Firm Capabilities, Technological Dynamism and Innovation Internationalisation – a Behavioural Approach

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Abstract: We develop a behavioural framework of bounded rational decision-making under uncertainty by which we analyse the effect of technological dynamism in the firm's environment on its decisions to internationalise innovation. Arguing that the firm's technological performance level affects its risk-preferences, a key-prediction is that firms with low technological competences will internationalise innovation when faced by technological uncertainty while firms with high competences will withdraw from international innovation. A fully rational absorptive-capacity framework would predict the opposite relationship because it ignores the role of differential risk-preferences. We test our framework using data from the German Community Innovation Survey (CIS).

Keywords: innovation internationalisation; speed of technological change; bounded rationality; prospect theory; uncertainty; technological capabilities

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INTRODUCTION

Following the internationalisation of less knowledge-intensive activities such as production and sales, firms are increasingly also internationalising innovation activities (Manning et al., 2008; Pyndt & Pedersen, 2006; Bardhan & Jaffe, 2005; Contractor et al., 2010; Criscuolo et al., 2010; Nieto & Rodríguez, 2011). Although some authors have started to discuss the strategic drivers of the internationalisation of innovation (Lewin et al., 2009; Mudambi & Venzin, 2010; Ambos & Ambos, 2011), a common critique of the literature has been that it abstracts from the decision-maker (Hutzschenreuter et al., 2007) and therefore largely ignores behavioural insights on decision-making under the condition of uncertainty and bounded rationality (Aharoni, 2010; Harvey et al., 2011). Uncertainty and bounded rationality, however, are highly relevant in internationalisation processes due to incomplete information, resulting e.g. from differences in culture, institutions, business approaches or language (Aharoni et al., 2011).

In this paper, we propose a behavioural framework for the internationalisation of innovation activities which explicitly allows for bounded rational decision-making under uncertainty. Following prospect theory, we argue that, in light of incomplete information, decision-makers will use decision heuristics based on satisficing rather than optimising principles (Kahneman & Tversky, 1979; Fiegenbaum et al., 1996; Shoham & Fiegenbaum, 2002; Aharoni, 2010). Prospect theory argues that satisficing behaviour implies discontinuous risk preferences, with high performing firms being risk-averse and low performing firms being risk-assertive.

While not dismissing other environmental factors such as culture, institutions or markets (see for example Hutzschenreuter et al., 2011; Kshetri, 2007), our primary goal is to analyse how the characteristics of a firm's technological environment affects its decision about internationalisation of innovation and how the decision differs between firms with high and low technological capabilities. Following the high velocity literature, we describe the characteristics of the technological environment by the speed and the uncertainty of technological change (Bourgeois & Eisenhardt, 1988; Gustafson & Reger, 1995; Eisenhardt & Martin, 2000). A striking prediction of our model is that firms with low technological capabilities will view uncertainty about the direction of technological change as an opportunity which drives international innovation activities, while firms with high technological capabilities are expected to be more risk-averse leading to a centralisation of innovation at the home base.

We test the predictions of our framework based on data from the German Innovation Survey in 2011, which is part of the Community Innovation Surveys (CIS) co-ordinated by the European Commission. Our results show that speed of technological change and uncertainty about its direction increase incentives for innovation activities in general. However, while high speed of technological change also increases the propensity to innovate internationally, the effects of uncertainty are highly conditional on the firms' internal technological capabilities. Uncertainty reduces the propensity to conduct innovation internationally for firms with high technological capabilities and increases it for firms with low technological capabilities. We also show that the negative effect of technological uncertainty for firms with strong technological capabilities disappears when firms invest in their transfer capability (Kuemmerle, 1999) by engaging in personnel exchange between headquarters and its subsidiaries.

We contribute to the literature in two major ways. First, we provide evidence on how technological dynamism (compare Narula, 2001) affects decisions regarding whether to internationalise innovation – a topic which has received very little attention so far. Secondly, by emphasising bounded rationality within the framework of prospect theory, we open a venue for explicitly considering behavioural patterns related to decision-making under uncertainty. Uncertainty is typically ignored in more rational approaches to decision-making used in international business studies. While uncertainty may be a lesser concern in decision-making in routine situations, in non-routine situations or when associated with constituent decisions (e.g. when firms have no prior experience with internationalisation of innovation or with the country of destination) our approach should provide insights going beyond the explanatory scope of fully rational models (compare Harvey et al., 2011; Aharoni et al., 2011).

THEORY

A core task of strategic management is to align the firm's capabilities with the characteristics of the environment it faces (Andrews, 1971; Drazin & de Ven, 1985; Zajac et al., 2000). Based on prospect theory (amongst others Kahneman & Tversky, 1979; Kahneman, 2003), authors have argued that decision alternatives aiming at aligning firm capabilities with environmental characteristics can be expressed in terms of their associated risks and returns (Fiegenbaum et al., 1996; Shoham & Fiegenbaum, 2002). While potentially many external factors affect the implied risk-return-trade-off associated with international innovation, based on the high-velocity literature, we focus on the characteristics of the technological environment in terms of uncertainty about technological developments and the speed of technological change (Bourgeois & Eisenhardt, 1988; Gustafson & Reger, 1995; Wirtz et al., 2007). In the next subsection we discuss how technological speed and uncertainty affect both returns and risks to innovation in general and international innovation specifically. Based on prospect theory, we then argue that the firms' technological capabilities govern their risk preferences, i.e. how firms trade off risks and returns.

Uncertainty and speed of technological change

With the increasing importance of innovation and new technology for firms' competitiveness in globalised markets (Porter, 1986; Scherer, 1992; Tushman & Murmann, 2003; Schiavone, 2011), the motives for internationalising firm activities have shifted from reducing costs (Bardhan & Jaffe, 2005, Winkler, 2009) and expanding markets (Grandstrand et al., 1993; Pearce, 1999) to seeking access to knowledge (Lewin & Peeters, 2006; Bunyaratavej et al., 2007; Meyer, 2015) and scarce highly-qualified human capital (Lewin et al., 2009). Several authors have argued that one source for the trend towards globalised knowledge-seeking is the increased technological dynamism resulting, for example, from shorter product life cycles (Tassey, 2008; Seppälä, 2013). Nonetheless, technological dynamism has not been a core topic in the IB literature, aside from very specific studies on the role of advances in IT (Abramowsky & Griffith, 2006; Blinder, 2006; Ernst, 2002; MacDuffie, 2007).

A theoretical treatment of environmental dynamism can be found in the high-velocity literature (Eisenhardt, 1989; Eisenhardt & Bourgeois, 1988; Bourgeois & Eisenhardt, 1988). While this literature has taken a broad stance on dynamism by discussing the role of general economic, competitive and strategic factors, special emphasis has been laid on the role of technological dynamism. The literature has made a distinction between the speed of technological change and the uncertainty about its direction (see Bourgeois & Eisenhardt, 1988; Gustaffson & Reger, 1995; Wirtz et al., 2007). Although speed and uncertainty of technological change are often correlated, they are conceptually not the same.

Building on Teece's (1986), Narula (2001) argues that technological environments can first be described by considering whether a dominant design has already emerged or not. In the pre-paradigmatic phase in which the dominant design has not yet emerged usually the technological problem to be overcome is defined, but the precise technological solution is not. Thus, several innovators compete by trying out alternative solution paths. In the pre-paradigmatic phase, technological uncertainty is high because it is a priori unclear which technology will succeed. In addition, the knowledge bases held by the firms are highly heterogeneous and large shares of that knowledge are not yet codified, implying that property rights are weak making the appropriation of any resulting benefits complicated. When the dominant design emerges as an incumbent solution, technological development moves into the paradigmatic stage which is characterised by much greater homogeneity of technological solutions (Abernathy & Utterback, 1978; Klepper, 1996; Beise, 2004). Hence technological uncertainty and knowledge heterogeneity between firms decline. At the same time, tacit knowledge becomes codified and property rights become more effective (Teece, 1986; Asheim & Coenen, 2005; Grillitsch et al., 2016). In that respect, uncertainty refers to how many different technological trajectories, i.e. individual solution paths, are followed at one time and how strongly they differ.

Speed of technological change, though often correlated with uncertainty, is conceptually different because it refers to how fast existing technological opportunities (Robin and Schubert, 2013; Vega-Jurado et al., 2008) associated with any of the competing trajectories can be exploited. In that respect, the observed speed of technological change refers to the rate of exploitation on the 'fastest' trajectory.

The fact that speed of technological change is defined by the fastest trajectory also explains the positive correlation with uncertainty since uncertainty is a positive function of the number of different paths. A higher number of existing trajectories increases the likelihood that at least one will be a ‘fast’ trajectory. A further mechanism explaining the high correlation is that technological opportunities offered by any trajectory deplete over time (Fagerberg & Verspagen, 2002) so that speed of technological change, like technological uncertainty, is, at least in the long-run, a negative function of time.

Despite this positive correlation, there is no a priori reason to assume that high uncertainty is mechanistically tied to high speed. For example, technological opportunities can remain abundant for quite some time after uncertainty has vanished, e.g. as a result of the emergence of a dominant design. An example is the development of micro-processors in the period of 1990 to 2005. Moore’s law predicted that processor speed would double approximately every 18 months. Yet, despite the enormous increase in processing power, the direction of technological progress was guided by the principle of miniaturisation. Radically differing approaches to increasing the processing power did not emerge. Hence uncertainty about the direction of technological change was low despite the high speed.

Likewise, uncertainty can be high in situations where speed is low. This can happen when basic technological obstacles to achieve the desired solution are not overcome. An example is the development of brain-machine interfaces. Since the knowledge concerning how the brain functions is still limited, interfaces developed so far work with a low degree of accuracy, even if some progress is made, e.g. the development of reactive prostheses. Speed of technological progress is therefore still low. Nonetheless, uncertainty is high because path-breaking insights will strongly affect the direction of technological progress (Wolpaw & Wolpaw, 2012; Hochberg et al., 2006).

Based on the differential effects of speed and uncertainty of technological change, we will now discuss how both affect the incentives for innovation and the internationalisation of innovation. Although speed and uncertainty are continuous variables (and will be treated as such in the empirical part) for expositional reasons, we follow Narula (2001) and base our discussion on the four archetypes summarised in Figure 1.

Quadrant III and Quadrant IV are characterised by high technological uncertainty usually resulting from limited understanding of the scientific principles in pre-paradigmatic phases. Innovation in both quadrants relies on highly tacit knowledge. The knowledge bases thus differ greatly between firms as tacit knowledge is often locally bound. Effectively absorbing this knowledge often requires localised interactions (Breschi & Lissoni, 2001; Asheim & Isaksen, 2002). When conducting innovation internationally great gains can be obtained, since knowledge relevant to innovation will be globally dispersed. (Bathelt et al., 2004). At the same time, international innovation will bear considerable risks in terms of knowledge leakage at foreign locations (Kotabe et al., 2008; Criscuolo, 2009; Jensen et al., 2013), particularly as tacit knowledge is more difficult to protect through property rights (Teece, 1986; Narula, 2001). Uncertainty, characterising both Quadrants III and IV, on the one hand leads to high returns of internationalising innovation, but it also leads to high risks because of the heterogeneity of firms' knowledge bases and the low effectiveness of property rights. Quadrants III and IV differ by the associated speed of technological change, i.e. by the rate of exploitation of technological opportunities. The higher exploitation rates in Quadrant IV imply that the level of the returns to innovation is higher than in Quadrant III. Also, the incentives to internationalise innovation are larger because firms aim at reducing the time to foreign markets and at adapting products to regional markets (Dunning, 1993; Cuervo-Cazzura and Narula, 2015). At the same time, higher speed will not make internationalisation a riskier strategy as higher speed is not causally linked to higher knowledge heterogeneity between firms. Thus, Quadrants III and IV represent high-risk-high-returns situations regarding the decision to conduct innovation internationally. The decision to internationalise innovation will thus depend on the firms' risk preferences.

Quadrant I and Quadrant II are characterised by low technological uncertainty. The gains in internationalising innovation are most likely lower because the knowledge bases are less heterogeneous between firms, implying that much of the knowledge is codified and globally accessible, making localised sourcing strategies obsolete. Thus, the gains from internationalising innovation will be lower. At the same time, risks associated with internationalisation will also be lower because the greater homogeneity in the knowledge sources and effective property rights reduce the risk that unique knowledge is leaked.

Again, the fact that both quadrants differ in terms of speed has some bearing on the returns associated with international innovation, but little on the associated risk. Quadrants I and II thus represent low-risk-low-returns situations, again implying that the decision to conduct innovation internationally will depend on the firms' risk preferences.

Because risks and returns are positively correlated in all quadrants, without knowledge about the firms' risk preferences it is not possible to determine which firms will internationalise innovation. To provide further explanations, we use insights from prospect theory on decision-making under uncertainty to argue that the firms' current technological capabilities determine the firms' risk-preferences.

Figure 1: Archetypes of technological velocity and the internationalisation of innovation

Uncertainty about the direction of technological change	Speed of technological change: low	Speed of technological change: high

high	**III. Unpredictable technological environment**
	– Competing trajectories but slow technological progress due to technological obstacles
	    – High risks of knowledge leakage because of great knowledge heterogeneity between firms and unclear property rights
	    – Medium to high gains of internationalisation by access to dispersed knowledge
	– Example: brain-machine interfaces
		IV. Unstable technological environment
		– Large number of competing (fast) trajectories with rich technological opportunities
		    – Very high risks of knowledge leakage because of great knowledge heterogeneity between firms
		    – Very high gains of internationalisation by access to globally dispersed and locally bound knowledge
		– Example: cancer drug development

low	**I. Stable technological environment**
	– Stable trajectories with poor technological opportunities
	    – Low risk of internationalisation because of very low knowledge heterogeneity between firms
	    – Low gains to internationalisation because of codified knowledge, effective property rights and a less knowledge intensive technology
	– Example: textiles
		II. Predictable technological environment
		– Fast trajectories with rich technological opportunities
		    – Low risk of internationalisation because of low knowledge heterogeneity between firms
		    – Low to medium gains to internationalisation of codified knowledge and effective property rights
		– Example: miniaturisation of computer chips

Speed of technological change

Risk preferences and technological capabilities

Expected utility theory treats risk preferences as an invariable parameter which is exogenously determined. In addition, the theory usually assumes that decision-makers are risk-averse. However, in their seminal paper Kahneman and Tversky (1979) presented the result of a series of experiments, showing that decision-makers' revealed risk preferences are inconsistent with expected utility theory and depend on the prospect they are faced by. A prospect refers to a contract by which an outcome A_i is realized with probability p_i for $i = 1, \ldots, N$. An important finding is that the observed decisions between prospects of one and the same decision-maker are sometimes consistent with risk-aversion and sometimes with risk-assertion. To explain this finding, Kahneman & Tversky (1979) developed an extension of the expected utility theory, called 'prospect theory'. This theory represents an alternative account of individual decision-making under risk.

In prospect theory, decision-makers rank prospects differently depending on whether they refer to gains or losses. When a prospect represents a loss, decision-makers tend to be risk-assertive. When a prospect represents a gain, decision-makers tend to be risk-averse. For example, Kahneman and Tversky (1979) show that facing students with the alternative of gaining 4,000 currency units with a probability of 20% or 3,000 with a probability of 80%, a great majority chose the latter option. This behaviour is consistent with risk-aversion. However, facing the same students with the alternative of losing 4,000 with a probability of 20% or losing 3,000 with a probability of 80%, the majority chose the former option, which is consistent only with risk-assertion. Thus, it exists a discontinuity in risk-preferences at a reference-point demarcating gains - where decision-makers are risk-averse - from losses - where decision-makers are risk-assertive. While in their original article, prospect theory was applied only to simple monetary games, it is possible to apply the theory in broader settings such as finance, insurance or consumption-saving decisions (for an overview see e.g. Barberis, 2013). The theory claims that decision-makers always evaluate alternative prospects against certain reference points. The reference points do not need to be monetary but rather resemble any – usually very subjective –

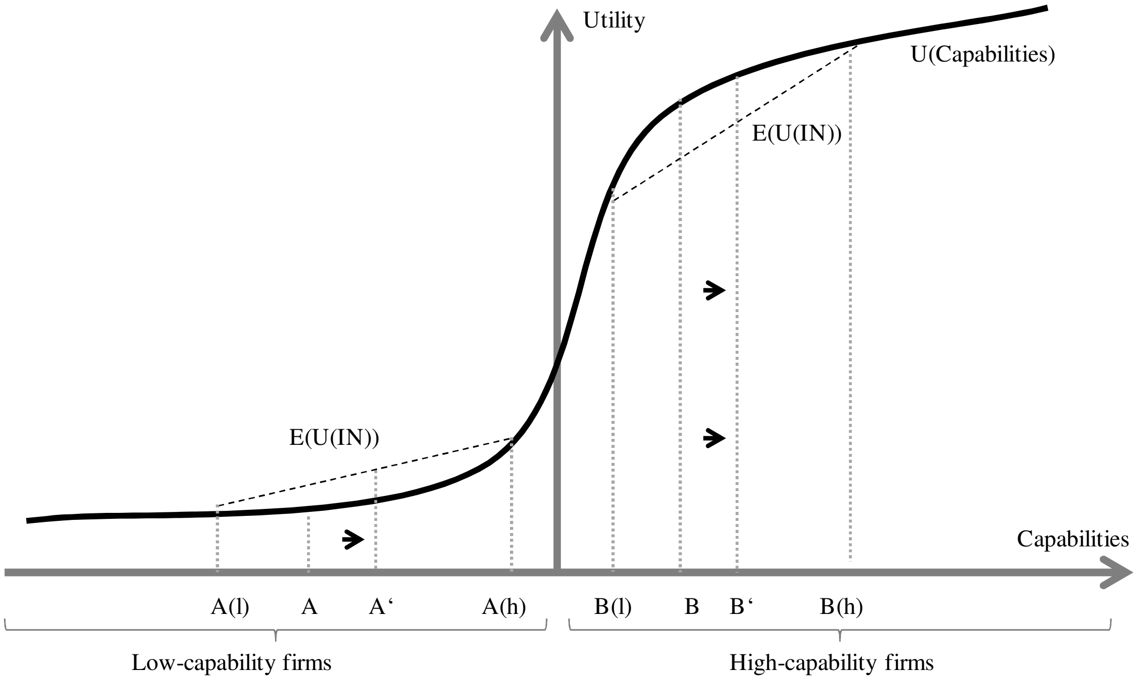
reference that the decision-maker perceives as satisficing (Shoham & Fiegenbaum, 2002; Fiegenbaum et al., 1996). Any outcome below the reference point will be understood as a loss and the decision-maker will act risk-assertively in order to avoid the loss situation (compare March & Shapira, 1987; Miller & Chen, 2004, Figuera-de-Lemos & Hadjikhani, 2014). Positions above the reference point are perceived as gains, and decision-makers will become risk-averse in order to avoid falling below the satisficing reference point.

When applying prospect theory to the case of internationalising innovation, we posit that a suitable reference scale is defined by the firms' perceived technological capabilities because a major motive for internationalising innovation is to receive access to globally dispersed knowledge or human capital to expand the firm's technological capabilities (Dunning & Narula, 1995; Narula & Zanfei, 2004; Meyer et al., 2009; Nieto & Rodriguez, 2011; Meyer, 2015; Cuervo-Caruzza et al., 2015). Furthermore, several authors have argued that the internationalisation of innovation will, even if initially associated with market- or efficiency-seeking motives (e.g. lower costs of innovation), lead to increasing emphasis of asset-seeking motives in the long-run (Zanfei, 2000; Le Bas & Sierra, 200; Narula & Zanfei, 2004; Castellani et al., 2015). By using technological capabilities as the performance scale, an implication of prospect theory is that firms with low technological capabilities (firms in a loss-situation) tend be risk-assertive while firms with high technological capabilities (firms in a gain situation) tend be risk-averse.

The main propositions of prospect theory can be summarized thus graphically: The coordinate system in

Figure 2 represents essentially the arguments from above, with the capabilities on the x-axis and the utility level on the y-axis. The location on the y-axis refers to the satisficing reference value of a firm's technological capabilities. Firms below this reference point perceive themselves as having low technological capabilities and therefore are in a loss-situation. Decision-makers faced by a loss-situation are risk-assertive and thus have (by drawing on the insights from utility theory) a utility function which is locally convex. This corresponds to the left-hand side of Figure 2. Above the reference point, decision-makers face a gain situation. They will act risk-aversely and their utility function is concave. This corresponds to the right-hand side of the graphical representation. To illustrate the mechanics of prospect theory, assume there exists a low-capability firm (A) and a high-capability firm (B) which start in point A and B respectively, implying utility level of $U(A)$ and $U(B)$. Now assume the firms have the possibility to implement an organisational strategy *IN*, the internationalisation of innovation, with the aim of improving their capabilities. Assume also that effects of internationalising innovation on the capabilities are uncertain and two outcomes can emerge. If the strategy is successful firms will experience an increase in capabilities to $A(h)$ and $B(h)$. If the strategy fails, the firms will experience a decrease to $A(l)$ and $B(l)$. Assume that in either case the expected values are A' and B' which are higher than A and B. We therefore assume that a firm expects internationalisation to be beneficial. However, according to prospect theory, firms will also consider the risk and maximise their expected utility which can be calculated as $U(I)=pU(A(l))+(1-p)U(A(h))$ and $U(I)=pU(B(l))+(1-p)U(B(h))$, where p is the probability of failure and 1-p is the probability of success. The expected utilities are represented by the dashed lines connecting the points $A(l)$ and $A(h)$ as well as $B(l)$ and $B(h)$. In our representation, we see that for the low-capability firm the expected utility of strategy *IN* is larger than the utility level without the implementation of strategy *IN* since $E(U(IN))>U(A))$. Therefore, the low-capability firm will implement *IN*. The reason is that low-capability firms are risk-assertive. The situation is different for high-capability firms. Although implementing *IN* increases the expectation value of the outcome, the high-capability firm will not implement *IN* because the utility level without strategy *IN* is larger than the expected utility of implementing strategy *IN* so that $U(B)>E(U(IN))$. Thus, although in expected terms strategy *IN* is beneficial, the high-capability firm over-values the risks and behaves in a risk-averse manner

Figure 2: A graphical representation of prospect theory



The hypotheses

Based on the preceding discussion we develop hypotheses on how speed and uncertainty of technological change affect the incentives to innovate internationally depending on a firm's level of technological capabilities. To provide a reference, we consider how speed and uncertainty affect innovation in general and the internationalisation of innovation in particular. We argued that high speed of technological change necessitates innovation because high speed indicates rich technological opportunities (compare Vega-Jurado et al., 2008; Robin & Schubert, 2013) and implies short product life cycles (Tassey, 2008; Seppälä, 2013) increasing the need for constant innovation. Regarding internationalisation of innovation, we have to consider how speed of technological change affects risks and returns associated with innovation. Firms not innovating fast may fall back against their competitors because the emergence of a dominant design implies winner-takes-all races for successful innovation. At the same time, high speed of technological change also increases the incentives for internationalising innovation in two ways. First, as time to market is important in a fast-moving technological environment, innovating internationally allows firms to serve international markets faster (Dunning, 1993; Cuervo-Cazurra & Narula, 2015). Secondly, if dominant designs emerge in specific regional settings, but the actual regional markets that will later generate the dominant design are unknown, firms have incentives to be present in all regional markets that may become a lead market for an innovation design (Beise, 2001; 2004). While high speed implies high potential returns for innovation as well as incentives for international innovation, it does not predispose heterogeneous knowledge bases which would increase the risks of knowledge leakage in international markets (Kotabe et al., 2008; Criscuolo, 2009; see also Narula, 2001). As a consequence, high speed of technological change is expected to increase incentives both for innovation in general and for international innovation. This prediction is in line with the findings that firms performing innovation internationally cluster in sectors with fast technological progress (Castellani et al., 2015). We conclude:

H1a: High speed of technological change increases the innovation intensity of firms with both high and low technological capabilities.

H1b: High speed of technological change increases the propensity to conduct innovation internationally both for firms with high and low technological capabilities.

High technological uncertainty typically occurs in pre-paradigmatic phases of technological development and is characterised by many competing and conceptually differing approaches to solve a certain (technological) problem. In pre-paradigmatic phases the stakes for successful innovation are high because a firm able to establish a dominant design will capture large shares of the market (Teece, 1986; Suarez & Utterback, 1995). At the same time, existing technologies and knowledge bases are constantly at risk of being eroded through a newly emerging dominant design (Figueira-de-Lemos & Hadjikhani, 2014). The erosion of existing knowledge bases implies that firms with high technological capabilities need to renew their technology base constantly, in order to avoid their technological capabilities becoming outdated by unanticipated developments. Several authors have argued that in volatile markets a competitive advantage usually cannot be sustained for long (Johanson & Vahlne, 1977;

Figueira-de-Lemos & Hadjikhani, 2014). By innovating, firms can reduce the risk of lock-out (Schilling, 2002). But high uncertainty does not only increase incentives to innovate for high-competence firms. Also, firms with low technological capabilities have incentives for innovation as uncertainty increases the chances of developing leap-frogging innovations by adopting novel solution paths (compare Lee et al., 2005). While innovation is itself already a risky strategy (Holmstrom, 1989), in pre-paradigmatic phases of the technological development firms are unlikely to shy away from innovation, in order to reduce risks as refraining from innovation will most likely jeopardize their competitive position.

H2: High uncertainty about the direction of technological change increases the innovation intensity both for firms with high and low technological capabilities.

Thus, based on H2, the decisive question is not so much whether to innovate at all, but rather where. Uncertainty increases both the risks and benefits of international innovation. High uncertainty implies that knowledge is heterogeneous between firms and more likely to be globally dispersed. Firms innovating internationally can hence gain access to unique globally dispersed knowledge sources and human capital (Bardhan & Jaffe, 2005; Barthélemy & Quélin, 2006; Lewin et al., 2009). However, the greater knowledge heterogeneity between firms implies an increased risk of knowledge leakage (Narula, 2001; Criscuolo, 2009) and loss of control over strategic assets (Kedia & Lahiri, 2007; Ceci & Prencipe, 2013). Thus, the decision to innovate internationally depends on the firms' risk preferences.

Based on prospect theory (Fiegenbaum et al., 1996; Shoham & Fiegenbaum, 2002) we argued that firms with low technological capabilities will be risk-assertive while firms with high technological capabilities will be risk-averse. Risk-aversion will make firms more inclined to apply familiar solutions and to centralise decision-making to avoid loss of control (Staw et al., 1981; Dutton & Jackson, 1987; Shoham & Fiegenbaum, 2002). We therefore expect that firms with high technological capabilities tend to centralise innovation activities, in order to keep tighter control over their innovative activities and to be able to quickly react to sudden changes in their technological environment (Granstrand, 1999; Baier et al., 2015).[1] Firms with low technological capabilities will have opposite risk-preferences and will therefore be more likely to opt for international innovation. In addition, firms with low competences have less to lose in terms of knowledge leakage.

H3a: High uncertainty about the direction of technological change increases the propensity to conduct innovation internationally for firms with low technological capabilities.

H3b: The effect in H3a is smaller (or even negative) for firms with high technological competences.

So far, we have treated the firm's technological capabilities as affecting the firms' risk preferences but not the risks and returns associated with international innovation themselves. This assumption neglects important insights from innovation studies and the IB literature which suggest that internal technological capabilities also determine the firms' absorptive capabilities (Cohen & Levinthal, 1990; Caloghirou et al., 2004; Soosay & Hyland, 2008). Bertrand & Mol (2013) argue that high R&D capabilities allow firms to absorb knowledge from their international subsidiaries more effectively. Thus, while high technological capabilities will make a firm more risk-averse, they will also increase the expected gains from internationalising innovation. While the net effect on the propensity to conduct innovation internationally is theoretically indeterminate, we argue that the return-increasing effect of higher absorptive capabilities will be the stronger the higher the effective mutual knowledge flows between the parent firm and its international subsidiaries is. Without such knowledge-flows the knowledge produced by the subsidiaries remains stuck locally (Gupta & Govindarajan, 2000). An important organisational mechanism to promote knowledge-flows is the coordinated exchange of personnel between

1 A counterargument is that high-competence firms may become more efficient over time in managing their international operations, thereby reducing risks (Dossani and Kenney, 2007; Jensen, 2009). In fact, the learning argument suggests that risks may decline as a function of internationalisation experience (compare also Johanson & Vahlne, 2009) making the risk component less important. This argument is indeed a pervasive counterargument. We will come back to it in the discussion section by indicating the limits of our approach.

parents and subsidiaries (Rycroft, 2003; Buckley et al., 2005; Persson, 2006; Li et al., 2013). Personnel exchange is particularly important in the case of innovation because it helps transfer tacit knowledge (Kim, 2001).

H4: Personnel exchange positively moderates the effect of technological uncertainty on the internationalisation of innovation.

DATA, VARIABLES AND IDENTIFICATION

Data

The data used to test the hypotheses are taken from the Mannheim Innovation Panel (MIP). The MIP is an annual survey of innovation activities of German enterprises. It is the German contribution to the Community Innovation Surveys (CIS) of the European Commission and fully complies with the methodological standards laid down for the CIS. The sample we use is a stratified random sample representing the firm population in Germany for firms with 5 or more employees in the sectors targeted by the Community Innovation Survey (mining, manufacturing, utilities, wholesale trade, transportation and storage, information and communication services, financial and insurance activities, and other business-oriented services). As the German innovation survey fully complies with the strict statistical methodology for Community Innovation Surveys in the EU (which is regulated by a European law), it is representative for the German enterprises sector. More details on the MIP can be found in Peters & Rammer (2013).

We use data from the MIP survey conducted in 2011, which collected information on innovation activities of firms conducted during the years 2008 and 2010. The MIP survey provides information on the core variables described in our theory (innovation internationalisation, technological dynamism, internal technological capabilities) as well as general information about the firms. The questions we use for our core variables were not part of the harmonised questionnaire for the CIS 2010 but have been added only to the survey in Germany.

We follow the approach of Baier et al. (2015) and restrict our sample to firms with headquarters in Germany. We applied this restriction in order to exclude sources of misunderstanding by respondents from firms with headquarters abroad as international innovation activities may either refer to the internationalisation of the subsidiary's innovation activities to locations abroad, or to the innovation activities of the parent firm at its home base or to innovation at sister companies abroad. Our sample restriction makes sure that R&D abroad always refers to outside Germany and never to the home-base of the parent firm. With these restrictions, we have a sample of 6,589 firms. Due to the item non-response for some of the model variables the sample used in the regressions consisted of approximately 4,400 firms.

Core Variables and Identification Strategy

Our aim is to explain the internal and external conditions that drive a firm's decision to conduct international innovation activities and the general incentives for innovation measured by a firm's innovation intensity. For innovation intensity, we use two alternative variables: total innovation expenditure as a share of turnover and R&D expenditure as a share of turnover. Total innovation expenditure includes R&D expenditure as well as expenditure for implementing innovations (new equipment, marketing, training etc.). As concerns international innovation, the MIP 2011 survey provides information on whether a firm was engaged in activities at foreign locations related to R&D, in manufacturing of new products, designs, or in implementing new processes during the three-year period of 2008 to 2010. We rely on the standard concepts and definitions of R&D, design and innovation as proposed in the respective OECD manuals (OECD & Eurostat, 2005; OECD, 2015). R&D and design refer to activities related to the development of innovations and involve the creation of new knowledge or the creative use of existing knowledge. Although manufacturing a new product at a foreign location or implementing a new process technology need not be linked to creative work performed at the foreign location, e.g. if the new product or new process technology has been transferred from the parent company, we still regard these activities as innovation since they constitute a new activity at the foreign location, requiring changes to existing routines and usually also adaptations of technologies and practices to the specific situation at the foreign location. In order to obtain a detailed insight into how technological capabilities and technological dynamism affect internationalisation decisions we report the effects on each of the four internationalisation variables (R&D, design, product, process) separately in our result tables (Table 3, Table 4, and Table 5).

A firm's internal technological capability as well as technological uncertainty and the speed of technological change in a firm's market are measured through an assessment done by managers. Firms were asked to rate their internal technological capabilities ("Ability to develop new technological solutions") on a Likert scale from 1 (very low) to 5 (very high).[2] Based on the decision-makers' assessments we created a dummy for high technological capabilities if managers rated their technological capabilities at 4 (high) or 5 (very high), while it takes a value of 0 for all classes up to 3 (intermediate). It should be noted here that our variable may be criticised for its subjectivity in telling apart losses from gains. Kahneman and Tversky (1979) concentrated on situations where the reference points where expressed in monetary terms and thus obviously determined. More generally, determining reference points is a rather subjective process and depends on the perceptions of the decision-makers (Fiegenbaum et al., 1996). So, a more objective measure may in fact be problematic. We nonetheless probed our results deriving measures based on more objective R&D data.

In addition, firms were asked to characterise their market environment on a 4-point Likert scale ranging from 1 (item does not apply) to 4 (item fully applies). Two items refer to technological dynamism of the firm's environment: "Technological development is difficult to predict" and "Products become outdated quickly". We use the first item as an indicator for technological uncertainty and the latter one as an indicator of speed of technological change. To measure the degree of personnel exchange we

2 We perceive technological capabilities as the sum of the firms' internal competences ranging from the production, use, adaption and improvement of new technological knowledge, value chain technologies and product development technologies, competences in technology forecasting and technology assessment as well as the ownership of patents and licenses.

make use of four dummy variables indicating whether a firm sent personnel from the parent to the subsidiary a) on short-term basis or b) on a long-term basis and whether the subsidiary has sent personnel to the parent c) on a short-term basis or d) on a long-term basis. We add up the four variables, leading to an index with values between 0 and 4.[3] The exact wording of the core survey items is shown in the supplementary material accompanying this article.[4]

In order to test H1a and H2 we use Tobit regressions because both the innovation and the R&D intensity are strictly positive and continuous with a high proportion of zero observations. In order to test H1b, H3a/b, and H4 we use Probit regressions taking the four types of innovation internationalisation activities as the key dependent variables to analyse the effect of speed of and uncertainty about technological change. In all cases, we split our sample by firms' technological capabilities and report the results for the two groups of firms separately.

Confounding Factors

Based on earlier findings (Baier et al., 2015), we identify a set of confounding factors. We consider size, group structure, export activities, and characteristics of the appropriability regime. We also discuss the role of innovation expenditures as well as the sector a firm belongs to. While we discuss these variables with regard to internationalisation of innovation, they can also be expected to be relevant for innovation in general.

Size: Although some authors find evidence that smaller companies also engage in innovation internationalisation (Roza et al., 2011), the literature has frequently discussed the phenomenon as being most relevant for large companies. The reasons for this are that large companies usually have greater financial resources, more complementary assets and greater managerial capacities (see Bardhan & Jaffe, 2005). Although small companies may have an advantage in coping with increased organisational

3 With 0.86 the Cronbach's Alpha was sufficiently high to warrant the creation of an index.

4 Note that all our key variables for measuring international innovation activities, technological capabilities, technological dynamics and the degree of personnel exchange are not part of the standard CIS questionnaire but have been added to the German questionnaire in order to enable this research.

complexity associated with innovation internationalisation, most authors find that the propensity to conduct innovation internationally strongly increases with size (Baier et al., 2015). We include the number of employees and its square as a functionally flexible control for size.

Group structure: Belonging to a group can contribute to making firms more accustomed to managing multi-site processes (Bartlett & Ghoshal, 2002). Furthermore, to the degree that parts of the group are based abroad, strong global links and thus opportunities for internationalisation activities may exist (Berry, 2006). Firms in a group structure may therefore be more likely to conduct international innovation. We include a dummy indicating whether the firm is part of a company group.

Export activities: The Uppsala model argues that firms gradually intensify their internationalisation activities (Johanson & Vahlne, 1977). In this model export activities are one of the first steps and act as the originator for more advanced types of internationalisation as described by Dunning (1980, 1988). In particular specificities in local demand may induce firms to internationalise innovation in an attempt to adapt products to foreign consumer preferences. Furthermore, exposure to international markets can create learning potentials (Gassmann & von Zedtwitz, 1999; Macharzina et al., 2001) which allow firms to handle their internationalisation activities more efficiently (Jensen, 2009). We therefore expect that export activities and innovation internationalisation are positively related. We include a variable which measures exports as a share of turnover (export intensity).

Intensity of product market competition: Alcácer et al. (2013) argue that the type of competition and internationalisation are strongly related, because industries dominated by MNEs are oligopolistic in nature. In oligopolistic markets, competitive interaction is an important source of strategic behaviour. Intense competition may for example induce a race for human capital (Lewin et al., 2009). In addition, firms may try to escape competition by moving to geographically distant places. Furthermore, by internationalising innovation firms may reduce costs bestowing them with a competitive advantage. We thus expect that the intensity of competition and innovation internationalisation are positively related. We include a variable measuring the intensity of price competition rated by managers on a Likert scale from 1 (low) to 4 (high).

Innovation intensity and sector dummies: The innovation intensity is a strong driver of international innovation at the firm level (Baier et al., 2015) because it measures the firms' overall orientation regarding innovation. Also, the sectors set important incentives for or against international innovation. We thus include both sector dummies according to the OECD classification of technology levels and the innovation intensity as control variables. For obvious reasons we include the innovation intensity only in the internationalisation regressions.

Patents: The strength of patent protection may considerably affect the appropriability and knowledge leakage risks associated with the internationalisation of innovation (Teece, 1986; Park, 2008). Including patents is very important for internationalisation decisions because major costs of international innovation are seen in loss of control over core technologies resulting from the inability to prevent key know-how spilling over to competitors at the foreign location (Kirner et al., 2009; Contractor et al., 2010; Hoecht & Trott, 2006). We therefore use an indicator on whether a firm used patents to protect its intellectual property.

Location in Eastern Germany: Since industrial structures, productivity and management practices are still different in the Eastern and the Western parts of Germany it is important to control for the firm location. We use a dummy for Eastern Germany.

Endogeneity Issues

There may be endogeneity issues when trying to test the hypotheses. For example, firms investing heavily in innovation abroad may perceive a higher speed of technological change because they are better informed about technological advances on a global scale. In this case, the reported technological change is not exogenous, but positively depends on the degree of international innovation investment presumably leading to an upward bias of our estimates. We therefore test for the possibility of endogeneity in our core hypotheses relating to the internationalisation decisions. To implement such a test, in a first step we create a variable measuring the firms' ratings of speed and uncertainty concerning technological change averaged at NACE 2-digit sectors, where we exclude the rating of the focal firm. We use this as an instrumental variable for individual firms' rating regression in a first step. The intuition behind this is that the sector averaged ratings are on the one hand correlated with the true speed of technological change in the sector. On the other hand, any individual firm decision will not have an effect on the sector average ratings concerning the speed and uncertainty of technological change. From each of these two first step regressions we obtain the residuals and include them in the second step Probit regression as additional explanatory variables. Endogeneity prevails if these two residuals are jointly significant (see Wooldridge, 2002).

RESULTS

Descriptive statistics

In Table 1 we present the summary statistics of the main variables used throughout this paper. Internationalisation of any kind of innovation activities is a phenomenon observed only in a minority of the firms. In particular we find that with a sample share of 2.6% international product innovation activities were still the most common. This was followed by internationalisation of design activities with 2.5%. 2.2% had international R&D activities. About 2.0% of the firms had internationalised parts of their activities related to process innovation. As a point of reference, we present the correlations in

Table 2.

Main results

Table 1 goes here

Table 2 goes here

In H1-H4 we argued that the speed of technological change and uncertainty concerning its direction can have distinct impacts on the firms' propensity to invest in innovation and their internationalisation patterns given the firms' technological capabilities. We first start with the analysis of the general incentives for innovation, which we present in

Table 3.

Table 3 goes here

Our results show that both technological uncertainty and speed of technological change drive innovation as well as R&D activities irrespective of the level of the technological capabilities. For all cases (except for one) the coefficients are positive and highly significant. This confirms our baseline hypotheses that both speed of technological change and technological uncertainty create strong incentives for innovation. While the confirmation of H1a and H2 is well in line with arguments from the high-velocity literature, the more interesting question is if and under which conditions increasing incentives for innovation in general also translate into higher incentives for international innovation. As argued in the section "Core Variables and Identification Strategy", we test the hypotheses relating to internationalisation of innovation for each type (R&D, manufacturing of new products, design, and process innovation) separately. The main results are presented in Table 4 (for R&D internationalisation and internationalisation of product innovation) and Table 5 (for design internationalisation and internationalisation of process innovation). In columns 2 and 5 we present the results for firms with high technological capabilities and in columns 3 and 6 we present the results for firms with low capabilities. Because we hypothesised the effects of uncertainty concerning technological change we present the results for the full sample in columns 1 and 3 as a point of reference.

Table 4 goes here

Table 5 goes here

As concerns speed of technological change, we expected that firms both with high and low competences become more likely to conduct innovation internationally (H1b). The positive effect on the likelihood of innovation internationalisation is indeed corroborated for all types of innovation, with the exception of R&D internationalisation for low-competence firms. As expected it also holds for the full sample. We thus are able to corroborate H1b for almost all cases.

As concerns uncertainty regarding the direction of technological change, for high-capability firms the effect of high uncertainty is negative on the internationalisation of innovation. As predicted, firms with low technological capabilities show a different pattern. For them the effect is positive. Again, as could be expected the results for the overall sample are insignificant as the positive effects of low-capability firms and the negative effects of high-capability firms cancel each other out. The differential pattern between low and high-capability firms corroborates H3a and H3b.

Moving to H4 we have extended our discussion of prospect theory underlying H1-H3, where we assumed that the technological capabilities only affect the firm's risk preferences. As we already highlighted, the concept of absorptive capacity suggests that technological competences will also affect the expected returns of internationalisation, because firms with high technological competences will be better able to absorb the knowledge from their international subsidiaries. While the mechanism based on absorptive capacity may confound the predictions that high-competence firms are less likely to conduct international innovation activities when technological uncertainty is high, we argued that the role of absorptive capacity is more relevant when the firms have effective knowledge transfer mechanisms in place. We further argued that high personnel exchange positively moderates the effect of uncertainty. Table 6 and Table 7 corroborate this argument for all types of international innovation activities, however only for firms with high technological capabilities. For high-capability firms a graphical representation indeed demonstrates a statistically significant overcompensation of the negative effect of technological uncertainty when firms make intense use of personnel exchange. For firms with low technological capabilities, there seems to be a positive effect, but only weakly so. The much weaker effects for the low capability firms may in fact be intuitively explained because low technological capabilities determine the absorptive capacity, which makes higher rates of personnel exchange much less effective. Overall, we corroborate H4, but only for high-capability firms.

Table 6 goes here

Table 7 goes here

Figure 3 goes here

Figure 4 goes here

Robustness checks

We performed several robustness checks. First, in order to deal with problems of endogeneity we instrumented the speed and uncertainty of technological change by their sector means on the NACE 2-digit level in the core tables relating to internationalisation. The results of the endogeneity tests were mostly far from significant (see statistics in Table 4-Table 9, where only one case with somewhat significant results emerged). We are thus reasonably confident that the results are not strongly plagued by endogeneity issues. We also checked the strength of the identification by inspecting the F-statistics of the first stage regressions. The statistics were very high for all instrumented variables with values of above 20, therefore weak identification should not be an issue.

Second, it is well documented that the relation between speed and uncertain is a non-trivial one. Narula (2001) for example suggests that there may be non-linear relationships over time. In fact, the four quadrant representation in Figure 1 may hide some of the complexity. While it is hard to disentangle the complex temporal relationship with our cross-sectional data, the argument suggests that it may be useful to include dummies for the quadrants to capture non-linearities. We therefore calculated four dummies indicating whether a firm was above the median for both technological uncertainty and speed, only for speed, only for uncertainty, or below the median for both. We then included these dummies in the regressions in Table 4 and Table 5 as additional explanatory variables. The results can be found in Table 8 and Table 9 in the appendix without observing any significant differences to our main results.[5]

Third, a case might be made against our measure of technological capabilities which is highly subjective. More objective measures can be derived based on a firm's R&D activity which is commonly used as a measure of technological competence (Cohen & Levinthal, 1990). We therefore probed our results by using the distinction in the CIS on whether firms conducted R&D continuously (i.e. they employ dedicated R&D staff or operate a separate R&D department) or whether R&D was conducted only occasionally. The results of the sample split models were somewhat less stable but overall showed similar patterns with regard to the influence of speed and uncertainty of technological change. In particular, the difference between high- and low-capability firms regarding the influence of uncertainty remained robust. Note, however, that despite the somewhat less subjective definition, using R&D-related variables comes with its own problems. Specifically, there are many sectors in manufacturing and in particularly in services where R&D is not necessarily a good proxy for technological capabilities defined as broadly as in this paper. Therefore, the self-assessment and its implied subjectivity may have advantages. A conceptual problem is that subjectivity in the context of prospect theory is in fact not a weakness because this theory relates precisely to subjective evaluations made by decision-makers. So, a case can be made that subjectivity in fact should be aimed for rather than avoided.

Finally, we probed our sample selection. In our analyses, we included firms irrespective of whether they innovate at all. On the one hand, this allows us to include firms which only innovate internationally – a phenomenon consistent with the hollowing-out hypothesis (Ghauri & Santangelo, 2012). On the other hand, we may misleadingly include firms which do not innovate at all, rendering an analysis of internationalisation of innovation problematic. We have therefore rerun the analyses excluding all non-innovators. The results remained quite robust, though at times, slightly less significant due to the reduced sample size.

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5 Note that the strong multi-collinearity between the dummy indicators and the main effects only allowed including the dummy for quadrant II and IV. Including any of the remaining quadrants implied a huge increase in the variance inflation factors from about 1.5 to 3.5 making many of the regression results insignificant without leading to any conceivable improvement in the explanatory power of the models.

DISCUSSION

In this paper, we provided a predictive framework analysing the internal and environmental technological factors driving firms' decisions to conduct innovation internationally. In doing so, we moved beyond the discussion concerning the motives for firms to perform certain activities abroad (for a recent review, see Cuervo-Cazurra & Narula, 2015). Instead of discussing the classical set of market-seeking, efficiency-seeking, resource-seeking or strategic asset-seeking motives (Kuemmerle, 1999; Dunning, 1993, 2000; von Zedtwitz & Gassmann, 2002), we developed a predictive approach suitable for explaining the internationalisation of innovation activities by firms in different technological environments. Similar to the work by Cuervo-Cazurra et al. (2015), our framework builds on behavioural theory emphasising bounded rationality of decision-makers (March & Simon, 1958; Cyert & March, 1963). We applied prospect theory (Kahneman & Tversky, 1979; Kahneman, 2003; Fiegenbaum et al., 1996) and characterised the decision for innovation internationalisation as a risk/return trade-off. According to the requirements brought forward by Fiegenbaum et al. (1996), our model represents risks and returns through the dynamics of the firm's technological environment (i.e. the speed of technological change and uncertainty concerning its direction), while the firms' risk preferences (i.e. how firms weigh risks and returns) are determined by the firms' internal technological capabilities.

On a general level, we contribute to an emerging literature emphasising the need to integrate behavioural aspects of decision-making into theory development in the IB literature (Aharoni, 2010; Aharoni et al., 2011; Cuervo-Cazurra et al., 2015). Although elements of behavioural theorising have left some footprints in IB (Aharoni, 1966; Johanson & Vahlne, 1977, 2009) the analysis of the influence of key behavioural concepts such as bounded rationality, satisficing behaviour, or decision-making under risk and uncertainty is still in its infancy (compare Figueira-de-Lemos et al., 2011; Harvey et al., 2011; Figuera & Hadjikhani, 2014; Cuervo-Cazurra et al., 2015). By applying prospect theory, we were able to provide a structural framework on how bounded rationality, risk and uncertainty, and satisficing behaviour play out with regard to the internationalisation of innovation by firms. We believe that the integration of satisficing decision-making under risk and uncertainty is crucial to improve our understanding of firms' internationalisation decisions whenever the high complexity of fast changing globalised markets renders the conception of the rational, fully-informed and optimising decision-makers problematic (Johanson &Vahlne, 1977; Eisenhardt & Martin, 2000; Teece, 2007).

While there is consensus in IB literature that firms face a risk-return trade-off (Hahn et al., 2009; Massini et al., 2010; Jensen et al., 2013) when internationalising activities, the existing works do not pay much attention to the stochastic meaning of the term risk. Rather risk is often used in the sense of anticipatable costs resulting from threats such as leakage of knowledge (Criscuolo, 2009; Kotabe et al., 2008; Lei & Hitt, 1995), higher organisational complexity (Bartlett & Goshal, 2002; Fifarek et al., 2008; Baier et al. 2015; Castellani et al., 2016), or loss of control (Nakatsu & Iacovou, 2009; Mudambi, 2008). We emphasise that we need to include risk and uncertainty explicitly because optimising and satisficing agents respond differently to risk issues. In particular, optimising agents will transform the decision problem into a quasi-deterministic problem expressed in terms of expected returns and costs. In addition, if at all, risk preferences are incorporated as an invariable trait (Jensen et al., 2013). This is problematic, since behavioural insights into actual risk-coping strategies are effectively moved outside the explanatory boundaries of the frameworks treating decision-makers as optimising. Our framework instead explicitly includes risk preferences and suggests that high-capability firms will be more risk-averse, in order to avoid falling below their satisficing reference point (Shoham & Fiegenbaum, 2002). We therefore contribute to the literature on strategic drivers of international innovation (Mudambi &Venzin, 2010; Manning et al., 2008; Ambos & Ambos, 2011) by explicitly incorporating behavioural issues of decision-making under uncertainty and bounded rationality.

A key result from our analysis is that when technological uncertainty is high, firms with high internal technological capabilities will tend to avoid the risks associated with internationalisation and will be more likely to concentrate innovative efforts at their home-base. We find the opposite pattern for firms with low technological capabilities. Our theory explains these findings, which proved to be robust across a variety of different specifications, in terms of risk preferences differing between high and low performing firms. We stress that the findings are hard to explain within a more traditional theoretical framework. First, with few exceptions – e.g. Roza et al. (2011) argue that risk preferences vary by firm size – existing theories provide very little guidance on the reasons why firms differ in their risk preferences. Thus, there are hardly any obvious risk-related arguments that could explain why high-capability firms are less likely to innovate internationally. In fact, treating risk preferences as given as suggested by rational choice models rather would be consistent with the opposite pattern. Since returns and risks must be positively related in the long-run (i.e. when all possibilities for arbitrage have been eliminated) more risk-assertive firms will perform better on average. By backward induction, a higher observed performance level will be the result of greater risk tolerance in the past (Aharoni et al., 2011; Harvey et al., 2011), which implies that high-capability firms should be more likely to accept the risks of internationalising innovation. A similar prediction would in fact result from the OLI framework (see e.g. Dunning, 2000), arguing that strong capabilities represent ownership advantages which can be exploited abroad to outcompete local firms. The implicit assumption of home-base exploiting strategies thus would suggest that high-capability firms are more likely to serve international markets. For home-base exploiting activities the argument is clearly convincing. However, for home-base augmenting activities like innovation, it is less so. In fact, an argument can be made that low-capability firms have more to gain in terms of improving their own capabilities (Kedia & Lahiri, 2007; Meyer et al., 2009) or accessing foreign technologies/knowledge sources (Manning et al., 2008; Lewin et al., 2009) but have much less to lose in terms of knowledge leakage (Kotabe et al., 2008; Jensen et al. 2013). The emphasis on behavioural approaches to risk thus seems crucial for understanding our findings.

We regard our approach as complementary to established models based on rational choice frameworks (for an overview compare e.g. Castellani et al., 2015). In particular, if the risks associated with internationalisation are low in a specific situation, rational models can provide very good approximations. Several authors have argued that internationalisation is a learning process (Johanson & Vahlne, 1977; Macharzina et al., 2001; Jensen, 2009) in which firms increasingly master transforming internationalisation into a routine-task (Dossany & Kenney, 2007). If decision-makers face only low levels of risk, e.g. because they have extensive experience with the internationalisation of innovation or because they know the country of destination very well, bounded rational decision-making theory may not provide insights substantially differing from those stemming from simpler models of rational choice. It is – as we have highlighted – precisely when risks and uncertainty are pervasive that we expect our framework to represent a more adequate account of the decision-making situation.

A second reason, why we think that our approach complements existing studies implies some limitations. In particular, we argued that our assumption that internal technological capabilities only affect risk preferences (we relaxed this assumption in our last hypothesis) is too rigid and neglects some well-understood mechanisms. A leading example is the role of absorptive capacity which allows firms to benefit more from internationalising innovation (Kotabe et al., 2011; Bertrand & Mol, 2013) through the exploitation of knowledge across borders (Macharzina et al., 2001). In the context of our model, the absorption mechanism means that technological capabilities do not only affect risk preferences (as assumed in H1-H3) but also incentives for conducting innovation internationally (which we allowed in H4). We provided evidence that high-capability firms can counteract their inward orientation resulting from high technological uncertainty by employing personnel exchange and thereby configuring their capabilities (Kuemmerle, 1999). We thus conclude that the focus on risk behaviour as proposed by prospect theory cannot be a stand-alone programme. Rather we argue that a fruitful line of research could be opened by integrating behavioural as well as more established concepts in IB and innovation studies.

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Tables and figures

Table 1: Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Int. R&D	4435	0.025	0.156	0.000	1.000
Int. product innovation	4435	0.026	0.160	0.000	1.000
Int. design	4435	0.027	0.163	0.000	1.000
Int. process innovation	4435	0.022	0.146	0.000	1.000
Innovation intensity	4435	0.084	1.235	0.000	75.000
R&D intensity	4246	0.046	0.706	0.000	34.000
Speed tech. change	4435	1.942	0.870	1.000	4.000
Uncertainty future tech. change	4435	2.037	0.807	1.000	4.000
Stable technological environment	4435	0.616	0.486	0.000	1.000
Predictable techn. env.	4435	0.111	0.314	0.000	1.000
Unpredictable techn. env.	4435	0.158	0.365	0.000	1.000
Highly volatile techn. env.	4435	0.115	0.319	0.000	1.000
Internal technological capabilities	4372	3.228	1.158	1.000	5.000
Cross-border personnel exchange	4435	0.075	0.457	0.000	4.000
Patents used	4435	0.279	0.449	0.000	1.000
Intensity of competition	4435	2.565	0.668	1.000	4.000
Employees	4435	246.123	1649.370	1.000	64432.000
Export intensity	4435	0.119	0.218	0.000	1.000
Eastern Germany	4435	0.334	0.472	0.000	1.000
Member of a group	4435	0.236	0.425	0.000	1.000
High-tech man.	4435	0.076	0.265	0.000	1.000
Med.-high-tech man.	4435	0.126	0.332	0.000	1.000
Med.low-tech man.	4435	0.125	0.331	0.000	1.000
Low-tech man.	4435	0.231	0.421	0.000	1.000
Knowledge intensive services	4435	0.311	0.463	0.000	1.000
Other services	4435	0.130	0.336	0.000	1.000

Table 2: Correlation table

	Int. R&D	Int. product innovation	Int. design	Int. process innovation	Innovation intensity	R&D intensity	Speed tech. change	Uncertainty future tech. change	Stable tech. env.	Predictable tech. env.	Unpredictable tech. env.	Highly volatile tech env.	Internal technological capabilities	Cross-border personnel exchange	Patents used	Intensity of competition	Employees	Export intensity	Eastern Germany	Member of a group
Int. R&D	1																			
Int. product innovation	0.7281	1																		
Int. design	0.7709	0.7983	1																	
Int. process innovation	0.6806	0.7757	0.7714	1																
Innovation intensity	0.0058	0.0004	-0.0012	-0.0008	1															
R&D intensity	0.011	0.0023	0.0011	0.0017	0.9408	1														
Speed tech. change	0.0784	0.0892	0.078	0.065	0.0343	0.0307	1													
Uncertainty future tech. change	0.0297	0.038	0.0426	0.0303	0.0616	0.0658	0.4231	1												
Stable tech. env.	-0.0565	-0.0617	-0.05	-0.0419	-0.0404	-0.0453	-0.6513	-0.684	1											
Predictable tech. env.	0.0601	0.0704	0.0391	0.0552	-0.0008	0.0006	0.5344	-0.1165	-0.45	1										
Unpredictable tech. env.	-0.0061	-0.0092	-0.0076	-0.0071	0.0078	0.0223	-0.0807	0.5654	-0.5494	-0.1523	1									
Highly volatile tech env.	0.0341	0.0354	0.0465	0.0176	0.0538	0.0432	0.5607	0.5143	-0.4559	-0.1264	-0.1543	1								
Internal technological capabilities	0.1423	0.1314	0.1357	0.1292	0.0581	0.0672	0.1745	0.2372	-0.1584	0.042	0.0666	0.1246	1							
Cross-border personnel exchange	0.6933	0.7472	0.7587	0.7353	-0.0002	0.0017	0.0711	0.0273	-0.0419	0.0596	-0.016	0.0236	0.1404	1						
Patents used	0.1993	0.2003	0.1998	0.1834	0.0691	0.0787	0.095	0.1161	-0.0997	0.0421	0.0486	0.0552	0.2998	0.2038	1					
Intensity of competition	-0.0087	-0.0037	0.0016	0.01	-0.0388	-0.0489	0.1692	0.1618	-0.1383	0.0477	0.0555	0.1009	-0.0224	-0.0003	-0.0505	1				
Employees	0.2772	0.3022	0.3011	0.2813	-0.0039	-0.0035	0.0375	0.028	-0.0302	0.0432	-0.0147	0.0203	0.083	0.337	0.0988	-0.007	1			
Export intensity	0.2421	0.2434	0.2304	0.2244	0.0072	0.0118	0.0396	0.0685	-0.0387	0.0111	0.0308	0.0129	0.2593	0.2495	0.3718	-0.0381	0.1233	1		
Eastern Germany	-0.0785	-0.101	-0.0941	-0.0832	0.0273	0.0229	-0.0051	-0.0476	0.0434	-0.0061	-0.0449	-0.0088	-0.0195	-0.0869	-0.0561	0.0155	-0.0714	-0.1102	1	
Member of a group	0.2138	0.2296	0.2328	0.2224	-0.0112	-0.0115	-0.0066	0.0071	0.0241	-0.0018	-0.0219	-0.0099	0.1283	0.219	0.1747	-0.0003	0.1963	0.2012	-0.0801	1

Table 3: The effect of technological change on the innovation and R&D intensity (raw coefficients based on Tobit regressions)

	All firms Innovation intensity	High cap. Innovation intensity	Low cap. Innovation intensity	All firms R&D intensity	High cap. R&D intensity	Low cap. R&D intensity
Speed tech. change	0.12874***	0.07905	0.01546***	0.12761***	0.08498*	0.01418***
	(3.32)	(1.18)	(3.03)	(4.14)	(1.77)	(3.14)
Uncertainty future tech. change	0.24708***	0.27950***	0.01692***	0.20559***	0.19279***	0.01272***
	(5.92)	(3.82)	(3.10)	(6.18)	(3.73)	(2.59)
Patents used	0.70859***	0.67981***	0.06075***	0.67809***	0.68605***	0.05403***
	(10.11)	(5.91)	(6.05)	(12.52)	(8.49)	(6.38)
Intensity of compe-tition	-0.12932***	-0.22882***	0.00072	-0.14247***	-0.22874***	-0.00498
	(-2.67)	(-2.65)	(0.12)	(-3.61)	(-3.69)	(-0.86)
Employees	0.00005	0.00002	0.00001	0.00003	0.00001	0.00001
	(1.59)	(0.39)	(1.56)	(1.35)	(0.31)	(1.46)
Employees^2	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000	-0.00000
	(-1.45)	(-0.46)	(-0.80)	(-1.32)	(-0.42)	(-0.64)
Export intensity	0.66404***	0.41175*	0.10960***	0.72689***	0.47837***	0.13169***
	(4.49)	(1.77)	(4.89)	(6.51)	(2.99)	(7.20)
Eastern Germany	0.15338**	0.30805***	0.00423	0.21011***	0.25732***	0.01855**
	(2.38)	(2.76)	(0.50)	(4.11)	(3.26)	(2.48)
Member of a group	0.13386*	0.00968	0.02356**	0.16243***	0.07879	0.02378***
	(1.84)	(0.08)	(2.35)	(2.89)	(0.93)	(2.77)
Constant	-1.97266***	-1.51428***	-0.20545***	-2.13771***	-1.58942***	-0.23335***
	(-11.44)	(-4.53)	(-9.63)	(-14.33)	(-6.39)	(-10.70)
Constant	1.72025***	2.13505***	0.15498***	1.19891***	1.39172***	0.11112***
	(67.48)	(53.86)	(38.29)	(54.19)	(46.15)	(26.71)
Sector dummies	YES	YES	YES	YES	YES	YES
Observations	4446	1975	2408	4492	1943	2482
Pseudo R^2	0.038	0.018	0.257	0.102	0.051	0.478
AIC	10980.36279	6964.68040	637.10345	6684.56981	4579.77720	374.10756

Table 4: The effect of technological change on internationalisation of R&D and product innovation (raw coefficients based on Probit regressions)

	All firms Int. R&D	High cap. Int. R&D	Low cap. Int. R&D	All firms Int. product innovation	High cap. Int. product innovation	Low cap. Int. product innovation
Speed tech. change	0.28750***	0.35174***	0.10831	0.35881***	0.39662***	0.35647**
	(4.36)	(4.41)	(0.62)	(5.17)	(4.54)	(2.37)
Uncertainty future tech. change	-0.07962	-0.26107***	0.42962**	-0.05601	-0.26367***	0.37790**
	(-1.04)	(-2.78)	(2.12)	(-0.71)	(-2.58)	(2.12)
Patents used	0.66728***	0.54709***	0.59757*	0.64942***	0.52087***	0.65025**
	(5.33)	(3.64)	(1.96)	(5.05)	(3.24)	(2.47)
Intensity of competition	-0.00923	0.00889	0.06278	0.05153	0.09164	0.00465
	(-0.10)	(0.08)	(0.23)	(0.52)	(0.76)	(0.02)
Employees	0.00014***	0.00017***	0.00101***	0.00017***	0.00024***	0.00095***
	(4.88)	(4.49)	(3.49)	(6.05)	(5.87)	(2.87)
Employees^2	-0.00000***	-0.00000**	-0.00000***	-0.00000***	-0.00000***	-0.00000*
	(-2.84)	(-2.49)	(-2.71)	(-4.02)	(-3.99)	(-1.93)
Export intensity	1.07253***	0.96277***	1.24751**	1.18111***	1.03907***	1.53756***
	(5.46)	(4.15)	(2.46)	(5.69)	(4.06)	(3.37)
Innovation intensity	0.01124	0.00676	3.08777***	-0.02922	-0.17202	1.23216**
	(0.38)	(0.17)	(3.06)	(-0.18)	(-0.52)	(2.15)
Eastern Germany	-0.32566**	-0.34935**	-0.06406	-0.89146***	-1.06790***	-0.27566
	(-2.33)	(-2.18)	(-0.18)	(-4.41)	(-4.05)	(-0.78)
Member of a group	0.77637***	0.71740***	0.87823***	0.87340***	0.81735***	0.89193***
	(6.74)	(5.32)	(2.73)	(7.20)	(5.53)	(3.19)
Constant	-3.50125***	-3.05902***	-12.99687	-3.72967***	-2.96488***	-5.10748***
	(-9.42)	(-6.34)	(-0.06)	(-9.67)	(-6.22)	(-5.67)
Sector dummies	YES	YES	YES	YES	YES	YES
Observations	4435	1966	2406	4435	1966	2406
Pseudo R^2	0.364	0.328	0.517	0.417	0.411	0.457
AIC	691.61165	531.36764	124.83858	662.75859	473.40439	157.62304
p.val. endog. Chi-sq(2) test	0.2429	0.5849	0.7417	0.1621	0.5536	0.9917

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: The impact of technological change on internationalisation of design and process innovation (raw coefficients based on Probit regressions)

	All firms Int. design	High cap. Int. design	Low cap. Int. design	All firms Int. process innovation	High cap. Int. process innovation	Low cap. Int. process innovation
Speed tech. change	0.27176***	0.29359***	0.39355**	0.22734***	0.24831***	0.32884*
	(4.12)	(3.61)	(2.45)	(3.11)	(2.77)	(1.85)
Uncertainty future tech. change	0.01793	-0.14829	0.33029*	-0.07085	-0.29371***	0.39936*
	(0.24)	(-1.60)	(1.93)	(-0.84)	(-2.73)	(1.94)
Patents used	0.57556***	0.44711***	0.54860**	0.62094***	0.53294***	0.52332*
	(4.81)	(3.05)	(2.14)	(4.62)	(3.20)	(1.80)
Intensity of competition	0.07624	0.13179	-0.10035	0.15711	0.25116**	-0.13851
	(0.81)	(1.18)	(-0.44)	(1.51)	(2.01)	(-0.52)
Employees	0.00017***	0.00023***	0.00081***	0.00015***	0.00016***	0.00140***
	(6.07)	(5.78)	(2.66)	(5.69)	(4.88)	(3.98)
Employees^2	-0.00000***	-0.00000***	-0.00000*	-0.00000***	-0.00000***	-0.00000***
	(-4.03)	(-3.95)	(-1.72)	(-3.64)	(-3.04)	(-2.59)
Export intensity	0.95147***	0.85460***	1.18170***	1.01706***	1.00649***	1.01282*
	(4.76)	(3.54)	(2.59)	(4.68)	(3.83)	(1.91)
Innovation intensity	-0.04658	-0.08880	0.21352	-0.03291	-0.10643	0.48682
	(-0.25)	(-0.41)	(0.20)	(-0.16)	(-0.38)	(0.44)
Eastern Germany	-0.64198***	-0.57252***	-0.72211	-0.59779***	-0.66599***	-0.22903
	(-3.94)	(-3.16)	(-1.61)	(-3.31)	(-3.09)	(-0.58)
Member of a group	0.81392***	0.85753***	0.47883*	0.94837***	0.98811***	0.55921*
	(7.21)	(6.22)	(1.82)	(7.23)	(6.19)	(1.81)
Constant	-3.75997***	-3.28290***	-4.34243***	-3.86468***	-3.40067***	-4.65279***
	(-10.11)	(-7.00)	(-5.50)	(-9.48)	(-6.57)	(-4.91)
Sector dummies	YES	YES	YES	YES	YES	YES
Observations	4435	1966	2406	4435	1966	2406
Pseudo R^2	0.377	0.360	0.429	0.390	0.374	0.502
AIC	723.43497	530.27568	158.67904	594.77212	442.58239	127.75325
p.val. endog. Chi-sq(2) test	0.2078	0.8729	0.4386	0.1431	0.4701	0.7181

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: The role of cross-border personnel exchange on internationalisation of R&D and product innovation (raw coefficients based on Probit regressions)

	All firms Int. R&D	High cap. Int. R&D	Low cap. Int. R&D	All firms Int. product innovation	High cap. Int. product innovation	Low cap. Int. product innovation
Speed tech. change	0.25170***	0.32804***	0.10892	0.33782***	0.32875***	0.61125**
	(3.18)	(3.30)	(0.50)	(3.87)	(3.00)	(2.45)
Uncertainty future tech. change	-0.13073	-0.36751***	0.26168	-0.04838	-0.26962*	0.08104
	(-1.28)	(-2.75)	(0.94)	(-0.45)	(-1.84)	(0.31)
Cross-border personnel exchange	0.32466	0.28133	-0.74128	0.48727**	0.36855	-11.55285
	(1.57)	(1.25)	(-0.35)	(2.21)	(1.52)	(-0.01)
(Uncertainty future tech. change)*(Cross-border personnel exchange)	0.25992***	0.30092***	1.00665	0.25797**	0.28215**	6.47428
	(2.65)	(2.79)	(1.00)	(2.45)	(2.40)	(0.01)
Patents used	0.49127***	0.43899**	0.56407	0.42596***	0.35537*	0.23709
	(3.27)	(2.37)	(1.41)	(2.66)	(1.76)	(0.57)
Intensity of competition	-0.12528	-0.17511	0.37560	-0.08095	-0.07728	0.10927
	(-1.15)	(-1.32)	(0.91)	(-0.66)	(-0.52)	(0.29)
Employees	0.00003	-0.00008	0.00062	0.00011***	0.00013**	0.00069
	(0.44)	(-0.79)	(1.57)	(2.76)	(2.16)	(1.31)
Employees^2	-0.00000	0.00000	-0.00000	-0.00000**	-0.00000	-0.00000
	(-0.02)	(0.80)	(-1.20)	(-2.31)	(-1.52)	(-0.68)
Export intensity	0.72827***	0.64353**	1.20838*	0.97139***	0.84077**	1.62337**
	(2.97)	(2.18)	(1.84)	(3.66)	(2.56)	(2.43)
Innovation intensity	0.01590	0.01236	3.69849***	0.00748	-0.10388	1.62065**
	(0.58)	(0.35)	(3.07)	(0.11)	(-0.30)	(2.28)
Eastern Germany	-0.12544	-0.13421	0.02054	-0.86671***	-0.97020***	-0.55926
	(-0.80)	(-0.73)	(0.04)	(-3.24)	(-2.94)	(-0.83)
Member of a group	0.53776***	0.47904***	1.03422**	0.55147***	0.48647***	0.79161*
	(3.83)	(2.81)	(2.14)	(3.65)	(2.61)	(1.88)
Constant	-2.84822***	-2.14139***	-5.86315***	-3.13251***	-2.14975***	-5.84339***
	(-7.03)	(-3.99)	(-3.57)	(-6.94)	(-3.87)	(-3.65)
Sector dummies	YES	YES	YES	YES	YES	YES
Observations	4435	1966	1657	4435	1966	2406
Pseudo R^2	0.578	0.573	0.680	0.656	0.653	0.757
AIC	473.97924	353.14634	91.69964	408.39453	296.19714	92.25665
p.val. endog. Chi-sq(2) test	0.2516	0.7135	0.8143	0.1870	0.4608	0.7479

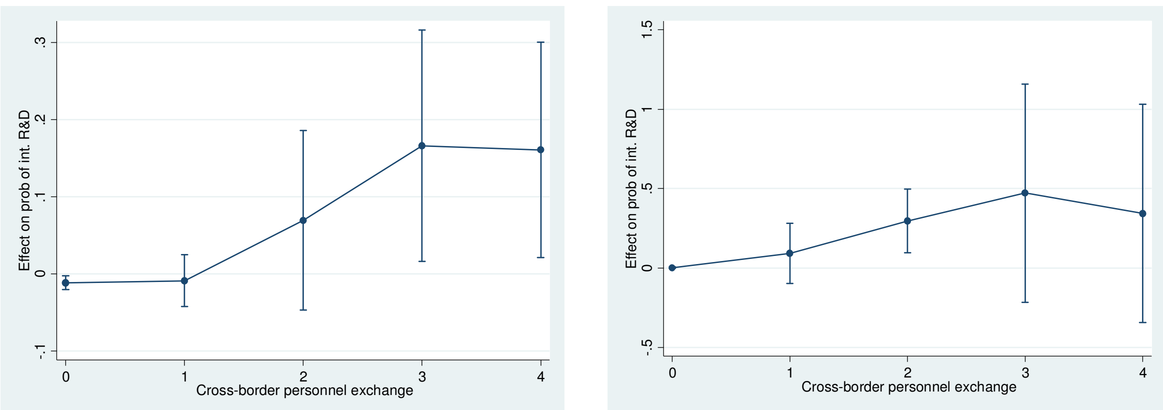
t-statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: The role of cross-border personnel on the internationalisation of design and process innovation (raw coefficients based on Probit regressions)

	All firms Int. design	High cap. Int. design	Low cap. Int. design	All firms Int. process innovation	High cap. Int. process innovation	Low cap. Int. process innovation
Speed tech. change	0.22329***	0.19946*	0.82800***	0.14110	0.10502	0.36082**
	(2.72)	(1.94)	(2.78)	(1.52)	(0.93)	(1.99)
Uncertainty future tech. change	0.05867	-0.15006	0.17133	-0.07538	-0.32821*	0.07652
	(0.58)	(-1.13)	(0.65)	(-0.59)	(-1.93)	(0.33)
Cross-border personnel exchange	0.41189*	0.27483	-0.36869	0.52666**	0.49970**	0.52684
	(1.88)	(1.15)	(-0.28)	(2.43)	(2.12)	(0.74)
(Uncertainty future tech. change)*(Cross-border personnel exchange)	0.30646***	0.38807***	0.98598	0.19529*	0.18571*	0.38548
	(2.87)	(3.24)	(1.58)	(1.91)	(1.65)	(1.14)
Patents used	0.35537**	0.33306*	0.11412	0.43887**	0.41530*	0.17838
	(2.35)	(1.77)	(0.29)	(2.51)	(1.92)	(0.56)
Intensity of competition	-0.02969	0.00213	-0.17693	0.06912	0.17283	0.40785
	(-0.25)	(0.01)	(-0.48)	(0.52)	(1.09)	(1.27)
Employees	0.00011***	0.00011*	0.00048	0.00005	-0.00000	0.00080**
	(2.79)	(1.95)	(1.16)	(1.36)	(-0.06)	(2.51)
Employees^2	-0.00000**	-0.00000*	-0.00000	-0.00000	0.00000	-0.00000*
	(-2.39)	(-1.75)	(-0.85)	(-1.33)	(0.02)	(-1.78)
Export intensity	0.59771**	0.45546	1.66112**	0.66460**	0.66394*	0.66819
	(2.25)	(1.39)	(2.32)	(2.26)	(1.89)	(1.33)
Innovation intensity	-0.00131	-0.02450	-0.41928	0.00782	-0.03741	1.30575
	(-0.02)	(-0.13)	(-0.22)	(0.10)	(-0.14)	(1.30)
Eastern Germany	-0.59312***	-0.47463**	-1.52050	-0.42799*	-0.46936*	-0.35009
	(-2.79)	(-2.05)	(-1.40)	(-1.87)	(-1.74)	(-0.80)
Member of a group	0.54324***	0.56108***	0.54798	0.77287***	0.81040***	0.90128**
	(3.80)	(3.18)	(1.37)	(4.58)	(4.01)	(2.37)
Constant	-3.27905***	-2.59164***	-5.21670***	-3.29692***	-2.68953***	-5.45029***
	(-7.40)	(-4.60)	(-3.85)	(-6.63)	(-4.29)	(-4.34)
Sector dummies	YES	YES	YES	YES	YES	YES
Observations	4435	1966	2406	4435	1966	2406
Pseudo R^2	0.636	0.644	0.720	0.649	0.632	0.681
AIC	439.68967	313.02505	98.11203	361.10550	277.33462	131.49492
p.val. endog. Chi-sq(2) test	0.2945	0.9170	0.0308	0.1744	0.4717	0.2089

t-statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 3: Graphical representation of the interaction of the effect of personnel exchange on internationalisation of R&D and product innovation (left: high-cap., right: low-cap.)



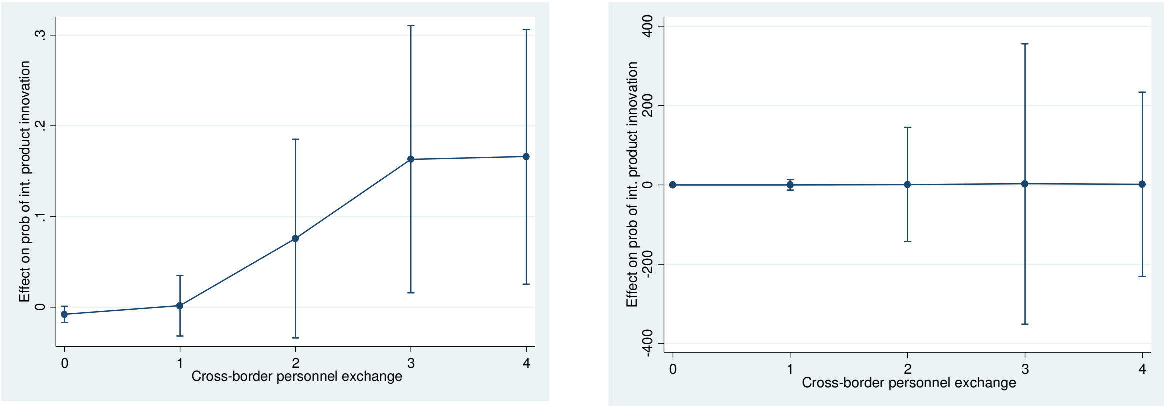


Figure 4: Graphical representation of the interaction of the effect of personnel exchange on the internationalisation of design and process innovation (left: high-cap., right: low-cap.)

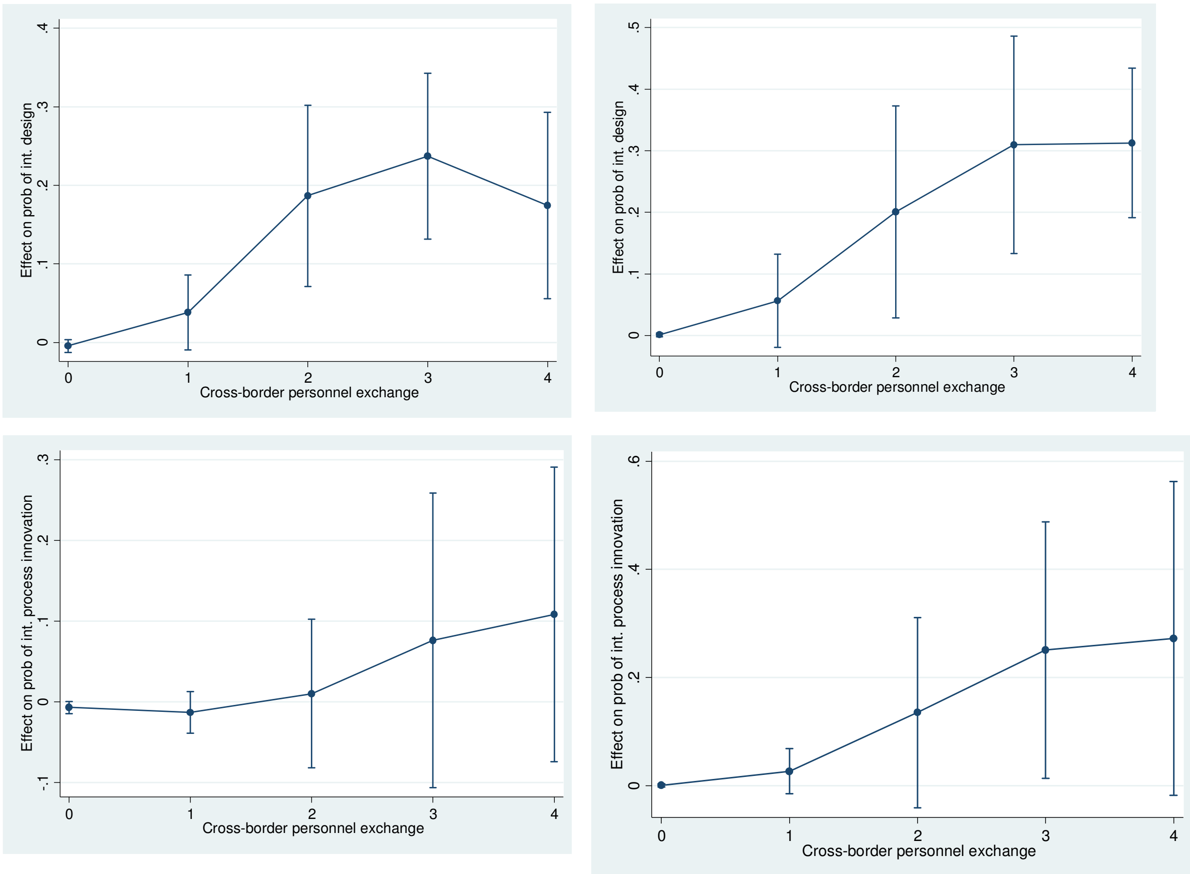


Table 8: The effect of technological change on internationalisation of R&D and product innovation with quadrant dummies (raw coefficients based on Probit regressions)

	All firms Int. R&D	High cap. Int. R&D	Low cap. Int. R&D	All firms Int. product innovation	High cap. Int. product innovation	Low cap. Int. product innovation
Speed tech. change	0.31352***	0.29555**	0.36036	0.38816***	0.25101	0.86523**
	(2.58)	(2.06)	(1.03)	(3.03)	(1.61)	(2.51)
Uncertainty future tech. change	-0.07503	-0.31899***	0.62884***	-0.02729	-0.27879**	0.46248**
	(-0.82)	(-2.71)	(2.59)	(-0.29)	(-2.17)	(2.19)
Highly volatile techn. env.	-0.07026	0.25901	-1.31144	-0.13866	0.35180	-1.28266*
	(-0.29)	(0.91)	(-1.58)	(-0.55)	(1.15)	(-1.87)
Predictable techn. env.	-0.04662	0.05221	-0.04537	-0.01744	0.27889	-0.81391
	(-0.20)	(0.20)	(-0.07)	(-0.07)	(0.97)	(-1.26)
Patents used	0.66733***	0.55222***	0.58215*	0.64573***	0.52777***	0.68514**
	(5.32)	(3.67)	(1.84)	(5.01)	(3.26)	(2.50)
Intensity of competition	-0.01083	0.01957	0.09236	0.04787	0.10211	0.00239
	(-0.12)	(0.18)	(0.31)	(0.48)	(0.84)	(0.01)
Employees	0.00014***	0.00017***	0.00108***	0.00017***	0.00024***	0.00099***
	(4.88)	(4.51)	(3.54)	(6.03)	(5.89)	(2.89)
Employees^2	-0.00000***	-0.00000**	-0.00000***	-0.00000***	-0.00000***	-0.00000**
	(-2.82)	(-2.51)	(-2.62)	(-4.00)	(-4.05)	(-2.00)
Export intensity	1.07372***	0.96217***	1.33001**	1.18616***	1.04297***	1.67566***
	(5.46)	(4.15)	(2.46)	(5.70)	(4.05)	(3.51)
Innovation intensity	0.01144	0.00627	3.29382***	-0.02612	-0.20196	1.23715**
	(0.39)	(0.15)	(3.15)	(-0.17)	(-0.56)	(2.03)
Eastern Germany	-0.32454**	-0.35473**	-0.02416	-0.88763***	-1.08191***	-0.27856
	(-2.32)	(-2.21)	(-0.06)	(-4.39)	(-4.05)	(-0.78)
Member of a group	0.77695***	0.71562***	0.91221***	0.87365***	0.81805***	0.89129***
	(6.74)	(5.30)	(2.74)	(7.20)	(5.52)	(3.12)
Constant	-3.54642***	-2.89413***	-13.87978	-3.82510***	-2.75013***	-6.24249***
	(-8.77)	(-5.66)	(-0.05)	(-9.04)	(-5.39)	(-5.30)
Sector dummies	YES	YES	YES	YES	YES	YES
Observations	4435	1966	2406	4435	1966	2406
Pseudo R^2	0.365	0.329	0.540	0.417	0.413	0.475
AIC	695.52755	534.32748	124.55575	666.33676	475.96473	157.50225
p.val. endog. Chi-sq(2) test	0.2479	0.5919	0.8804	0.1591	0.5602	0.9846

t-statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9: The effect of technological change on the internationalisation of design and process innovation with quadrant dummies (raw coefficients based on Probit regressions)

	All firms Int. design	High cap. Int. design	Low cap. Int. design	All firms Int. process innovation	High cap. Int. process innovation	Low cap. Int. process innovation
Speed tech. change	0.34997***	0.27477*	0.64271**	0.30789**	0.23603	0.63089*
	(2.90)	(1.91)	(2.00)	(2.30)	(1.47)	(1.71)
Uncertainty future tech. change	-0.03778	-0.24747**	0.35066*	-0.03178	-0.27457**	0.48905**
	(-0.42)	(-2.15)	(1.76)	(-0.32)	(-2.14)	(2.05)
Highly volatile techn. env.	-0.02597	0.28100	-0.55092	-0.30759	-0.02769	-0.86226
	(-0.11)	(1.00)	(-0.94)	(-1.13)	(-0.09)	(-1.19)
Predictable techn. env.	-0.26082	-0.09853	-0.43257	-0.09852	0.04722	-0.37244
	(-1.10)	(-0.36)	(-0.72)	(-0.39)	(0.16)	(-0.54)
Patents used	0.57952***	0.46066***	0.54822**	0.61637***	0.53168***	0.51226*
	(4.83)	(3.13)	(2.12)	(4.58)	(3.19)	(1.74)
Intensity of competition	0.07799	0.14464	-0.11113	0.15153	0.24922**	-0.16897
	(0.83)	(1.28)	(-0.48)	(1.44)	(1.98)	(-0.61)
Employees	0.00017***	0.00023***	0.00080**	0.00015***	0.00016***	0.00144***
	(6.11)	(5.82)	(2.54)	(5.66)	(4.88)	(4.02)
Employees^2	-0.00000***	-0.00000***	-0.00000	-0.00000***	-0.00000***	-0.00000***
	(-4.04)	(-3.98)	(-1.59)	(-3.58)	(-3.03)	(-2.67)
Export intensity	0.95378***	0.84505***	1.25373***	1.03304***	1.00988***	1.09593**
	(4.77)	(3.49)	(2.69)	(4.72)	(3.83)	(2.02)
Innovation intensity	-0.05059	-0.10247	0.10755	-0.02572	-0.10392	0.43710
	(-0.27)	(-0.44)	(0.10)	(-0.14)	(-0.38)	(0.37)
Eastern Germany	-0.64505***	-0.58123***	-0.71036	-0.59325***	-0.66248***	-0.23923
	(-3.96)	(-3.19)	(-1.60)	(-3.28)	(-3.07)	(-0.59)
Member of a group	0.81807***	0.86064***	0.48263*	0.95134***	0.98783***	0.54975*
	(7.22)	(6.22)	(1.82)	(7.23)	(6.18)	(1.76)
Constant	-3.77866***	-3.09622***	-4.79476***	-4.05041***	-3.41379***	-5.27523***
	(-9.33)	(-6.20)	(-4.99)	(-9.08)	(-6.19)	(-4.70)
Sector dummies	YES	YES	YES	YES	YES	YES
Observations	4435	1966	2406	4435	1966	2406
Pseudo R^2	0.379	0.363	0.433	0.392	0.374	0.511
AIC	725.72277	531.85312	161.72850	597.35771	446.50768	130.07567
p.val. endog. Chi-sq(2) test	0.2181	0.8638	0.4139	0.1434	0.4747	0.6680

t-statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$