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Firm capabilities, technological dynamism and the internationalisation of innovation: A behavioural approach

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Abstract
We develop a behavioural framework of bounded rational decision-making under uncertainty to analyse the role of technological dynamism in the firm's environment for its decision to internationalise innovation. Applying prospect theory, we argue that technological uncertainty in the firm's environment affects its risk preferences differently depending on its technological capabilities. A key prediction is that firms with low capabilities will internationalise innovation when faced by technological uncertainty while firms with high capabilities will concentrate their innovation at the home-base. We also argue that our behavioural approach based on prospect theory is not a stand-alone programme but benefits from the integration with traditional concepts in IB. In particular, we make a case that organisational measures fostering absorptive capacity, such as intensive personnel exchange between headquarters and subsidiaries, can help to attenuate the high-capability firms' tendency to concentrate innovation at the home-base when faced by high uncertainty. We corroborate the predictions of our framework based on data from the German part of the Community Innovation Survey.
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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, Massini, & Lewin, 2008; Pyndt & Pedersen, 2006; Bardhan & Jaffe, 2005; Contractor, Kumar, Kundu, & Pedersen, 2010; Criscuolo, Haskel, & Slaughter, 2010; Nieto & Rodríguez, 2011). Although some authors discussed the strategic drivers of the internationalisation of innovation (Lewin, Massini, & Peeters, 2009; Mudambi & Venzin, 2010; Ambos & Ambos, 2011), a common critique of the literature has been that that it abstracts from the decision-maker (Hutzschenreuter, Pedersen, & Volberda, 2007) and therefore largely ignores behavioural insights on decision-making under uncertainty and bounded rationality (Aharoni, 2010; Harvey, Griffith, Kiessling, & Moeller, 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, Tihanyi, & Connelly, 2011).

In this article, we propose a behavioural framework for studying the internationalisation of innovation activities which explicitly considers bounded rational decision-making under uncertainty. Following prospect theory, we argue that, in light of incomplete information, decision-makers will use heuristics based on satisficing rather than optimising principles (Kahneman & Tversky, 1979; Fiegenbaum, Hart, & Schendel, 1996; Shoham & Fiegenbaum, 2002; Aharoni, 2010). In specific, prospect theory postulates the existence of satisficing reference points (aspiration levels), where firms above the reference point will be risk-averse in order to avoid falling below the reference point. Firms below will be risk-assertive in order to maximise the chances of passing the reference point.

While not dismissing other environmental factors such as culture, institutions or markets (see for example Hutzschenreuter, Voll, & Verbeke, 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 speed and 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 their 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). Our results show that both speed of technological change and uncertainty about its direction increase innovation activities in general. But while high speed of technological change also increases the propensity to innovate internationally, the effects of uncertainty are conditional on the firms' internal technological capabilities. Uncertainty reduces the propensity to conduct innovation internationally for firms with high capabilities and increases it for firms with low capabilities. In addition, we show that the negative effect of technological uncertainty for firms with high technological capabilities disappears when firms adopt organisational measures to increase their absorptive capacity and transfer capability (Kuemmerle, 1999) by engaging in personnel exchange between headquarters and subsidiaries.

We contribute to the literature in two major ways. Firstly, we provide evidence on how technological dynamism (Narula, 2001) affects decisions on internationalising 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, which is typically ignored in more traditional models with fully rational decision-makers. While uncertainty may be a lesser concern in decision-making in routine situations, in non-routine situations (e.g. when firms have no prior experience with internationalisation of innovation or with the country of destination), our approach provides insights beyond the explanatory scope of 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, Kraatz, & Bresser, 2000). Based on prospect theory (amongst others Kahneman & Tversky, 1979; Kahneman, 2003), alternative choices can be characterised by the associated risks and returns (Fiegenbaum et al., 1996; Shoham & Fiegenbaum, 2002). This is also true for decisions to innovate and how to locate innovation activities on an international scale. We focus on two characteristics of the technological environment: 'uncertainty about the direction technological change' and 'speed of technological change' because they decisively affect the risk and returns with innovation in general and its internationalisation in particular (compare Bourgeois & Eisenhardt, 1988; Gustafson & Reger, 1995; Wirtz, Mathieu, & Schilke, 2007). Based on prospect theory, we then argue that the firms' technological capabilities govern their risk preferences, which determine 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 (Granstrand, Hakanson, & Sjölander, 1993; Pearce, 1999) to seeking access to knowledge (Lewin & Peeters, 2006; Bunyaratavej, Hahn & Doh, 2007; Meyer, 2015) and scarce highly qualified human capital (Lewin et al., 2009). Several authors have argued that one source for this trend is increased technological dynamism spurred, for example, by 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 dynamism in a firm's environment 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 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; Gustafson & 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 (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 yet known. 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, which complicates the appropriation of any resulting benefits. 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, Martin, & Srholec, 2016). Uncertainty is not only driven by the number of different technological trajectories (solution paths) that are followed simultaneously but also by the extent to which these trajectories differ. In general, uncertainty will be higher in pre-paradigmatic phases and lower afterwards.

Though often correlated with uncertainty, speed of technological change is conceptually different because it refers to how fast existing technological opportunities (Robin & Schubert, 2013; Vega-Jurado, Gutiérrez-Gracia, Fernández-de-Lucio, & Manjarrés-Henríquez, 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 explains the positive correlation with uncertainty since uncertainty positively depends on the number of different trajectories. 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 the positive correlation, speed and uncertainty are not mechanistically tied together (for some examples see Figure 1).

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

Uncertainty about the direction of technological change		

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 because of codified knowledge and effective property rights
		– Example: miniaturisation of computer chips

	low **Speed of technological change**	high

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

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 thus 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, Malmberg, & Maskell, 2004). At the same time, international innovation will bear considerable risks in terms of knowledge leakage at foreign locations (Kotabe, Mol, & Ketkar, 2008; Criscuolo, 2009; Jensen, Pedersen, & Petersen, 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. 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-Cazurra & 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-return 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 less crucial. Thus the gains from internationalising innovation will be lower. At the same time, risks associated with internationalisation will also be lower because knowledge sources are more homogeneous and effective property rights reduce the risk that unique knowledge leaks. 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-return 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' technological capabilities determine the firms' risk preferences.

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 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 with, where a prospect refers to a contract by which an outcome A_i is realised with probability p_i for $i = 1,\ldots,N$. An important finding is that the observed decisions of one and the same decision-maker are sometimes consistent with risk-aversion and sometimes with risk-assertion. To explain this finding, Kahneman and Tversky (1979) developed an extension of the expected utility theory, called 'prospect theory', which 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 4000 currency units with a probability of 20% or 3000 with a probability of 80%, a great majority chose the latter option, which is consistent with risk-aversion. However, facing the same students with the alternative of losing 4000 with a probability of 20% or losing 3000 with a probability of 80%, the majority chose the former option, which is consistent only with risk-assertion. Based on this observation, prospect theory posits that there 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 extend the theory to 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, Figueira-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 use a firm's technological capabilities as a suitable reference scale because a main motive for the internationalising innovation is to expand technology-related capabilities by accessing globally dispersed knowledge or human capital (Dunning & Narula, 1995; Narula & Zanfei, 2004; Meyer, Wright, & Pruthi, 2009; Nieto & Rodríguez, 2011; Meyer, 2015; Cuervo-Cazurra, Narula, & Un 2015). Several authors have shown that internationalising innovation is increasingly aiming at asset-seeking goals (Zanfei, 2000; Le Bas & Sierra, 2002; Narula & Zanfei, 2004; Castellani, Mancusi, Santangelo, & Zanfei, 2015). An implication of prospect theory is that in technological competition, firms with low technological capabilities are in a 'loss-situation' and hence tend to be risk-assertive while firms with high technological capabilities have a competitive advantage (gain situation) and tend to be risk-averse.

The main propositions of prospect theory can be summarised graphically: The coordinate system shown in Figure 2 represents 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

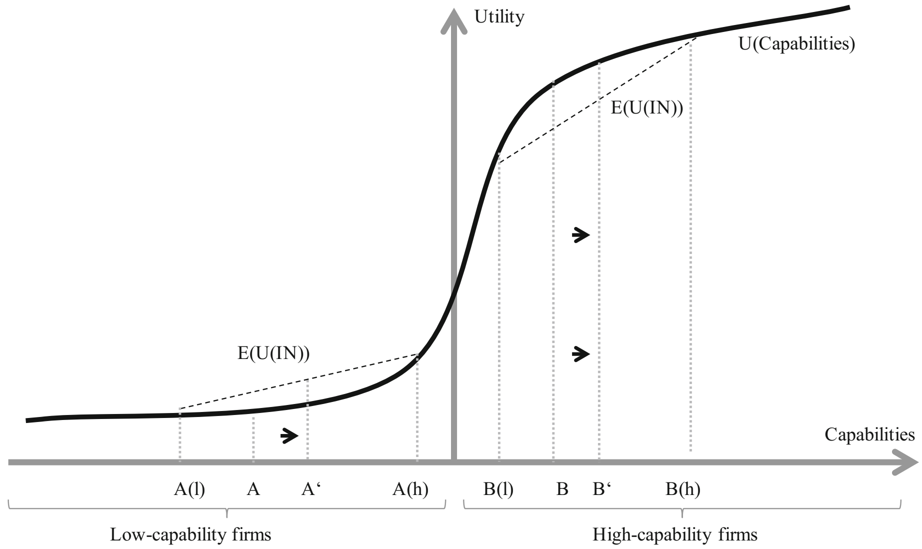

Figure 2 A graphical representation of prospect theory.

function which is locally convex, corresponding 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, corresponding 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 levels $U(A)$ 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 on average. 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 Figure 2, 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*. It is risk-assertive. The situation is different for the high-capability firm. 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 (e.g. knowledge leakage or fragmentation of knowledge resources) and behaves in a risk-averse manner.

The Hypotheses

Based on the preceding discussion we develop hypotheses on how speed and uncertainty of technological change affect the incentives to internationalise innovation activities depending on a firm's level of technological capabilities. High speed of technological change necessitates innovation because it provides rich technological opportunities (compare Vega-Jurado et al., 2008; Robin & Schubert, 2013) and implies rapid technological ageing of existing products (Tassey, 2008; Seppälä, 2013). Firms which do not innovate fast may fall back against their competitors, particularly if firms compete over a future dominant design implying winner-takes-all races for successful innovation. High speed of technological change also increases the incentives for internationalising innovation. 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). Second, 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 in particular. 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:

Hypothesis 1a: High speed of technological change increases the innovation efforts for firms with both high and low technological capabilities.

Hypothesis 1b: High speed of technological change increases the propensity to conduct innovation activities internationally for firms with both 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 eroding 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-bases constantly, in order to avoid their technological capabilities to become outdated by unanticipated developments. In this vein, several authors have argued that in volatile markets competitive advantage is not sustainable without innovation (Johanson & Vahlne, 1977; Figueira-de-Lemos & Hadjikhani, 2014). By innovating, firms can reduce the risk of technological lock-out in the long run (Schilling, 2002). But high uncertainty does not only increase incentives to innovate for high-competence firms. Also, firms with low technological capabilities have incentives to innovate as uncertainty increases the chances of developing leap-frogging innovations by adopting novel solution paths (compare Lee, Lim, & Song, 2005). It should be noted that the outcomes of innovation in pre-paradigmatic phases can be particularly uncertain, which implies that risk considerations also apply to home-base innovation. Nonetheless, prospect theory will not automatically imply that risk considerations will always dominate the decision. With reference to Figure 2, if the increase in the expected value of a strategy is sufficiently large, risk-induced effects will lose importance. In pre-paradigmatic phases, gains of innovation are typically very high because of the prospect to establish a dominant design, which is likely to make risk considerations secondary. Moreover, not innovating because of risk-aversion (right part of Figure 2) cannot be considered a low-risk strategy in pre-paradigmatic phases because without innovation firms are likely to be outcompeted and will leave the market sooner or later. Instead of representing a low-risk strategy guaranteeing the status-quo, not innovating in pre-paradigmatic markets is a guarantee to fail. We expect:

Hypothesis 2: High uncertainty about the direction of technological change increases the innovation intensity both for firms with high and low technological capabilities.

Thus when technological uncertainty is high the decisive question is not so much whether to innovate, but where. 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 argue 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, Sandelands, & Dutton, 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 and unexpected changes in their technological environment (Granstrand, 1999; Baier, Rammer, & Schubert 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 capabilities have less to lose in terms of knowledge leakage.

Hypothesis 3a: High uncertainty about the direction of technological change increases the propensity to conduct innovation internationally for firms with low technological capabilities.

Hypothesis 3b: The effect in H3a is smaller (or even negative) for firms with high technological capabilities.

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 activities. 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, Kastelli, & Tsakanikas, 2004; Soosay & Hyland, 2008). Bertrand and 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 parents and subsidiaries (Rycroft, 2003; Buckley, Carter, Clegg, & Tan, 2005; Persson, 2006; Li, Wang, & Liu, 2013), because it helps transfer tacit knowledge (Kim, 2001).

Hypothesis 4: 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 German Innovation Survey. The German Innovation Survey 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 survey uses a stratified random panel sample that is refreshed every second year and represents the firm population in Germany for firms with five or more employees in the sectors targeted by the CIS (mining, manufacturing, utilities, wholesale trade, transportation and storage, information and communication services, financial and insurance activities and other business-oriented services). More details on the German Innovation Survey can be found in Peters and Rammer (2013).

We use data from the German Innovation Survey survey conducted in 2011, which collected information on innovation activities of firms conducted during the years 2008 and 2010. The German Innovation Survey 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.

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 other subsidiaries abroad. Our sample restriction ensures that innovation abroad always refers to outside Germany and never to the home-base of the parent firm. With these restrictions, we have a sample of 6589 firms. Due to the item non-response for some of the model variables, the sample used in the regressions consisted of approximately 4400 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 the 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 German Innovation Survey in 2011 survey provides information on whether a firm was engaged in activities at foreign locations related to R&D, manufacturing of new products, designs or 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. 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 nevertheless 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 (Tables 3, 4 and 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. While indeed Kahneman and Tversky (1979) concentrated on situations where the reference points were expressed in monetary terms and thus objectively measurable, determining reference points is typically 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 four-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 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, van den Bosch, & Volberda, 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 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). 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, Oesterle, & Brodel, 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, Dezsö and Zaho (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 the internationalisation of innovation are positively related. We include a variable measuring the intensity of price competition rated by managers on a Likert scale ranging 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 risk of knowledge leakage 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, Kinkel, & Jäger, 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 two-digit sectors, where we exclude the rating of the focal firm. We use this as an instrumental variable for the individual firms' ratings. The intuition 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 article. Internationalisation of any kind of innovation activities is a phenomenon observed only in a minority of the firms. We find that with a sample share of 2.6% international product innovation activities were the most common, 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 a correlation matrix in Table 2.

Main Results

In H1–H4 we argued that the speed of technological change and uncertainty concerning its direction can have distinct effects on the firms' propensity to invest in innovation and their internationalisation patterns depending on the firms' technological capabilities. We first start with the analysis of the general incentives for innovation, which we present in Table 3.

Table 1 Summary statistics

Variable	Obs	Mean	SD	Min	Max
International R&D	4435	0.025	0.156	0	1
International product innovation	4435	0.026	0.160	0	1
International design	4435	0.027	0.163	0	1
International process innovation	4435	0.022	0.146	0	1
Innovation intensity	4435	0.084	1.235	0	75
R&D intensity	4246	0.046	0.706	0	34
Speed of technological change	4435	1.942	0.870	1	4
Uncertainty about future technological change	4435	2.037	0.807	1	4
Stable technological environment	4435	0.616	0.486	0	1
Predictable technological environment	4435	0.111	0.314	0	1
Unpredictable technological environment	4435	0.158	0.365	0	1
Highly volatile technological environment	4435	0.115	0.319	0	1
Internal technological capabilities	4372	3.228	1.158	1	5
Cross-border personnel exchange	4435	0.075	0.457	0	4
Patents used	4435	0.279	0.449	0	1
Intensity of competition	4435	2.565	0.668	1	4
Employees	4435	246	1649	1	64,432
Export intensity	4435	0.119	0.218	0	1
Location in Eastern Germany	4435	0.334	0.472	0	1
Member of an enterprise group	4435	0.236	0.425	0	1
High-tech manufacturing	4435	0.076	0.265	0	1
Medium-to-high-tech manufacturing	4435	0.126	0.332	0	1
Medium-to-low-tech manufacturing	4435	0.125	0.331	0	1
Low-tech manufacturing	4435	0.231	0.421	0	1
Knowledge-intensive services	4435	0.311	0.463	0	1
Other services	4435	0.130	0.336	0	1

Table 2 Correlation table

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
A	Int. R&D	1.00																			
B	Int. product inn.	0.73	1.00																		
C	Int. design	0.77	0.80	1.00																	
D	Int. process inn.	0.68	0.78	0.77	1.00																
E	Innovation intens.	0.01	0.00	0.00	0.00	1.00															
F	R&D intens.	0.01	0.00	0.00	0.00	0.94	1.00														
G	Speed tech. change	0.08	0.09	0.08	0.07	0.03	0.03	1.00													
H	Uncertainty tech. change	0.03	0.04	0.04	0.03	0.06	0.07	0.42	1.00												
I	Stable tech. env.	−0.06	−0.06	−0.05	−0.04	−0.04	−0.05	−0.65	−0.68	1.00											
J	Predictable tech. env.	0.06	0.07	0.04	0.06	0.00	0.00	0.53	−0.12	−0.45	1.00										
K	Unpredictable tech. env.	−0.01	−0.01	−0.01	−0.01	0.01	0.02	−0.08	0.57	−0.55	−0.15	1.00									
L	Highly volatile tech env.	0.03	0.04	0.05	0.02	0.05	0.04	0.56	0.51	−0.46	−0.13	−0.15	1.00								
M	Internal techn. capabil.	0.14	0.13	0.14	0.13	0.06	0.07	0.17	0.24	−0.16	0.04	0.07	0.12	1.00							
N	Cross-border pers. exch.	0.69	0.75	0.76	0.74	0.00	0.00	0.07	0.03	−0.04	0.06	−0.02	0.02	0.14	1.00						
O	Patents used	0.20	0.20	0.20	0.18	0.07	0.08	0.10	0.12	−0.10	0.04	0.05	0.06	0.30	0.20	1.00					
P	Intensity of competition	−0.01	0.00	0.00	0.01	−0.04	−0.05	0.17	0.16	−0.14	0.05	0.06	0.10	−0.02	0.00	−0.05	1.00				
Q	Employees	0.28	0.30	0.30	0.28	0.00	0.00	0.04	0.03	−0.03	0.04	−0.01	0.02	0.08	0.34	0.10	−0.01	1.00			
R	Export intensity	0.24	0.24	0.23	0.22	0.01	0.01	0.04	0.07	−0.04	0.01	0.03	0.01	0.26	0.25	0.37	−0.04	0.12	1.00		
S	Eastern Germany	−0.08	−0.10	−0.09	−0.08	0.03	0.02	−0.01	−0.05	0.04	−0.01	−0.04	−0.01	−0.02	−0.09	−0.06	0.02	−0.07	−0.11	1.00	
T	Member of a group	0.21	0.23	0.23	0.22	−0.01	−0.01	−0.01	0.01	0.02	0.00	−0.02	−0.01	0.13	0.22	0.17	0.00	0.20	0.20	−0.08	1.00

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 competition	−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)
Sigma (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	10,980.4	6964.7	637.1	6684.6	4579.8	374.1

Notes: *t* statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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 the second and fifth column we present the results for firms with high technological capabilities and in the third and sixth column we present the results for firms with low capabilities. We present the results for the full sample in the first and fourth column as a point of reference.

As concerns the speed of technological change, we expected that both firms with high and with low technological capabilities become more likely to conduct innovation internationally (H1b). The positive effect 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.

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.	−0.07962	−0.26107***	0.42962**	−0.05601	−0.26367***	0.37790**
change	(−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	691.6	531.4	124.8	662.8	473.4	157.6
p.val. endog. Chi-sq(2) test	0.2429	0.5849	0.7417	0.1621	0.5536	0.9917

Notes: *t* statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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 capabilities will also affect the expected returns of internationalisation, because firms with high technological capabilities 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-capability 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. Tables 6 and 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

Table 5 The effect 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.	0.01793	−0.14829	0.33029*	−0.07085	−0.29371***	0.39936*
change	(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	723.4	530.3	158.7	594.8	442.6	127.8
p.val. endog. Chi-sq(2) test	0.2078	0.8729	0.4386	0.1431	0.4701	0.7181

Notes: *t* statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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 (Figures 3 and 4).

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 two-digit level in the core tables relating to internationalisation. The results of the endogeneity tests were mostly far from significant (see statistics in Tables 4, 5, 6, 7, 8 and 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 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)*	0.25992***	0.30092***	1.00665	0.25797**	0.28215**	6.47428
(Cross-border personnel exchange)	(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	474.0	353.1	91.7	408.4	296.2	92.3
p.val. endog. Chi-sq(2) test	0.2516	0.7135	0.8143	0.1870	0.4608	0.7479

Notes: *t* statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Tables 4 and 5 as additional explanatory variables. The results can be found in Tables 8 and 9 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 article. Therefore the self-assessment and its implied subjectivity may have measurement 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

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)*	0.30646***	0.38807***	0.98598	0.19529*	0.18571*	0.38548
(Cross-border personnel exchange)	(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	439.7	313.0	98.1	361.1	277.3	131.5
p.val. endog. Chi-sq(2) test	0.2945	0.9170	0.0308	0.1744	0.4717	0.2089

Notes: *t* statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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.

DISCUSSION

In this article, we provided a predictive framework to analyse internal and environmental technological factors that drive a firm's decision to conduct innovation internationally. We moved beyond the discussion on motives for performing certain activities abroad (for a recent review, see Cuervo-Cazurra & Narula, 2015) such as market-seeking, efficiency-seeking, resource-seeking or strategic asset-seeking motives (Kuemmerle, 1999; Dunning, 1993, 2000; von Zedtwitz & Gassmann, 2002). We employed prospect theory (Kahneman & Tversky, 1979; Kahneman, 2003; Fiegenbaum et al., 1996) to explain different outcomes of internationalising innovation activities in different

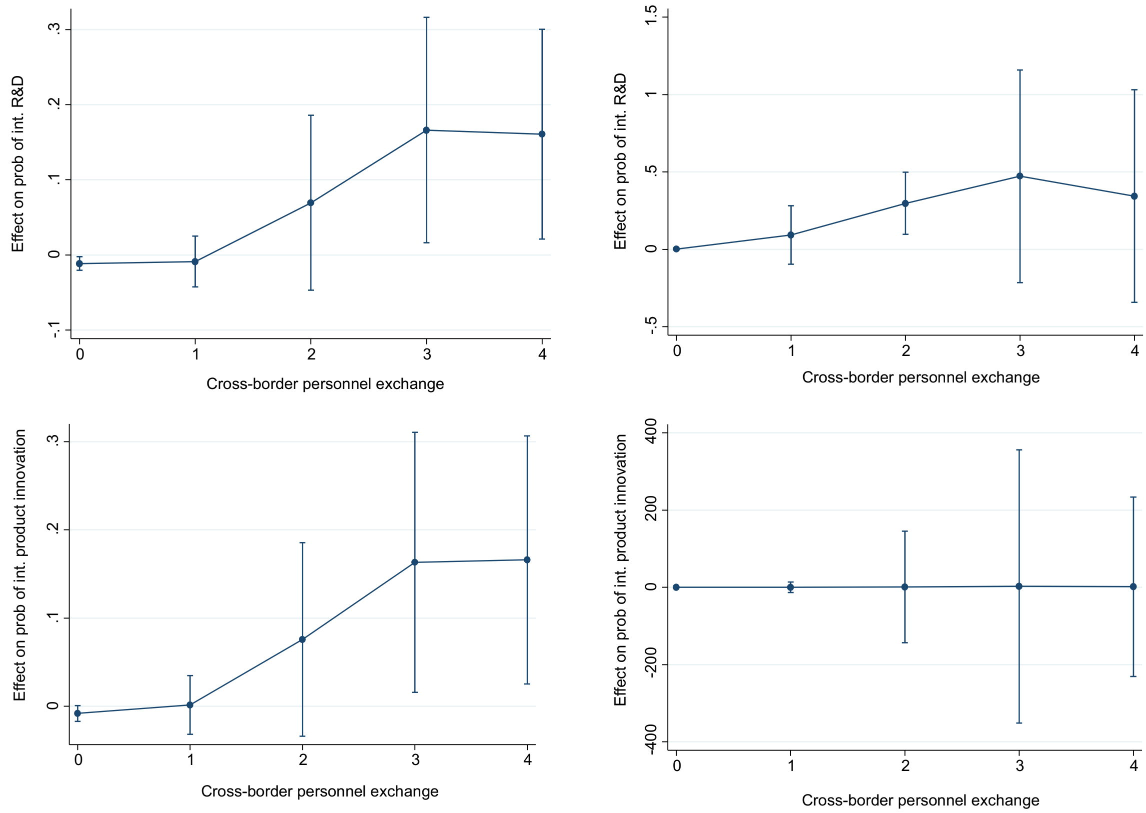

Figure 3 Graphical representation of the interaction of the effect of personnel exchange on internationalisation of R&D and product innovation (*left* high-cap., *right* low-cap).

technological environments as the result of a risk-return trade-off. 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 level of internal technological capabilities. 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).

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; Figueira-de-Lemos & 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 the IB literature that firms face a risk-return trade-off when internationalising activities (Hahn, Doh, & Bunyaratavej, 2009; Massini, Perm-Ajchariyawong, & Lewin, 2010; Jensen et al., 2013), 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

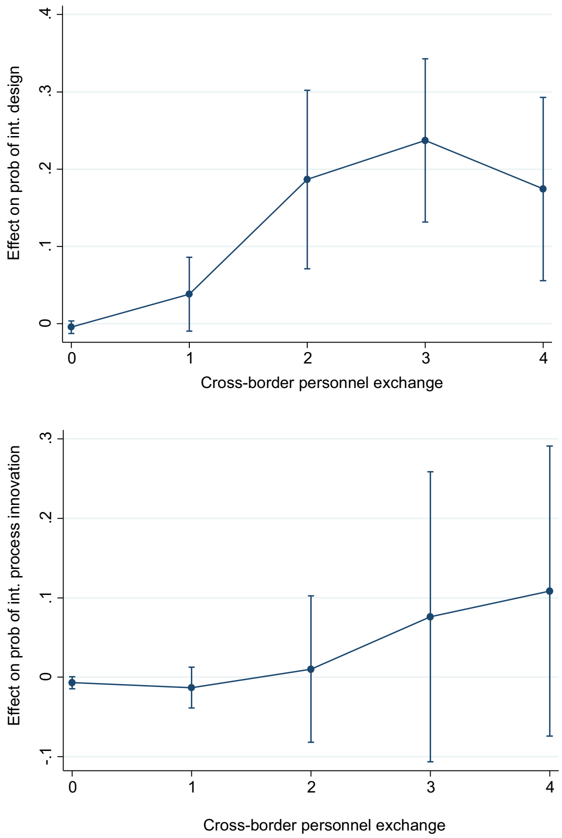

Figure 4 Graphical representation of the interaction of the effect of personnel exchange on the internationalisation of design and process innovation (*left* high-cap., *right* low-cap).

such as leakage of knowledge (Criscuolo, 2009; Kotabe et al., 2008; Lei & Hitt, 1995), higher organisational complexity (Bartlett & Ghoshal, 2002; Fifarek, Veloso, & Davidson, 2008; Baier et al., 2015; Castellani, Montresor, Schubert, & Vezzani, 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 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 fully rational. 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. The result that high-capability firms concentrate their innovation activities at the home-base is interesting because it seems in conflict with findings that purely domestic firms will forego important internationalisation benefits such as globally dispersed human capital (Lewin et al., 2009) or greater multicultural diversity (Un, 2016), both leading to higher innovation capacity. Thus, if the effect of risk-aversion leads some firms to forego such substantial benefits, the importance of varying risk-preferences must be non-negligible.

Our theory explains these findings, which proved to be robust across a variety of different

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	695.5	534.3	124.6	666.3	476.0	157.5
p.val. endog. Chi-sq(2) test	0.2479	0.5919	0.8804	0.1591	0.5602	0.9846

Notes: *t* statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

specifications, in terms of risk preferences differing between high and low-capability firms. We stress that the findings are hard to explain within a more traditional theoretical framework. First, with the exception that risk preferences vary by firm size (compare Roza et al., 2011), existing theories provide very little guidance on the reasons why firms may have differing 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

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	725.7	531.9	161.7	597.4	446.5	130.1
p.val. endog. Chi-sq(2) test	0.2181	0.8638	0.4139	0.1434	0.4747	0.6680

Notes: *t* statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

home-base augmenting activities like innovation it is less so. One may argue 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 and 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 internationalisation becomes an increasingly routine task (Dossani & Kenney, 2007). Gooris and Peeters (2016), for example, show that international firms over time learn to mitigate risks of knowledge leakage through the effective use of strong legal protection (if available) or the improvement of internal control systems. Thus we would expect that with increasing experience in the internationalisation of innovation and with the foreign location, the relevance of the risk component vanishes. The learning argument thus provides a way to incorporate a time dimension in the relationship, tentatively implying a set of more dynamic hypotheses. We would for example expect that the risk effect leading high-capability firms to concentrate innovation at the home-base is the stronger the lower the firms' experience in internationalisation is. We would also expect that the probability to discontinue already established foreign innovation activities decreases as the firm improves its protection strategy over time. While these hypotheses must remain untested here, they could pave the way for highly relevant future research.

Our approach is of course subject to limitations. The 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, Jiang, & Murray, 2011; Bertrand & Mol, 2013) through the exploitation of knowledge dispersed 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. A further line for future research could be opened by more systematically integrating behavioural as well as more established concepts in IB and innovation studies.

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NOTES

[1]A counterargument is that high-capability firms may become more efficient over time in managing their international operations, thereby reducing risks (Dossani & 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.

[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.

[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.

[5]Note that the strong multicollinearity 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.

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