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Learning–by–failing.
An empirical exercise on CIS data

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1 Introduction

Since the seminal work by Cyert and March (1963), theoretical and empirical contributions have converged in the conviction that firms' learning patterns are crucial to their innovativeness. The organisational literature literature

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has emphasised that organisational learning is a key element in generating differences in firms' performance (Levitt and March, 1988; March, 1991) due to changes in the patterns of knowledge accumulation through experience (Argote, Beckman, and Epple, 1990; Pisano and A., 2001). For firms seeking to adopt an innovative behaviour it is essential to generate, maintain and develop their ability to build and/or recognise internal knowledge. Learning is the main means for redefining existing processes, by analysing, refining, modifying and restructuring routines and operating procedures (Stalk, Evans, and Shulman, 1992). This reduces the likelihood of failure by improving a firm's efficiency, as well as enhancing the organisation's resiliency. This improves its chances of survival by increasing its ability to recover from a poor performance (Baum and Dahlin, 2007).

As innovative activity is inherently uncertain, it often results in failure. Failure is seen as a problem in a firm's economic activity. The early literature made the point that, in the wake of a failure, organisations typically pursue strategies aimed at survival. They engage in activities that focus, for instance, on containing costs, risky investments, organisational burdens (for a survey, see van der Panne, van Beers, and Kleiknecht (2003)).

The aim of this paper is to see whether failure in innovative projects can strengthen or hamper a firm's innovative activity. To do so, a set of empirical estimates will be performed on a large dataset of innovative firms from sixteen countries, drawn from the 2008 Community Innovation Survey. A two-step model will be used to analyse the patterns of failure in innovation, and then examine whether failures have a positive impact on the production of innovation.

At first sight, the failure of a given project may be (and usually is) judged negatively by the firm (Nystrom and Starbuck, 1984). Once its outcome has been thoroughly investigated, however, the firm may realise that the failed project has generated value. This value may be generated in the form of new knowledge about a previously-unnoticed neighbourhood service, or of the creation of new innovative avenues that the failed project had overlooked. In such cases, the real value of the failed project escapes the assessment tools ordinarily adopted to compare ex-post results with ex-ante targets (Elmquist and Le Masson, 2009).

Recent literature has emphasised that failures can have a positive role in organisational activity (Desai, 2010b,a; Chesbrough, 2010). They reveal where and how the organisation was unable to cope with pressure from the outside (Haunschild and Sullivan, 2002; Dorfler and Baumann, 2014), and this has the merit of focusing the organisation's attention on its inability to adapt its techno-economic efforts to market needs. As a consequence, a subset of this literature underscores that learning and failure are closely connected because trial-and-error procedures are among the main elements of discovery (Chesbrough, 2010). In the case considered here, organisational learning is engendered by the capacity of the organisation's members to make sense of the disparate and possibly contradictory reactions of the environment: the only way to cope with them is by providing a creative answer (Coe and Barnhill, 1967).

This paper therefore addresses two related research questions. The first concerns how different types of knowledge affect the probability of a firm failing to innovate. Intuitively, as different types of knowledge imply a different capacity to define the firm's relationships with the outside world, they influence its capacity to face the challenges of innovative activity. On the one hand, direct knowledge acquisition demands a clear definition of the problems involved and an understanding of the consequences of certain actions. On the other hand, vicarious forms of knowledge acquisition involve the typical spillover mechanisms that generate externalities from which firms only benefit indirectly. After empirically examining how knowledge affects the probability of failure, the next research question concerns how failure to innovate impacts a firm's innovative activity. If the knowledge stock gives rise to differential failure patterns, then failure becomes a way of refocusing the firm's relationships, means and targets. This influences their innovative capacity because firms benefit from re-adjusting their knowledge base.

The paper is organised as follows: section 2 reviews the theoretical literature on the subject and presents the hypothesis to test empirically; section 3 describes the data, the econometric method and the variables; section 4 presents the results; and section 5 some concluding remarks.

2 Literature review

The idea that you learn from experience dates back to Adam Smith at least. Learning takes place through a process of trial and error; it happens as a result of repeated attempts to solve problems as they appear.[1] It is therefore a dynamic process that only takes place in the development stage of techno-

[1]For an analysis of the difficulties of defining the concept of knowledge and its relationships with techno-economic performance, see Schneider (2007).

economic activities. Failure is one of the experiences that makes problems emerge and become manifest, thus triggering learning processes.

From the point of view of behavioural theory of the firm (Cyert and March, 1963; Levinthal and March, 1993), organisational learning (for a survey, see Barker Scott, 2011) associated with organisational routines stored within the firm. These routines can adequately represent (following Herbert Simon, 'satisfycingly' well) a firm's response to the challenges coming from the outside environment (Nelson and Winter, 1982). If a routine can cope with the outside world, then it is functionally appropriate and does not need to be changed or questioned. Routines are defined on the strength of past actions, and adopted as a result of strategies to explore and exploit the environment (March, 1991) Once an organisational routine has reached a satisfycing level, it can presumably remain unaltered until it repeatedly proves incapable of representing the world correctly. If a routine is judged successful, it engenders no search activities, but only marginal maintenance procedures (for a review see Becker, 2004).

However, if an organisational behaviour is leading to failure, it is assumed to misrepresent the world, so a procedure (a meta routine) is implemented to ascertain when and where it failed, and to correct it. This search process is implicitly a learning process. This means that firms probably perceive certain problems more effectively once they have actually encountered them. In other words, problems are normally encountered (and presumably solved) by innovative firms. The learning process is also more focused in the case of failure than it would be in the case of success.[2] Failure points more clearly

[2]A paradoxical result of a history of repeated successes (Tushman and Nadler, 1986)

to the new directions the learning process may take because it focuses the firm's attention and underscores the crucial elements that led to a subpar performance. In this sense, failure is a better 'focusing device' than success.

The main bulk of the literature on this topic was developed from an organisational perspective with several papers addressing the issue of the 'benefit of failure'. All these papers analyse case studies on major disasters. The reason for choosing them is because catastrophic failures are easily observed in their full deployment and great visibility, both economic and political (on this point, see the Collins and Pinch (1998) book on the Golem of technology, for instance), and this makes them ideal for the purpose of future organisational and political learning (Desai, 2010b).

In his analysis of the Xerox business model, Chesbrough (2010) supports the idea that failure can provide and convey new ways to understand and implement innovative approaches within an organisation. If failure is perceived as an experiment, new data are created that might reveal opportunities that would otherwise have gone unnoticed. Chiou, Magazzini, Pammolli, and Riccaboni (2012) find in the pharmaceutical industry that knowledge gained from both successes and failures contributes to learning, but failures are particularly important because they may point to hitherto-neglected routes. This increases the chances of finding a different route for patenting new drugs, one that had previously not emerged because other successful routes had been preventing further exploration.

might be a greater organisational complexity and a declining ability to learn: "The effect of success may be even more insidious for motivation, since success increases the likelihood of overconfidence, which may further reduce the motivation to learn" (KC, Staats, and Gino, 2013, p. 2437).

Haunschild and Sullivan (2002) analyse the impact of failures involving airline companies on their subsequent accident rates: they find that accidents deriving from multiple causes induce the airlines involved to conduct more careful investigations. The consequence is that these airlines subsequently have fewer accidents than those experiencing less complex failures. An interesting example is the case study by Dorfler and Baumann (2014) on the 'catastrophic' failure experienced by Airbus during the development of the wide-body jet airliner A380. The A380 program proved to be a dramatic failure that was initially due to wiring problems, but ultimately snowballed into severe issues in the overall organisation of the design and production process. Among other things, this resulted in an eighteen-month delay in delivery and a huge slump in the price of Airbus shares. Analysing this failure suggests that the switch from an 'ordinary' to an 'emergency' behaviour usually follows two paths: a top-down ad hoc process and a bottom-up systemic process. While the former might seem reasonable in the aftermath of the failure (promoting an initial 'quick fix' of the problems), it is the adoption of an appropriate, systemic, bottom-up approach to learning that proves crucial to the establishment of an effective problem-solving activity capable of generating much needed organisational changes to survive the crisis.

Madsen and Desai (2010) analyse the impact of the 2003 disaster of the Columbia Space Shuttle.[3] They find that, straight after that catastrophic incident, the immediately-established Columbia Accident Investigation Board

[3]It is noteworthy that in the wake of the analysis based on major disasters, Labib and Read (2013) place the Columbia accident side by side with three other 'landmark' accidents: the sinking of the Titanic, the BP Texas City incident and the Chernobyl nuclear plant explosion.

highlighted the value of prior failure in driving organisational learning. Just like successes, previous near misses (i.e. minor incidents that never turned into full-blown failures, like the similar damage suffered during the launching of the Atlantis Space Shuttle some months earlier) were less likely to generate a thorough review of the organisation's practices (Dillon and Tinsley, 2008). Much the same picture emerged from other analyses conducted on accidents in the gas (Desai, 2010a) and railroad industries (Desai, 2010b; Baum and Dahlin, 2007).

An important element emerging from this literature concerns the role of observing other agents' behaviour in deciding one's own. In the sphere of psychology it is argued that people's own past failures have a positive effect on their innovative performance (KC, Staats, and Gino, 2013). Individual experience of others' failures also has an impact on individuals' performance and, notably, other people's failures have a stronger positive influence than their successes. Based on these premises, an interesting body of literature concerns the processes of learning from others' experience of failure. It has been demonstrated that because organisations have a strong tendency to look more at success stories than at failures (typically because they select a sample of firms that survive, so they must be successful), they are liable to a systematic bias by under-sampling failure in their vicarious learning (Denrell, 2003). In their analysis of US commercial banks, Kim and Miner (2007) show that both near-failure and failure can engender vicarious learning, which is stronger for local than for non-local experiences. When Chuang and Baum (2003) analyse nursing homes operating in Ontario, and Ingram and Baum (1997) examine the failure rates of US hotel chains, the picture is similar:

learning from others is localised and related to the operating and competitive experience of the particular industry in which the focal firms are located.

As already mentioned, the papers discussed so far are analyses based on case studies. They are constructed to provide a thorough understanding of particular processes and have a theory-building aim. These papers have consequently been successful in generating conceptual propositions that have been the object of subsequent publications based on more extensive and systematic datasets statistically representative of the universe to which they refer. The bulk of this literature focuses on the so-called "barriers to innovation".[4]

Galia and Legros (2004), Blanchard, Huiban, Musolesi, and Sevestre (2013), and Lhuillery and Pfister (2009) conduct analyses on the situation in France, while several other reports are based on data collected in Spain (D'Este, Rentocchini, and Vega-Jurado, 2014; Madrid-Guijarro, Garcia, and Van Auken, 2009; Garcia-Vega and Lopez, 2010), the UK (D'Este, Iammarino, Savona, and von Tunzelmann, 2012), and Canada (Baldwin and Lin, 2002). Mohnen and Roller (2005) analyse data from four European countries

[4]Although it is beyond the scope of this paper, it should be noted that some contributions address the role of other, intangible elements in possible barriers to innovative activity. By referring to psychology, some of the literature has emphasised the role of such intangible factors as managerial perception. Mental models, defined as "[...] deeply ingrained assumptions and generalisations that influence how individuals and organisations understand the world and how they take action" (Yannopoulos, Gorish, and Kefalaki, 2011, p. 118), have thus been proposed, and "[...] it can be hypothesised that an important set of clues to the problem of the management of innovation will be located in the domains of managerial perceptions of *the need for change*, managerial perception of *the opportunity to change* and the perception about *the way to change* (Storey, 2000, p. 351).

(Ireland, Denmark, Germany and Italy), while Galia, Mancini, and Morandi (2012) draw a comparison between France and Italy. Iammarino, Sanna-Randaccio, and Savona (2009) analyse multinational firms, while Hadjimanolis (1999) considers the case of a small country like Cyprus. The only article dealing specifically with failure (Radas and Bozic, 2012) comes fully within this line of study, highlighting factors that help to deal with it.

The papers addressing this topic consistently define several types of barrier (e.g. costs, human capital/knowledge, markets, financial barriers and, sometimes, regulatory obstacles), and they focus on the 'prime suspect' covariates (such as sectoral differences, R&D activity, firm size, belonging to an industrial group, etc.). In almost every case, a sort of 'surprising' result emerges, and that is the positive correlation between a proxy of innovative activity and barriers of this kind. This seems to mean that firms are more aware of these barriers if they appear to come closer to them in their innovative activity. Almost all the papers find financial barriers quite binding (see below), while for other types of barrier the results are not very consistent. The sector involved and whether or not a firm is part of an industrial group generally seem to be important, but their effects sometimes differ, depending on the type of innovative activity involved. Where it is checked for, another important element concerns the influence of the outside industrial environment, and particularly its role in knowledge acquisition, as in collaboration (Lhuillery and Pfister, 2009; Galia and Legros, 2004; Mohnen and Roller, 2005) and networking (Hadjimanolis, 1999).

Particular attention has been paid to financial constraints, which can apparently be major barriers to innovation. Financial constraints are shown to discriminate between different types of firm — large vs small, and market-based vs bank-based systems (Canepa and Stoneman, 2005; Mohnen and Roller, 2005; Mohnen, Palm, Schim Van Der Loeff, and Tiwari, 2008; Garcia-Vega and Lopez, 2010; Hajivassiliou and Savignac, 2007; Savignac, 2008). One particularly relevant finding concerns the impact of financial barriers at different stages of the innovative project: financial constraints seem more likely to have a significant impact on the early stages of innovative projects (stopping them prematurely, or seriously delaying them), whereas they do not affect innovative activities already well underway (Canepa and Stoneman, 2005).

Though interesting, these papers deal more with obstacles to innovative activity than with failures *per se*. They focus on why innovative projects never actually started or were delayed rather than on the unsuccessful outcome of innovative projects actually undertaken (as in the present paper). Though they address problems relating to firms' inability to innovate, they concentrate on a different set of phenomena and related issues. By focusing on the barriers to innovative activities, these papers are still steeped in the traditional idea of a market failure that prevents firms from fully exploiting their innovative potential. They continue to address the problem of how to remove impediments to a firm's innovative activity, to nurture a fully-fledged system that enables firms to maximise their innovative efforts. The present paper aims to address a different topic, relating to how firms are liable to fail not because they meet with some obstacle, but because their innovative activity is inherently uncertain, so — through a process of trial and error — they are likely (sooner or later) to experience a failure. But that is precisely why failure might become a positive opportunity to increase a firm's knowledge stock rather than just a negative setback.

2.1 Testable hypothesis

2.1.1 The probability of an innovative project being abandoned or to have it still ongoing

The previous analysis suggests some essential issues that are worth testing empirically. Organisations gain from their operating experience, learn from failures, and thus become less prone to making the same mistakes. This happens for several reasons. What organisations gain from their previous operating experience comes from at least two different sources (Desai, 2010a): i) operational experience gives firms a chance to learn because, being reliant on routines and repetitive in nature, it repeatedly provides opportunities for firms to test their routines and procedures vis-à-vis the outside world; and ii) operational experience generates an absorptive capacity, through which relevant knowledge becomes more readily accessible (Cohen and Levinthal, 1989). As this paper concentrates on innovative activities, operating experience can be defined in terms of R&D. In particular, when it comes to improving and integrating the management of a firm's innovation, it is natural to focus on R&D because its function is to provide innovation input and produce knowledge. It also differs from the firm's other attributes in that it is the outcome of a managerial decision, a deliberate, voluntary addition to the firm's stock of knowledge. This is especially true when innovative activities are underway (e.g. Chesbrough, 2010; Chiou, Magazzini, Pammolli, and Riccaboni, 2012) and highly innovative projects are encountering major problems (e.g. Madsen and Desai, 2010; Dorfler and Baumann, 2014).

Operating experience thus makes organisations less likely to make more mistakes when responding to failures by enhancing their capacity to learn. Their learning curve is better suited to improving their ability to interpret situations more correctly than they might have done if they had no prior experience.

This leads us to formulate the following hypothesis:

H1a. Firms with more operating experience are less likely to experience failures in their innovative projects.

However, as firms build up their operating experience, their ability to further develop their knowledge in ongoing innovative projects increases too, and this could well lead to delays in ongoing innovative projects. Another testable hypothesis is therefore:

H1b. Firms with more operating experience are more likely to have ongoing innovative projects.

Another element that suggests different ways to develop organisational learning is the distinction between generalist and specialist organisations, particularly as concerns how they deal with failure (Ingram and Baum, 1997; Haunschild and Sullivan, 2002; Haunschild and Rhee, 2004; Rhee and Haunschild, 2006). The distinction between generalist and specialist firms refers to the fact that generalist organisations have larger portfolios of products, suppliers and stakeholders. We use the term generalist here to mean the degree of organisational complexity (not mere size[5]), in the sense of a broader range

[5]Organisational complexity should not be intended as merely a matter of size; firms

of products and suppliers than in specialist firms. Mobilising, coordinating and deploying capabilities demands a particular kind of knowledge related to what is called resource management, which is complex, tacit and idiosyncratic. The process by means of which firms build their resource portfolio involves bundling resources and leveraging on these capabilities. A process of asset orchestration is needed to achieve results (Sirmon, Hitt, and Ireland, 2007; Sirmon and Hitt, 2009). Many contributions thus make the point that, being complex and articulated, generalist firms are more liable to inertial processes and consequently less likely to start internal learning processes promptly and endogenously, and less willing to modify their routines (Haunschild and Rhee, 2004).

Precisely because of these particular characteristics, generalist firms appear to be more resilient to failure. They learn by means of complex processes and face a variety of challenges. While this may be detrimental in the case of positive learning processes, it is undoubtedly positive for the organisation's attitude to failure because its stock of knowledge is used to focus on facing and solving more complex and challenging tasks than those of specialist organisations. Faced with failures, generalist organisations can thus draw on a broad knowledge base that they have acquired from a variety of experiences. The more complex organisational structure of a generalist firm makes it better able than a specialist firm to deal with multidimensional relationships (Desai, 2010b, p. 7),[6] and it is more likely than specialist organisations to

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of much the same size may well have different degrees of organisational complexity. For instance: "US automakers are more likely to be generalist that foreign automakers are" (Rhee and Haunschild, 2006, p. 109).

[6]This element should not be confused with open innovation strategies designed to

apply the knowledge it has acquired and successfully draw on outside knowledge sources as well as its own, given that failures are normally complex and unfamiliar events.

Hence another hypothesis:

H2a. Firms faced with failures can benefit from outside knowledge.

As already stated, firms can also learn indirectly from the experience of others, from knowledge that involuntarily spills out of other, competing firms. Firms can benefit from knowledge externalities generated by neighbouring firms (as is the case, for instance, in industrial districts). In this case, we maintain that firms benefit from the chance to observe other organisations experiencing problems similar to their own — especially if they are industrially or geographically close (Ingram and Baum, 1997).

We also expect direct and indirect external knowledge to interact in determining the likelihood of failure. To benefit from indirect knowledge, firms must have certain levels of operating experience and organisational complexity. The ability to recognise and assess other firms' experiences is crucial to an organisation, but to be able to understand such experiences it needs to have accumulated a knowledge stock of its own. We therefore maintain that operating experience and organisational complexity act as moderating variables with respect to indirect learning. Hence the following hypothesis:

H2b. External knowledge affects the likelihood of failure differently, de-

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benefit from knowledge coming from very diverse (in breadth) or very deep sources. The dimension we refer to here is truly organisational, relating to the strategies used to obtain knowledge from different sources. This has to do more with an organisation's innovative activity than with its operating experience. A firm with specialist aims can still pursue a 'broad', open innovation strategy.

pending on whether it is direct or indirect.

2.1.2 The probability of producing an innovation

Since the patterns of learning within organisations are complex and idiosyncratic, they differ when they address strengths and weaknesses. Learning is also associated with different patterns depending on whether or not the organisation's routines are successful. If its routines happen to be successful, they are adequately representative of the firm's needs and its relationships with the outside environment (i.e. they well represent the world). They are consequently maintained unaltered. If instead they consistently fail, the firm conducts an investigation to see what went wrong. In this case, we might expect to find that the more a firm deals effectively with failures, the more it will conduct investigations that lead to learning processes. We thus advance the following hypothesis:

H3. A firm that has faced an experience of organisational failure is less likely to fail again.

As well as failures, firms may have ongoing innovative projects too. It may also be that an innovative project meets with some unforeseen problems and has to be postponed, and firms may not necessarily see this as a failure. They may realise that they had not foreseen all the problems involved, or discover that the project is more promising than they originally thought. In both cases, projects may remain ongoing for longer than expected. If this happens, it means the firm was unable to predict the impact of its project correctly (overestimating it in the former case, underestimating it in the latter). Innovation that is ongoing or postponed (for whatever reason) is therefore likely to be a sign of a limited capacity for innovation, since the problems encountered along the way are simply deferred, instead of being properly addressed (and solved). A fourth and final hypothesis to test is thus:

H4. As ongoing innovative projects show a poor capacity to deal with innovation, they carry a lower likelihood of being innovative.

3 Data, method and variables

3.1 Data

The empirical analysis in this paper is based on the anonymised *Community Innovation Survey 2008 (CIS 2008) — The harmonised survey questionnaire* co–ordinated by Eurostat (OECD/Eurostat, 2005). The Survey, in its sixth round, covered the period from 2006 to 2008 and included sixteen countries: Bulgaria, Cyprus, Czech Republic, Germany, Estonia, Hungary, Ireland, Italy, Latvia, Lithuania, Norway, Portugal, Romania, Slovakia, Slovenia, and Spain. Firms with at least 20 employees answered questions primarily concerning: the nature of their technological innovations, the supervision of these innovations (i.e. innovation projects), the internal and external sources involved (in R&D), the objectives of their technological innovations, the sources of information used, cooperation to innovate and obstacles to innovation projects (for a description, see for instance Mairesse and Mohnen (2010)).

The CIS 2008 dataset comprises 127,338 firms and 24% of which introduced a product innovation in the three-year period from 2006 to 2008, while 29% introduced a process innovation, 29% introduced an organisational innovation, and 23% a marketing one. Almost 17,000 firms introduced a product innovation that was also new to the market (and 23,400 one that was new to the firm), while only 12,600 introduced a process that was new to the market (and 16,700 one that was new to the firm). The knowledge needed to develop a product innovation came mainly from within the business (for 23,500 firms), while only 3,400 reported using outside sources, and 8,000 used both; for process innovations, the figures were much the same for the numbers of firms reportedly relying on internal sources (25,000) and both internal and external sources (8,000), while almost twice as many firms (6,000) used outside sources.

3.2 Econometric method

The strategy adopted in our estimates[7] is a two-step model, which was chosen to mitigate the inevitable problems of endogeneity and reverse causality in the use of a cross-sections (in practice, it is a way to instrument the model to correct for biases due to endogeneity): (i) the first step deals with the

[7]The econometric strategy of this paper mimics the Crepon, Duguet, and Mairesse (1998) model, which was developed to assess the impact of innovative activity on a firm's performance. The original CDM model is a structural model in three steps. First, an R&D equation is estimated (i.e. how firms decide whether or not to undertake R&D and, if so, how intensively). Then, in a second step, the predicted R&D values are input in an equation that models the relationships between innovation inputs and innovative output (either share of innovative sales or patent counts). In the third step, the innovative output is used as an explanans in a productivity equation. The third step cannot be implemented in the present paper because the dataset lacks consistent data on economic performance.

determinants of the patterns of abandoned innovation (and then of ongoing innovation) by means of a Heckman procedure to deal with the presence of selection bias; (ii) the second step deals with the probability of producing an innovation by using the values estimated in step 1 as the main covariates to examine the role of failed innovative projects in a firm's innovative activity.

The Heckman procedure (Heckman, 1979) needs to be used in the first step to cope with selection bias. Firms answer a question on whether or not they have abandoned any innovation projects, so we can collect both true zeroes due to innovation being abandoned after making an effort to innovate, and zeroes due to a firm having no innovative activity. Because of the particular structure of the dataset covering three years (2006-'08) the firms declaring that they have abandoned an innovative project may have started it during the same three-year period or beforehand. This gives rise to a selection bias because we may have some firms that in 2006-2008 abandoned an innovative project started during the same period and others that abandoned a project begun before 2006. So we may have firms reportedly experiencing a failure as a result either of a project started and abandoned during the same period, or of a project started beforehand (and in the latter case, the firm may have no failures concerning projects initiated during the three years considered, but they would still answer 'yes' to the question about whether they had experienced a failure). The opposite could happen too: a firm reporting no innovative activity might report experiencing no failures, or it might report a failure relating to an innovative activity started during the previous period; conversely, it might report no failures, but this is thanks to the good outcome of a project initiated earlier.

Since a Heckman model is used because of the selectivity problem generated by the fact that only a fraction of firms abandon innovation in a given period, the information used for selection purposes must be independent and refer to the whole set of firms (Vella, 1998). In this case, the firms' size, in terms of their turnover ($lturn08$), and whether or not they belong to an industrial group ($Group$) are used as the identification variable (see Vella (1998) for a discussion on the caution needed in using such models). As already mentioned earlier, although the effect of a firm's size on the probability of it conducting R&D, and thus on its innovativeness is a sort of standard result, there is agreement in the literature on failure that the chances of an innovative project being abandoned depends less on the size of the organisation, and more on its complexity. The only article dealing with this issue identified no such relationship (Radas and Bozic, 2012), so it seems reasonable to use firms' size in the selection equation. Belonging to a group should work too because this variable seems to have an impact on innovative activity, but its influence on failure is questionable at least. On the one hand, having a broader business environment might enable a given firm to benefit from a larger pool of knowledge that it can draw on to avoid failure. On the other hand, innovative activity could be used strategically by a whole group, in which case a group might be induced to abandon an innovative project — even though it could generate positive results — because it comes up against constraints on the availability of resources for the industrial group as a whole. If the group opts to abandon certain lines of research in favour of others, the evidence at firm level would be that an innovation project is abandoned for no other reason than that the firm is part of an industrial group. For both variables, the correlation table shows very low values (see below).

3.3 Variables

3.3.1 The first step

The dependent variable of the first step is a dummy variable ($InAba$), which is 1 if a firm answered yes, and 0 if the answer was no, to the first part of question n. 4 in the CIS questionnaire ["During 2006 to 2008, did your enterprise have any innovation activities that did not result in a product or process innovation because the activities were abandoned or suspended before completion?"].

The set of independent variables comprises the log of R&D ($lR\&D$) expenditure (from question 5.2). The expectation is that a larger stock[8] of R&D coincides with a firm having more experience, and thus being less likely to experience failure. This provides an empirical test for H1.

The second set of independent variables includes dummy variables describing the origin from which product (question 2.2) and process (question 3.2) innovation develop. This enables us to obtain information on how the firms were able to produce and gather the knowledge they needed to innovate, be it from outside the firm ($ExtKnow$), from within ($IntKnow$), or from a combination of the two ($JoinKnow$). The assumption is that, for a firm to be able to draw on knowledge from external sources, its innovative activity

[8]It is worth emphasising that the available data on R&D concern the three years 2006-08, so it might appear inappropriate to use these data to capture the R&D stock. This appears to be a minor issue, however, since an important characteristic of R&D lies in its stability over time (see for instance, OECD (2014)).

must be more general. Thus, the wider the pool from which knowledge is gathered, the broader the set of competences the firm needs to develop in order to produce a marketable innovation; and therefore the broader the set of competences, the lower the likelihood of failure. Vice versa, a firm that draws exclusively (or nearly) on internally produced knowledge is unlikely to have a broad set of competences. This should provide an empirical test for H2a.

While the previous set of variables refers to the direct and purposeful acquisition of knowledge by the firm, another independent variable concerns indirect learning. Firms can gain useful knowledge indirectly from a set of other firms lying within a certain cognitive distance from them (see for instance, Boschma (2005); D'Este, Guy, and Iammarino (2013)). In particular, it seems likely that firms can benefit from other firms' knowledge spillovers if they are close enough both geographically and in terms of the business sector involved. Such indirect knowledge acquisition is approximated using a variable ($IndLearn$) constructed as follows: the total number of abandoned innovation projects is allocated by business sector and country, then any given firm is assigned the number of abandoned projects in its same sector and country. This gives us the number of abandoned projects to which the firms were 'exposed', and from which they may have learned something (since projects abandoned in the same country and sector would be easier for them to understand than others farther removed from their area of expertise).

The indirect learning variable is introduced to enable a comparison to be drawn between knowledge flows that the firm introduces directly (from direct experience with certain types of information source that they report having used in the past three years) and those absorbed indirectly (through contact with similar experiences that the firm knows about, from which it can extract useful information). This covariate should provide additional evidence on H2b.

Finally, a dummy variable ($NewMkt$) is added, which takes the value of 1 if the firm answers yes, and 0 if it answers no to question n. 2.3 ["Did your enterprise introduce a new or significantly improved good or service onto the market before your competitors?"], so that we can control the estimation for the riskiness of producing leading-edge innovation.

A second set of estimates is performed with the same set of covariates and ongoing innovation as the dependent variable ($InOng$), which is a dummy variable taking the value of 1 if the firm answers yes, and 0 if it answers no to the second part of question n. 4 ["During 2006 to 2008, did your enterprise have any innovation activities that did not result in a product or process innovation because the activities were still ongoing at the end of the 2008?"].[9]

[9] This question should shed light on the innovative projects that were not completed, neither successfully nor unsuccessfully. Answering this question is tricky, however, because it allows for two possible interpretations: either the firms answer yes because they have ongoing projects that they are still conducting, or they have encountered unforeseen problems that caused a delay. It is obviously impossible to disentangle the two. As in the previous case, since the firms are reporting that a project was incomplete, it seems reasonable to interpret them as projects that for some reason took a long time to complete (we can exclude projects initiated close to the end of the three-year period because they would be counterbalanced by those finished immediately after the beginning of the period). For this reason, it seems feasible to define both categories as innovative projects that are more 'burdensome' for the firms and consequently likely to absorb more of the

Thirteen sectoral dummies are included. The descriptive statistics and correlation values are given in Table 1, where we can see that the covariates are not correlated (*Group* and *turn*08 in particular). Only the three sources of knowledge show stronger correlations, and that is why they are used separately in the estimations.

3.3.2 The second step

The dependent variable for the second step (*InSal*) is the proportion of innovative sales, as captured by the "percentage of total turnover in 2008 coming from new or significantly improved goods and services that were new to the market". In this way, we describe an important innovative output in line with the CDM model (see footnote 7).

The independent variables are: the predicted values obtained from the estimates carried out in the first step: (i) abandoned innovation (*PredInAba*) will provide evidence for H3; while (ii) the predicted value from ongoing innovation in the first step (*PredInOng*) will provide evidence relating to H4.

Two sets of covariates are added to elucidate the role of knowledge in producing innovation. The first set relates to the depth and breadth (Laursen and Salter, 2006) of the sources of innovation (question 6.1). The *Breadth* variable is obtained by assigning a value of 1 to any of the 10 sources of information and cooperative activities reportedly used by a firm, and 0 if they are not. Then the sum of the 10 values provides a count ranging from 0 if no knowledge sources are used by the firm to 10 if all the sources are used.

organisation's resources.

The *Depth* variable takes on a value of 1 if a source of knowledge is judged very important, and 0 if it is judged to be of moderate or little importance. Here again, the sum of the values for the 10 sources gives us a score where 0 means that no source of knowledge was reportedly particularly important, while a score of 10 means that the firm considered all the knowledge sources very important.

The second set of variables derive from the answers given to question 6.3 on the types of cooperation with partners by location. The first is a dummy variable ($CoopHC$) taking a value of 1 for cooperation in a firm's home country, and 0 otherwise. The other is a dummy variable ($CoopRW$) taking a value of 1 for cooperation with the rest of the world, and 0 otherwise.

Country dummies are added for the 16 countries sampled. The descriptive statistics and the correlations are given in Table 2. Since some covariates are strongly correlated, they are used separately in the regressions.

4 Results

4.1 First step — The probability of failure

4.1.1 Abandoned innovation

The first step of the empirical exercise is presented in Table 3. The Heckman procedure proves to be a good choice as the ρ coefficients are significant in all five specifications indicating the presence of a selection bias. The test of independent equations (shown at the bottom of the Table) also confirms that the null hypothesis of no correlation and consequently of no selection bias is rejected. Finally, the variables used for the selection procedure appear to be statistically significant and thus represent appropriate selection instruments.

It emerges from Table 3 that the probability of an innovative project being abandoned is negatively related to the level of R&D, thus confirming H1a concerning the need to have a certain absorptive capacity also with respect to the abandonment of innovative project. The level of R&D has the effect of increasing the stock of knowledge engendered with respect to failure.[10]

The production of new-to-the-market innovation is significant and positively related to the likelihood of failure. This is because such innovation is more risky and consequently more strongly associated with the possibility of something going wrong.

The capacity to learn from external knowledge sources has a positive role in reducing the chances of an innovative project being abandoned (in fact it is negatively correlated and statistically significant). The same does not hold when the firm builds its knowledge stock either completely ($IntKnow$) or at least partially ($JoinKnow$) in-house, in which case both coefficients are statistically significant, but positive. This seems to confirm H2a.

The effect of indirect learning is quite an interesting example of how the

[10]There may be a problem of simultaneity for the variable on abandoned innovation and R&D. As already mentioned, however, investments in R&D appear to be fairly constant over time, so it is reasonable to expect R&D expenditure to be scarcely volatile. A certain level of R&D (because we are interested here in the level of R&D, not just in the presence of any level of R&D) in a given year can be seen as a result of previous investments. From the empirical standpoint, and as a robustness check, the same regressions were run using the amount of R&D expenditure only for the firms that reported undertaking R&D, in-house or externally, in the years 2006-08 (question 5.1): the results obtained were consistent (and are available on request).

learning process follows far from ‘linear’ patterns. If the variable *IndLearn* is considered alone (column 4 of Table 3), it is found positively and significantly related to the probability of an innovative project being abandoned. Once it is interacted with the main covariates (here again, the Heckman procedure is justified by the statistical tests), however, the relationship becomes negative and significant in interaction with external knowledge (column 2 of Table 4), and with R&D (column 3 of Table 4). This seems to confirm the complementary role of indirect learning, which becomes relevant in reducing the likelihood of failure only when it is used in relation to the stock of existing knowledge. So, if we select the firms investing in acquiring knowledge, this investment gives them the chance to better understand what happens in the outside world.

4.1.2 Ongoing innovation

Another test is performed to see whether there is a different pattern behind ongoing innovative projects with respect to those being abandoned (Table 5). Here too, a Heckman procedure (for which all the statistical tests are satisfactory once again) shows that higher levels of R&D coincide with a higher likelihood of a project lasting longer than the three-year period covered by the survey. This confirms H1b: the more experience the organisation possesses, the higher the probability of new elements coming to light that necessitate further investigations, and take more time.

The production of new-to-the-market innovation is positively related, here again, to the probability of innovation being ongoing because their riskiness demands more resources. The probability of an innovative project still being underway is related negatively to external knowledge acquisition and positively to knowledge produced exclusively or partially in-house. This seems to suggest a dual role of knowledge production, and the possibility that accessing new knowledge outside the organisation enables firms to understand better the innovative process and consequently reduce the likelihood of projects lasting a long time.

4.2 Second step — The probability to innovate

4.2.1 Abandoned innovation

The probability of innovation succeeding (i.e. of a firm having a high proportion of its total turnover deriving from new or significantly improved goods or services) is shown in Table 6, where the prediction emerging from the first step concerning the innovative projects likely to be abandoned is input in the logistic estimation. This predicted value is positive and significant, confirming H3 on the role of failure in contributing to the innovative capabilities of an organisation.

All the controls have the expected signs, positively influencing the likelihood of innovation. A cooperative attitude (inside and outside the firm's home country) thus has a positive impact, as does the breadth and depth of knowledge acquisition.

4.2.2 Ongoing innovation

Table 7 shows the probability of a firm achieving high percentages of its total turnover from new or significantly improved goods or services when the prediction of ongoing innovative activity emerging from the first step is taken into account.

The results are quite similar to those seen in the previous case, except that the main covariate reveals a lower marginal impact, thus confirming H4: when the two cases were compared (in an estimation not shown), the marginal impact of abandoned innovation was almost four times larger, i.e. 2.95 as opposed to 0.78 for ongoing innovation. These results seem to be consistent with the previously-cited literature on the different roles of small and large failures, and, more in general, on the fact that a project still underway may well subtract resources from new innovative activity.

5 Conclusion

This paper provides novel empirical evidence of the impact that the failure of innovative projects has on the production of innovative goods by the sample of firms covered by the Community Innovation Survey 2008. It shows that the idea that an unsuccessful innovative activity might ultimately have a positive fallout on a firm's organisation is far from absurd. If firms are seen as learning organisations, their learning patterns are bound to be more stimulated if they are under stress due to negative results. Several articles have consistently shown that, within a behaviouralist framework, firms typically persist in their organisational routines if they happen to be successful in their representation of the outside world, whereas they challenge them whenever those same routines become unreliable.

If this is true, then organisational routines are only questioned when they systematically fail to produce a certain level of satisfycing performance. This situation can only occur when projects fail to perform as expected. Failure thus seems to be important in driving innovative activity, acting as a supplementary means for building organisational knowledge.

This paper provides fresh empirical support for these models on two related levels: on the one hand, the elements both positively and negatively influencing the failure of an innovative project; and on the other the role of failure in spurring innovative activity.

The main findings are consistent with the scanty literature on the topic, and underscore the positive role of the experience accumulated by a firm and the degree of generality it adopts in dealing with knowledge flows. Once failure is incorporated in an innovative equation, it can positively affect the production of innovation. If innovative activity remains ongoing (instead of being abandoned) the estimation shows that this impact is reduced. In such cases, accumulated experience has the effect of leading to innovative projects being postponed due to the fact that, during the innovative process, new discoveries may slow the pace of the original project because they open up new avenues of research.

The policy implications of these results can be considered from several points of view. First, failure should not be seen exclusively as a negative element, the determinants of which (the barriers to innovation) should be the sole target of policies aiming to remedy the market failure, and thus enable society to benefit fully from the innovative activity. Second, instead of removing 'tangible' barriers, policy-makers should help firms to remove the 'intangible' ones relating to the negative stigma usually associated with failure. It should be made clear that, as failure is strongly associated with complex and idiosyncratic processes of learning, it can be a positive element for both the firm's organisation and the outside world. For the former, failure should be seen not as a drawback but as an opportunity to improve the organisation's knowledge stock. For the latter, attention to the experiences of others should focus more on how they deal with difficulties than on their successes. Third, the accumulation of a stock of knowledge, both from direct investments in innovative activity and from networking efforts, should be encouraged and ought to be the target of direct policy interventions.

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Table 1: Summary statistics for Step 1

	min	max	N	InAba	lR&D	NewMkt	ExtKnow	JoiKnow	IntKnow	IndLearn	Group	lturn08
InAba	0.0	1	122,676	1								
lR&D	-0.4	22	39,016	-0.0323***	1							
NewMkt	0.0	1	55,060	0.101***	0.165***	1						
ExtKnow	0.0	1	127,338	-0.0826***	-0.0718***	-0.0961***	1					
JoiKnow	0.0	1	127,338	0.0376***	-0.00574	0.0486***	-0.107***	1				
IntKnow	0.0	1	127,338	0.0335***	0.0853***	0.154***	-0.304***	-0.433***	1			
IndLearn	0.0	2109	127,338	0.107***	-0.0264***	0.0606***	-0.0640***	-0.0670***	0.147***	1		
Group	0.0	1	127,163	0.0918***	0.305***	0.0865***	-0.0743***	0.00912	0.0471***	-0.0154*	1	
lturn08	-1.1	24	125,642	-0.0534***	0.881***	0.110***	-0.0460***	-0.00668	0.0538***	-0.0509***	0.379***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2: Summary statistics for Step 2

	min	max	N	InSal	Depth	Breadth	CoopYC	CoopRW
InSal	0.05	0.15	92,054	1				
Depth	0.55	1.20	127,338	0.276***	1			
Breadth	2.26	3.47	127,338	0.317***	0.672***	1		
CoopYC	0.11	0.31	40,307	0.215***	0.408***	0.458***	1	
CoopRW	0.06	0.24	127,338	0.178***	0.307***	0.330***	0.543***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Step 1 — Probability of abandoning an innovation, Heckman regression

	(1)	(2)	(3)	(4)	(5)
InAba					
lR&D	-0.00810***	-0.00780***	-0.00796***	-0.00705***	-0.00732***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
NewMkt	0.0890***	0.0929***	0.0924***	0.0905***	0.0839***
	(0.006)	(0.005)	(0.006)	(0.006)	(0.004)
ExtKnow	-0.0935***				-0.0783***
	(0.007)				(0.009)
JoiKnow		0.0340***			0.0376***
		(0.006)			(0.007)
IntKnow			0.0165***		0.00758
			(0.005)		(0.008)
IndLearn				0.0000492***	0.0000487***
				(0.000)	(0.000)
Cons	0.452***	0.434***	0.432***	0.387***	0.380***
	(0.010)	(0.011)	(0.011)	(0.015)	(0.012)
InnoTot					
Group	0.586***	0.587***	0.587***	0.586***	0.584***
	(0.012)	(0.011)	(0.009)	(0.010)	(0.010)
lturn08	-0.00448***	-0.00463**	-0.00460**	-0.00429**	-0.00417*
	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)
Cons	-0.354***	-0.352***	-0.353***	-0.346***	-0.347***
	(0.023)	(0.027)	(0.026)	(0.024)	(0.029)
Sector Dummies	yes	yes	yes	yes	yes
athrho	-0.301***	-0.315***	-0.311***	-0.273***	-0.260***
	(0.013)	(0.012)	(0.013)	(0.015)	(0.013)
lnsigma	-0.800***	-0.795***	-0.795***	-0.807***	-0.812***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Chi2	244.29	276.51	266.57	189.19	166.69
Prob	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
N	92061	92061	41 92061	92061	92061

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: The role of indirect learning, Heckman regression

	(1)	(2)	(3)
InAba			
lR&D	-0.00732***	-0.00734***	-0.00507***
	(0.001)	(0.001)	(0.001)
NewMkt	0.0839***	0.0857***	0.0900***
	(0.005)	(0.005)	(0.006)
ExtKnow	-0.0783***	-0.0759***	
	(0.007)	(0.009)	
JoiKnow	0.0376***		
	(0.007)		
IntKnow	0.00758		
	(0.008)		
IndLearn	0.0000487***	0.0000495***	0.0000818***
	(0.000)	(0.000)	(0.000)
ExtKnow x IndLearn		-0.0000246*	
		(0.000)	
lR&D x IndLearn			-0.00000298**
			(0.000)
Cons	0.380***	0.397***	0.362***
	(0.016)	(0.012)	(0.016)
InnoTot			
Group	0.584***	0.584***	0.585***
	(0.009)	(0.011)	(0.011)
lturn08	-0.00417**	-0.00418*	-0.00420**
	(0.001)	(0.002)	(0.001)
Sector Dummies	yes	yes	yes
Cons	-0.347***	-0.347***	-0.347***
	(0.031)	(0.028)	(0.027)
athrho	-0.260***	-0.262***	-0.266***
	(0.017)	(0.015)	(0.014)
lnsigma	-0.812***	-0.811***	-0.808***
	(0.004)	(0.004)	(0.004)
Chi2	116.69	169.09	172.26
Prob	(0.000)	(0.000)	(0.000)
N	92061	92061	92061

Bootstrapped standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Step 1 — Probability of innovation still ongoing, Heckman regression

	(1)	(2)	(3)	(4)	(5)
InOng					
lR&D	0.0409***	0.0411***	0.0410***	0.0422***	0.0421***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
NewMkt	0.0956***	0.100***	0.101***	0.0994***	0.0914***
	(0.005)	(0.006)	(0.006)	(0.005)	(0.006)
ExtKnow	-0.129***				-0.117***
	(0.009)				(0.011)
JoiKnow		0.0491***			0.0462***
		(0.005)			(0.007)
IntKnow			0.0127*		0.00113
			(0.006)		(0.009)
IndLearn				0.0000474***	0.0000473***
				(0.000)	(0.000)
Cons	0.164***	0.148***	0.150***	0.0927***	0.0833***
	(0.018)	(0.016)	(0.021)	(0.016)	(0.019)
InnoTot	0.579***	0.579***	0.579***	0.580***	0.580***
	(0.011)	(0.012)	(0.011)	(0.011)	(0.009)
lturn08	0.0000427	0.0000199	0.0000158	0.0000194	0.0000386
	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)
Cons	-0.356***	-0.354***	-0.355***	-0.352***	-0.353***
	(0.024)	(0.027)	(0.020)	(0.032)	(0.027)
athrho	-0.201***	-0.236***	-0.229***	-0.176***	-0.148***
	(0.024)	(0.023)	(0.024)	(0.020)	(0.023)
lnsigma	-0.756***	-0.748***	-0.748***	-0.758***	-0.766***
	(0.004)	(0.004)	(0.005)	(0.003)	(0.003)
Chi2	74.48	109.47	102.69	57.81	40.05
Prob	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
N	92801	92801	92801	92801	92801

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: Step 2 — Logit estimation of the probability of producing a market innovation with abandoned innovation

	(1)	(2)	(3)	(4)	(5)
PredInAba	17.77***	17.79***	17.75***	17.77***	17.75***
	(0.219)	(0.219)	(0.219)	(0.220)	(0.220)
Depth	0.128***	0.127***			0.0816***
	(0.013)	(0.013)			(0.014)
Breadth			0.0901***	0.0888***	0.0676***
			(0.008)	(0.008)	(0.008)
CoopHC	0.417***		0.381***		0.174***
	(0.042)		(0.042)		(0.047)
CoopRW		0.642***		0.609***	0.482***
		(0.051)		(0.052)	(0.057)
Cons	20.46***	20.42***	20.07***	20.03***	19.99***
	(0.343)	(0.343)	(0.345)	(0.345)	(0.345)
Country dummies	yes	yes	yes	yes	yes
N	26065	26065	26065	26065	26065

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7: Step 2 — Logit estimation of the probability of producing a market innovation with still ongoing innovation

	(1)	(2)	(3)	(4)	(5)
PredInOng	2.453***	2.422***	2.446***	2.411***	2.404***
	(0.046)	(0.046)	(0.046)	(0.045)	(0.046)
Depth	0.0334***	0.0324***			0.00523
	(0.009)	(0.008)			(0.009)
Breadth			0.0348***	0.0343***	0.0328***
			(0.004)	(0.004)	(0.005)
CoopHC	0.136***		0.116***		0.0196
	(0.029)		(0.029)		(0.032)
CoopRW		0.276***		0.263***	0.251***
		(0.035)		(0.035)	(0.039)
Cons	1.433***	1.412***	1.267***	1.241***	1.233***
	(0.036)	(0.035)	(0.043)	(0.043)	(0.044)
Country dummies	yes	yes	yes	yes	yes
N	27279	27279	27279	27279	27279

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$