. The last innovation survey was conducted in 2002 and covered the period 2000-2002. From 1996 onwards the survey includes construction industry and services, in addition to the manufacturing firms. It is sent out by mail and is non-obligatory. The Swiss survey is to a large extent adapted to the 'European' CIS and the Oslo Manual (OECD, 1997). The survey is based on a (with respect to firm size disproportionately stratified) random sample of 6600 firms covering 28 industries. For each industry a relevant classification is made for small, medium-sized and large firms.

The Swiss Innovation Survey asks for several issues that are related to a firm's organization, market and activities, and its innovations. It is divided into different sections (11 in total) and starts by questions on the general characteristics of the firm and its main market. Subsequently, it asks for its innovation activities, focusing on both product and process innovation. As this is the central section for this study, it will be elaborated in more detail below. The following sections deal with (national and foreign) R&D activities, innovation expenditures, public support for innovation, R&D collaborations, protection of innovation related competitive advantage, technological potential, external sources of information for innovation, strategic and organizational changes, and constraints for innovation.

In line with the concepts and definitions described in the previous section, we focus on innovative firms that introduce product and/or process innovations which are defined as being significantly changed or new (to the firm) technologies. The questions in the questionnaire on R&D make the distinction between continuous and discontinuous R&D (in addition to *no* R&D). In line with the extension of the definition of innovation, as described above, this trade-off between continuous and discontinuous R&D is central to the literature on informal R&D, which – to the extent it can be captured in this survey – is largely captured by discontinuous R&D. With regard to informal innovation (beyond informal R&D), a large part of this is captured by the 'no R&D' group of firms, in particular because they indicate to be innovative themselves.

In the questionnaire, furthermore, the output side of innovation is investigated by asking for the impact of the innovations. Because the existing literature tends to deal mainly with R&D firms, a share of innovators is missed because they do not implement formalized and continuous R&D. However, as already indicated before, an innovative firm can also innovate in processes or products without any declared R&D, neither continuous nor discontinuous. We thus broadly define informal innovation as innovation that does not require any R&D activities inside the firm. Due to the (limitations of) available questions in the questionnaire (the CIS as well as Swiss one) it is not possible to distinguish

[3] Full versions of the Swiss Innovation Survey in German, French and Italian are downloadable at www.kof.ethz.ch. The questions that were primarily used for this paper can be found in the Appendix.

between innovation coming from formal or collective invention activities (marketing, design, packaging, etc.) and innovation deriving from individual and unplanned parts of innovative activities. While this clearly delimits the possibilities to give definite statements on the exact role of informal innovation within the surveyed firms, it still gives a good indication how significant it might be (building on some of the assumptions given in the previous section). In addition, sales of new products as well as costs lowered by process innovation are asked for in the Swiss questionnaire. Using these date, we can go into further detail by computing the shares of informal product and informal process innovation in the knowledge economy. This shows the impact of informal innovation and clearly indicates what part of the innovation outcome cannot be explained by formal R&D activities.

The tendency to be involved in informal activities, either at the process or product level, may strongly depend on the size of the firm as well as on the activities in the specific sector. We therefore distinguish between classes of employees and use the NACE classification, which we consider at the 2 digit level (energy, real estate and leasing, entertainment, waste disposal, and health care are not considered here because of the restricted size of the sector). Furthermore, firms with less than 10 employees are not considered. Our final sample includes 1356 innovative firms. There are some sectors without many respondents (automotive industry and clothing) that we nonetheless keep in the sample at the two digit level because of the difficulty to aggregate them with others.

APPENDIX II: QUESTIONS USED FROM SWISS INNOVATION SURVEY

Question 2.1

a) *Did you introduce* ***innovations*** *in the period 2000-2002?*
YES ***- product innovation****s*
- process innovations
NO *Introduced neither product nor process innovations*

b) ***If yes****:*
Who ***developed*** *the innovations that were introduced? (Multiple answers possible)*
- mainly other enterprises/institutions
- your enterprise together with other enterprises/institutions
- mainly your enterprise

Question 2.2

The turnover of your enterprise in 2001 was distributed according to the following ***product types****:*
From the beginning of 1999 introduced **new** *products: __%*
[…]

Question 2.6

a) *If your enterprise introduced* ***process innovations*** *in the period 2000-2002 (question 2.1a), did these process innovations cause a* ***significant reduction of the average production costs****?*
yes no

b) ***If yes****: the reduction of costs in 2001 amounts to:*
approximately __ %

Question 3.2

In case of ***R&D activities in Switzerland****, how frequent:*
- occasionally
- continuously