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Taking risks in the face of uncertainty: An exploratory analysis of green innovation

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ABSTRACT

The relationship between uncertainty and firms' risk-taking behaviour has been a focus of investigation since early discussion of the nature of enterprise activity. Here, we focus on how firms' perceptions of environmental uncertainty and their perceptions of the risks involved impact on their willingness to undertake green innovation. Analysis is based on a cross-sectional survey of UK food companies undertaken in 2008. The results reinforce the relationship between perceived environmental uncertainty and perceived innovation risk and emphasise the importance of macro-uncertainty in shaping firms' willingness to undertake green innovation. The perceived (market-related) riskiness of innovation also positively influences the probability of innovating, suggesting either a proactive approach to stimulating market disruption or an opportunistic approach to innovation leadership.
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1. Introduction

The relationship between uncertainty and firms' risk-taking behaviour has been a focus of investigation since the early work of Knight (1921) and discussion of the nature of business enterprise. For Knight, uncertainty was always immeasurable in that the distribution of potential outcomes itself was uncertain, while risk might either be measurable or immeasurable depending on the specific context. For example, a bet based on a throw of a die involves a calculable risk – the distribution of outcomes is clear; a parachute jump involves a set of predictable risks of injury but the probability attached to each risk is immeasurable. In business, incomplete information generally renders both uncertainty (Anderson and Tushman, 2001, often linked to the operating environment of an enterprise, and risk-taking immeasurable, i.e. ex ante there is no clear probability distribution of potential outcomes). This emphasises the importance for decision making of perceived rather than measured uncertainty and risk (Tidd, 2001). According to Milliken (1987) therefore, uncertainty becomes 'an individual's perceived inability to predict something accurately' while, analogously, risk-taking might be thought of as an individual's perceived inability to predict accurately the outcome of an action. In the context of innovation, this emphasises the importance for decision making of perceived environmental uncertainty (PEU) (Meijer et al., 2007; Vecchiato, 2015) and the perceived risk associated with any innovation (Dill, 1958; Meijer et al., 2010).

Theoretical perspectives, however, are ambiguous in the relationship they suggest between PEU and firms' willingness to take further risks such as those associated with innovation. Previous research (Souitaris, 2001) has shown that risk taking small firms tend to be more innovative. Strategic perspectives suggest that market turbulence may create new competitive spaces as rivals close or retrench, potentially increasing the returns to (inherently risky) innovation investment (Todd, 2010). Indeed, some firms may actively seek to create market turbulence by engaging in disruptive innovation in order to establish a position of market or technological leadership (Anthony et al., 2008; Hang et al., 2010). Russell and Russell (1992), for example, observe that in response to high levels of PEU, more entrepreneurial companies would seek to capitalise on opportunities from the environment while more conservative organisations would innovate as a means of 'strategic adaptation'. For these more conservative firms, less uncertain business conditions in which markets are predictable might provide a more conducive environment in which to undertake innovation.

Building on previous research (Dijk and Yarime, 2010; Mazzucato and Tancioni, 2008) our focus here is on the relationship between firms' perceptions of environmental uncertainty and their willingness to take risks in making environmentally-friendly innovations. Green innovation is generally associated with product, process or organisational changes which reduce the environmental burden of firms' operations, including potentially innovation related to energy saving, pollution prevention, waste recycling and reduced toxicity (Chen et al., 2006; Wang, 2015; Yang et al., 2015). The success of such innovation is important from at least three perspectives. First, green innovation plays a potentially important role in terms of sustainability (Shapira et al., 2014; Shi and Lai, 2013). In the energy sector, for example, innovation has been

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a key element of developing cost-effective wind and solar energy (Keirstead, 2007; Shum and Watanabe, 2008). Second, the increasing global emphasis on a low carbon economy is creating new markets which create opportunities for effective innovators (Marinova and Balaguer, 2009; van der Bergh, 2013). Thirdly, pioneers in green innovation may enjoy first mover advantages, maximising potential profitability in these new market spaces albeit with associated commercial risks (Chen et al., 2006).[1] One of the general lessons from developing renewables markets, however, particularly where capital costs are high, is that stability rather than uncertainty seems to play a key role in encouraging sustained entrepreneurial activity and innovation (Suurs et al., 2010). The experience of other sectors has also suggested the increasing difficulty of using past experience to shape future scenario planning in the context of changing technologies and business models (Tierney et al., 2013).

In this context, our analysis contributes to the on-going debate about the relationship between innovation risk and perceived environmental uncertainty. Also, we contribute to the growing body of research on the determinants of green innovation and its potential to address environmental issues, providing a firm-level perspective rather than the more standard macro-economic or market view (Nordhaus, 2011). Our results emphasise the link between some elements of PEU and innovation risk. Simultaneously, we reinforce the importance of both PEU and the perceived riskiness of innovation projects as stimuli for green innovation. The argument proceeds as follows. In Section 2 we briefly review previous evidence on PEU, risk and innovation and specify our hypotheses. Section 3 deals with our data and modelling approach, while Section 4 outlines the main findings. The final sections of the paper discuss the results and identify the key conclusions.

2. Literature and hypotheses

2.1. Innovation risk

Behavioural models of innovation suggest that firms' willingness to engage in innovation will be positively related to anticipated post-innovation returns and negatively related to the perceived riskiness of the project (Calantone et al., 2010; Mechlin and Berg, 1980). There are several conceptualisations of innovation depending on the dimensions considered (see Abernathy and Clark, 1985; Henderson and Clark, 1985, for two characteristic examples). The perceived riskiness of an innovation project will itself reflect the technological complexity of the project as well as commercial concerns about sales, profitability and potential competition (Cabrales et al., 2008; Keizer and Halman, 2007; Roper et al., 2008). Radical drug discovery projects, for example, are inherently more risky than more incremental innovations, and project risks may either be exacerbated or offset by a firm's prior experience of undertaking similar projects and their ability to manage elements of innovation risk during the development process using techniques such as real options (Malik, 2011).[2] The technological and market related elements of innovation risk are not independent, however, as Keizer and Halman (2007) suggest: 'Radical innovation life cycles are longer, more unpredictable, have more stops and starts, are more context-dependent in that strategic considerations can accelerate, retard or terminate progress, and more often include cross-functional and or cross-unit teamwork. Incremental projects are more linear and predictable, with fewer resource uncertainties, including simpler collaboration relationships' (p.30).[3] Iyer et al. (2006) also stress the impact of market context, arguing that in some situations such as that in developing countries incremental innovation might represent a more appropriate strategy than radical innovation (Hang et al., 2010). Other studies have suggested that while market turbulence itself may not influence the nature of innovation activity, technological turbulence can have an effect on innovation returns (Calantone et al., 2010). This suggests the possibility that firms embracing technological risks, particularly in the context of environmental uncertainties, may benefit by gaining first mover advantages or market leadership (Leenders and Voermans, 2007).

Technological innovation risks are associated primarily with the potential failure of development projects to achieve the desired technological or performance outcomes, an inability to develop a solution which is cost-effective to manufacture/deliver (Astebro and Michela, 2005), or issues around project development time (Menon et al., 2002; Von Stamm, 2003, p. 308–309). Each may have implications for the subsequent market success or viability of an innovation. In terms of development time, for example, it has been suggested that compressed development time may necessitate overly rapid decision making, reducing innovation quality (Zhang et al., 2007) with potentially negative effects on post-innovation returns (Bower and Hout, 1988). Market-related innovation risks have a commercial dimension linked directly to the demand for the innovation but may also involve issues around rivalry or appropriability conditions. Astebro and Michela (2005), for example, emphasise demand instability as one of three main factors linked to reduced innovation survival in their analysis of 37 innovations supported by the Canadian Inventors Assistance Programme.[4] In newly evolving industries, in particular, demand can play a key role in stimulating innovation (Klepper and Malerba, 2010). Studies of a range of environmental technologies, for example, have emphasised the role of the contemporaneous development of supply-side capability and market demand, often supported by public policy (Dijk and Yarime, 2010; Norberg-Bohm, 2000; Taylor, 2008). In domestic markets for photovoltaics, for example, feed-in tariffs and other fiscal incentives have been used successfully to encourage demand in some countries (Germany, Spain) in the hope of stimulating innovation and market development (Frondel et al., 2008). Market rivalry and competitors' responses may also play a critical role in shaping market-related innovation risks. Rivals' new product announcements may reduce future returns (Fosfuri and Giarratana, 2009), for example, while appropriability conditions may shape firms' ability to benefit from new innovations and therefore shape their market strategy (Leiponen and Byma, 2009). We argue therefore that:

Hypothesis 1. The probability of green innovation will be negatively related to perceived innovation risk.

Beyond the specific innovation project, firms' assessment of the likely returns to any innovation might be said to depend on their perceptions of environmental uncertainty.

2.2. Perceived environmental uncertainty (PEU)

Some studies have considered PEU as a single construct, for example, related to technology (Taminau, 2006), economic conditions (Koetse et al., 2006), or ex ante measures of profit and loss (Ballantine et al., 1993). Other studies have used a single construct for PEU but included a range of different sources of uncertainty. For example, Miles and Snow (1978) examine PEU in terms of financial markets, trade unions, government and regulatory bodies for the macro-external environment and customers, suppliers and competitors for the micro-external environment. Similarly, Ruth et al. (2000), following Daft et al., (1988) and Sawyer (1993), consider both macro-external PEU factors such as technological and political uncertainty, alongside micro-external PEU factors such as customers, markets and resources. The majority of most recent studies have, however, emphasised the multi-dimensional or multi-level aspect of PEU. Miller (1992), for example, writing in the international business tradition, examines macro-level uncertainty

[1] See Kim and Lee (2011) for an exploration of the advantages and commercial risks implicit in first mover and early-entrant strategies.

[2] Incremental innovation might be said to involve 'product line extensions or adding modifications to existing products or platforms (Iyer et al., 2006). Radical innovations are usually said to differ in at least one of two ways reflecting significant changes in product or process technologies and/or a firm's business model (Wuyts et al., 2004)

[3] See also Leifer et al. (2000).

[4] The other predictors of innovation survival identified by Astebro and Michela (2005) are 'technical product maturity' and 'entry cost and price'.

focusing on political, governmental policies, macroeconomics, social and natural; and industry-level uncertainties related to input markets, product markets and competition. In the economics literature, Freel (2005) adopts an essentially similar multi-level approach reflecting macro-economic uncertainties (regulation, standardisation and information) and industry-level factors such as customers, suppliers and competition. Other studies have also included sources of uncertainty internal to the firm with Duncan (1972) and Bourgeois (1985) both emphasising that uncertainty may arise from either internal or external sources. Duncan (1972), for example, investigated customers, suppliers, competitors, socio-political and technological factors as part of the external environment and personnel, functional and staff units, and organisational-level factors for the internal environment. Liao and Gartner (2006) adopt a similar perspective defining PEU in terms of three dimensions: financial, commercial and operational.

2.3. PEU and innovation risk

Two empirical results stand out from prior studies of the relationship between PEU and innovation. First, a number of studies (Damanpour, 1996; Haptuar and Hirji, 1998; Pierce and Delbecq, 1977; Souder et al., 1999) have found a positive relationship between environmental uncertainty and innovation. DeTienne and Koberg (2002), for example, examined the influence of environmental (as well as organisational and managerial) characteristics on innovation and found that discontinuous innovation was positive correlated with environmental uncertainty (examined as environmental dynamism). Souder et al. (1999) also found PEU to have a significant influence on R&D which correlated to new product development effectiveness. Similarly, Calantone et al. (1997) concluded that PEU has a positive impact on new product success. Second, and significantly for our study, Freel (2005) and others have found different relationships between the various different dimensions of PEU and firms' innovation activity. Damanpour and Schneider (2006) report similar results with some elements of environmental uncertainty (wealth and population growth) positively correlated with innovation while others (urbanisation and unemployment rates) are not. In general terms, however, the evidence suggests:

Hypothesis 2. The probability of undertaking green innovation will be positively linked to perceived environmental uncertainty.

3. Data and methods

Data for our analysis is taken from a specially commissioned telephone survey conducted with firms in the UK food manufacturing sector in summer 2008. We consider the food sector specifically, as most previous studies of green innovation have focussed on more high tech sectors such as chemicals, electronics. By contrast food manufacturing has traditionally been considered a low-tech sector, although the sector is rapidly becoming more technology intensive (Cuerva et al., 2014). Recent issues in the food supply chain have also focussed attention on the green and environmental credentials of food suppliers (Chebolu-Subramanian and Gaukler, 2015). The sampling frame for our survey was derived from the Dun and Bradstreet database as a random drawing of SMEs (i.e. firms with 5–250 employees). The survey was conducted using Computer Aided Telephone Interviewing (CATI) technology which allows randomised ordering of question options. Respondents were senior managers or managing directors in the target firms. The survey was conducted in the period of international uncertainty after the start of the sub-prime crisis of 2007 and subsequent recession but prior to the collapse of Lehman Brothers (September 2008) and the banking and financial crisis in Iceland (October 2008).

In the survey firms were said to have undertaken green innovation if, over the previous three years, they had introduced a new or improved product which had resulted in improved energy saving, better pollution prevention, more waste recycling or reductions in raw material usage.[5] Overall 67.5% of respondents indicated that they had undertaken product innovation with one or more of these characteristics: 36% had undertaken energy-saving innovation, 38% had undertaken innovation related to pollution prevention, 54% had undertaken innovation related to waste recycling and 39% had innovated in terms of raw material usage.

To measure both PEU and perceived innovation risk (PIR) we adopt a multi-factor approach reflecting the multi-dimensional nature of the construct. For PEU we separately identify macro, micro and internal elements of perceived uncertainty. For macro-PEU (Cronbach alpha = 0.705) we follow Miles and Snow (1978) and Bourgeois (1985), and consider policy and regulation (tax policy, regulation) economic factors (exchange rates, interest rates, prices), socio-cultural factors (attitudes, demographic change) and technological factors (the emergence of new technologies and new materials). In each case firms were asked to indicate the importance of each factor on a Likert scale taking value 1 if a factor was unimportant and 5 where a factor was very important. Energy and fuel prices (mean score, 4.63) emerged as the most important factor in the macro-economic dimension of PEU with demographic changes (mean score, 2.76) the least important (data annex). For micro-PEU (Cronbach alpha = 0.862) we follow Miller (1992) and Freel (2005) including measures of competition, customers' tastes and preferences, suppliers, competitors and complementary products or services. Again, firms were asked to indicate the importance of each factor on a 5-point Likert scale. Changes in demand emerge as the most important dimension of micro-PEU (mean score, 4.27), with the availability of substitute products least important (mean score, 2.78). Our scale of PEU is similar to that used by Brouthers et al. (2000) with the inclusion of internal PEU, taking into consideration previous studies (Freel, 2005; Garg et al., 2003; Priem et al., 2002) which have emphasised its importance. For internal-PEU (Cronbach alpha = 0.827) we follow Freel (2005) measuring access to skills, the availability of appropriate information/advice and firms' access to finance. Of the seven factors included here, the most important was the availability of appropriate information/advice (mean score, 3.83) with access to equity finance (mean score, 2.45) least important. Notably mean scores for the internal-PEU were lower than those for both the macro-PEU and micro-PEU (data annex).

Measures of perceived innovation risk are less well developed in the literature than those for PEU and therefore represent a more experimental element of our analysis. We focus on the three dimensions of perceived innovation risk (PIR) identified earlier: technical, market and rivalry risks. In terms of technical-PIR (Cronbach alpha = 0.864) we include development time, technical goals, product complexity and firms' prior knowledge of the green technologies they are using (Keizer and Halman, 2007). Again, firms were asked to indicate the importance of each factor on a 5-point Likert scale with concern about the costs of innovation projects the dominant issue (mean score, 3.64). In terms of market-PIR (Cronbach alpha = 0.906) we emphasise the demand-side factors identified by Astebro and Michela (2005) relating to the uncertainty of market outcomes and the demand for green products/services. Concern about low profit margins on green products or services was the dominant market risk (mean score, 3.03) with the instability of demand seen as less important (mean score, 2.73). The final PIR factor relates to rivalry (Cronbach alpha = 0.881) reflecting issues around intellectual property protection (Lane, 2009), competition and disruptive innovation (Markides and Oyon, 2010). Here, the dominant concern is the intensity of price competition (mean score, 2.77) with the risks posed by disruptive innovation seen as least important (mean score, 2.13).

[5] In our analysis we focus specifically on product innovations although these are strongly correlated to green process changes (correlation coefficient = 0.388).

Table 1
Descriptive statistics.
Source: Green Innovation Survey (see data annex).

	No of obs.	Mean	Std dev.
Green innovation (% of firms)	154	0.675	0.470
Log(employment)	148	3.306	1.153
Average age (years)	149	38.732	48.185
Exporting firms (% firms)	154	0.396	0.491
PEU – macro	154	3.584	0.589
PEU – micro	154	3.560	0.767
PEU – internal	153	3.332	0.876
PIR – technical	153	2.835	0.977
PIR – market	153	2.854	1.167
PIR – rivalry	153	2.399	1.109

To test our hypotheses we include these six factors in a knowledge or innovation production function of the probability of undertaking green innovation (Griliches, 1995; Love and Roper, 1999). If GI_i indicates the probability of undertaking green innovation:

$$GI_i = \alpha + \beta_1 PIRTEC_i + \beta_2 PIRMKT_i + \beta_3 PIRRIV_i + \beta_4 PEUMAC_i + \beta_5 PEUMIC_i + \beta_6 PEUINT_i + \beta_7 FC_i + \varepsilon_i$$

where $PIRTEC_i$, $PIRMKT_i$, and $PIRRIV_i$ are the three elements of perceived innovation risk, $PEUMAC_i$, $PEUMIC_i$ and $PEUINT_i$ are the three elements of perceived environmental uncertainty and FC_i is a vector of firm-specific control variables. Our hypotheses then suggest we would expect $\beta_1, \beta_2, \beta_3 < 0$ and $\beta_4, \beta_5, \beta_6 > 0$. In the set of controls we include variables which have previously been shown to influence firms' innovation activity. For example, previous research (Koetse et al., 2006) has suggested that firm size – here measured by employment - may influence the impact of PEU on decision making, and is also regularly included as a control factor in innovation studies (Hewitt-Dundas and Roper, 2009). Firm vintage is also included to reflect the potential for cumulative accumulation of knowledge capital by older business units (Klette and Johansen, 1998) or life-cycle effects (Atkeson and Kehoe, 2005). Finally, we include an indicator of whether or not a firm is exporting to reflect potential demand-side effects (Woerter and Roper, 2010). See Table 1 for the descriptive statistics of the results.

The dependent variable in our analysis is a binary variable indicating whether or not firms undertook green innovation suggesting a probit estimator. One other issue arises in the econometric estimation. Correlations between the PIR factors are relatively high (Table 2) and so to minimise potential problems with multi-collinearity we include each factor separately in the innovation production functions at least initially. A final model includes the full set of PEU and PIR factors.

4. Empirical results

Estimates of the innovation production function are reported in Table 3. Model 1 includes only control variables and is poorly defined.

Table 3
Probit models of the probability of undertaking green innovation: PEU and PIR effects.
Source: Green Innovation Survey (see data annex).

	Model 1	Model 2	Model 3	Model 4	Model 5
	b/se	b/se	b/se	b/se	b/se
Log(employment)	−0.014	−0.043	−0.047	−0.056	−0.048
	(0.037)	(0.039)	(0.040)	(0.040)	(0.041)
Average age (years)	−0.001	−0.001	0	0	0
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Exporting firms	0.033	0.084	0.089	0.106	0.092
	(0.085)	(0.085)	(0.085)	(0.085)	(0.087)
PEU – macro		0.148*	0.160*	0.182**	0.164*
		(0.089)	(0.089)	(0.088)	(0.092)
PEU – micro		−0.067	−0.084	−0.098	−0.087
		(0.067)	(0.068)	(0.067)	(0.070)
PEU – internal		0.088	0.078	0.087	0.078
		(0.054)	(0.054)	(0.054)	(0.055)
PIR – technical		0.083*			−0.009
		(0.044)			(0.064)
PIR – market			0.106***		0.103*
			(0.038)		(0.062)
PIR – rivalry				0.093**	0.013
				(0.042)	(0.066)
N	144	143	143	143	143
Equation chi-2	1.169	18.244	22.847	19.684	22.894
p	0.76	0.011	0.002	0.006	0.006
Pseudo R^2	0.006	0.101	0.126	0.109	0.126
BIC	200.608	202.564	197.96	201.123	207.839
% correct	67.4	71.33	74.83	70.63	74.13
Joint significance PEU		6.52	6.61	8.77	6.31
		(0.089)	(0.085)	(0.032)	(0.098)
Joint significance PIR		3.55	7.98	4.92	8.03
		(0.06)	(0.004)	(0.027)	(0.045)

Coefficients reported are marginal values. Dependent variables are binary indicators taking value 1 if firms engaged in green innovation. Standard errors in parentheses.
* Significance at the 10% level.
** Significance at 5% level.
*** Significance at the 1% level.

Models 2 to 5 which include the elements of PIR and PEU are more strongly defined although the explanatory power of the models remains relatively low. Taken together the three elements of PEU are jointly significant in each of the Models (2 to 5) in which they are included. Only macro-PEU is individually significant, however, taking the expected positive sign. This provides some support for Hypothesis 2, i.e. the probability that firms will undertake green innovation increases as macro-PEU increases. Neither micro-PEU or internal-PEU have any significant effect on firms' probability of undertaking green innovation. Including the innovation risk variables in Models 2 to 5 suggests a rather different picture with only market-PIR being consistently significant. Contrary to the expectation of Hypothesis 2, however, this has a positive sign suggesting that the probability of green innovation increases when market-PIR is greater. Neither technical-PIR or rivalry-PIR have any consistently significant effect on green innovation.

Table 2
Variable correlations.
Source: Green Innovation Survey (see data annex).

|	1	2	3	4	5	6	7	8	9	10
1 Green innovation (% of firms)	1.000									
2 Log(employment)	−0.035	1.000								
3 Average age (years)	−0.080	0.218	1.000							
4 Exporting firms (% firms)	0.023	0.314	0.068	1.000						
5 PEU – macro	0.226	0.170	0.001	−0.052	1.000					
6 PEU – Micro	0.078	−0.015	−0.026	−0.124	0.463	1.000				
7 PEU – internal	0.243	0.047	−0.068	−0.132	0.421	0.388	1.000			
8 PIR – technical	0.262	0.018	−0.012	−0.097	0.366	0.250	0.382	1.000		
9 PIR – market	0.316	0.016	−0.087	−0.115	0.273	0.264	0.334	0.710	1.000	
10 PIR – rivalry	0.234	0.058	−0.073	−0.183	0.249	0.391	0.352	0.677	0.754	1.000

5. Discussion

Our empirical results have strategic and behavioural implications. First, in strategic terms, we find that firms seem willing to engage in risky innovation activity even where they face considerable environmental uncertainty. More specifically, our research shows that firms' probability of undertaking green innovating is positively related to both environmental uncertainty and the market-related risks of innovation.

The positive link between perceived environmental uncertainty and firms' innovation is not unexpected given prior evidence (DeTienne and Koberg, 2002; Calantone et al., 1997; Damanpour and Schneider, 2006;), and evidence that innovation during recessions can yield significant commercial advantages (Todd, 2010). More interesting is the result that firms are willing to engage in green innovation even where this is perceived to involve significant, market-based innovation risks. More specifically, in our analysis, this reflects risks associated with unpredictable demand, uncertain sales growth and profit margins. There are three possible explanations. First, it is possible that firms are willing to undertake green innovation despite the associated risks due to the potential environmental benefits. Mzoughi (2011), for example, demonstrates that environmental concerns are a significant determinant of the strategic choices of French fruit and vegetable producers. A second, and perhaps more plausible possibility, is that firms may be willing to embrace (market-based) innovation risks in the hope of creating disruptive innovation and gaining market advantage (Yu and Hang, 2010). Tushman and Anderson (1986) using data from the cement, airlines and computer industry demonstrate, for example, that firms which engage in disruptive innovation grow more rapidly than other firms in their sectors. Finally, it is possible that firms may make a strategic decision to synchronise their innovation activity with periods of market turbulence in an attempt to achieve a first mover advantage while other competitors are retrenching. In this context it is important to reflect that the fieldwork for our study was undertaken in Summer 2008 at the start of the great recession.

In more behavioural terms our results suggest that the primary determinants of innovation risk are external and market-related rather than internal resource or skill constraints. This strong market focus may reflect recent trends in the food sector which, in general, is seen as becoming more strongly market-driven and innovative in response to consumer needs (Fryer and Versteeg, 2008; Trippl, 2011). This result also provides a link to two emerging literatures related to the antecedents of business strategy. First, as here, Liao and Gartner (2006), find that financial and commercial uncertainty have a more significant impact on the business planning activities of a group of US entrepreneurs than more internal or operational issues. Secondly, the evidence from recent panel data studies emphasises a positive relationship between the adoption of a pro-active environmental strategy, improved financial performance and firms' internal resources (Clarkson et al., 2011). The dynamics of this relationship are not directly observable in our cross-sectional data. If, however, firms' engagement with green innovation is persistent, the returns from previous periods' innovation may have enhanced firms' resource base, enabling strategy to be market-led rather than resource-constrained.

This suggests one clear limitation of our analysis – the cross-sectional nature of our data – and the potential for future studies based on panel or longitudinal data to explore the performance benefits or disbenefits of green innovation as an indicator of perceived innovation risk behaviour. In particular it would be interesting to explore further whether the types of feedback from green innovation to performance identified by Clarkson et al. (2011) occur in a broader range of industrial sectors. Our focus here is also on a single innovation measure – whether firms did or did not introduce green innovations. We recognise, however, that this single variable does not capture the diversity of different types of innovation and future studies could usefully examine whether the influence of PEU and PIR work similarly for green innovation with different levels of novelty and based on different underlying technologies. One other element of our analysis which is rather experimental is the three indicators of perceived innovation risk. Our data suggests the validity of these for the food sector but it would also be interesting to explore the application of these to other sectors where the balance of technological and market risks associated with innovation differs. In sectors which are more heavily R&D-based than food, for example, the balance of technological and market risks associated with innovation might be different to that observed here with potential consequences for the determinants of green innovation.

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Appendix A. Data annex

Perceived Environmental Uncertainty – macro-economic dimension.
Thinking first about the situation in the UK generally. How important is each of the following factors for your business:

	No. of obs.	Mean	Std. dev	
Tax policy '(e.g. concerning business taxes, income tax etc.)	152	4.09	0.98	
Regulation '(e.g. health and safety or employment legislation)	153	4.48	0.79	
The effectiveness of public service provision	147	2.94	1.21	
Exchange rates	153	3.44	1.55	Avg. covariance = 0.238
Interest rates	150	3.78	1.23	Cronbach Alpha = 0.705
Energy and fuel prices	153	4.63	0.78	
The general price level	153	4.06	0.95	
Changes in social or environmental concerns '(e.g. attitudes to crime or global warming)	153	3.16	1.17	
Changes in the population '(e.g. increasing older population)	152	2.76	1.29	
The emergence of new technologies	153	3.09	1.22	
The emergence of new materials	152	2.87	1.31	

Perceived Environmental Uncertainty – micro-dimension
Now focussing more specifically on the markets and industries within which you operate can you please tell me how important the following have been for your business:

	No. of obs.	Mean	Std. Dev	
Shifts in competitors' supply levels	151	3.60	1.16	
Changes in the resources used by competitors	150	3.13	1.15	
The availability of other products which enhance yours	153	3.16	1.30	
Changes in competitors' prices	154	4.04	1.03	Avg. covariance = 0.498
Changes in the markets served by competitors	151	3.75	1.03	Cronbach Alpha = 0.862
Changes in competitors' strategies	152	3.59	1.03	
The entry of new firms into the market	154	3.29	1.26	
The availability of substitute products	151	2.78	1.32	
Changes in customer preferences/tastes	154	4.00	1.06	
Changes in demand for your products/services	154	4.27	0.96	

(continued on next page)

(*continued*)

Perceived Environmental Uncertainty – macro-economic dimension.
Thinking first about the situation in the UK generally. How important is each of the following factors for your business:

Perceived environmental uncertainty – internal dimension
Now we would like to ask you about factors, which are internal to your business and how important these factors are in shaping your business activity?

	No. of obs.	Mean	Std. Dev	
Your access to technological skills	151	3.28	1.18	
Your access to marketing skills	151	3.38	1.20	
Your access to financial skills	151	3.61	1.11	Avg. covariance = 0.635
The availability of appropriate Information/Advice	153	3.83	0.99	Cronbach Alpha = 0.827
Access to debt finance '(e.g. bank loans or overdraft)	141	3.37	1.31	
Access to equity finance '(e.g. venture capital or angel investments)	139	2.45	1.37	
Access to government grant support	144	3.16	1.55	

Innovation risk – technical dimension
Now we would like to ask you about some things, which might have influenced your decision whether or not to undertake any 'green innovation' over the last three years.

	No. of obs.	Mean	Std. Dev	
Concern about the length of time it would take to develop green products/processes/services	153	2.68	1.30	
Concern about the costs of the project	152	3.64	1.36	
Concern about the effectiveness of your project team	148	2.91	1.37	Avg. covariance = 0.828
Concern that you might not achieve your technical goals for green products etc.	152	2.80	1.34	Cronbach Alpha = 0.864
Uncertainty about the uniqueness of your product/service ideas	149	2.48	1.29	
Your previous knowledge of the technology for green products etc.	152	2.60	1.21	
Concern about the technical complexity of developing green products/services	151	2.74	1.35	

Innovation risk – market dimension
Still thinking about factors, which might have influenced your decision whether or not to undertake 'green innovation' over the last three years.

	No. of obs.	Mean	Std. Dev	
Unstable or unpredictable demand for new green products or services	150	2.73	1.32	
Uncertainty about the value of green products/services to consumers	150	2.89	1.32	Avg. covariance = 1.24
Concern about not achieving short-term sales goals with any green products you developed	152	2.82	1.39	Cronbach Alpha = 0.906
Concern about not achieving medium-term sales goals with any green products you developed	151	2.76	1.38	
Concern that margins might be lower than anticipated on green products/services	153	3.03	1.44	

Innovation risk – rivalry
Still thinking about factors, which might have influenced your decision whether or not to undertake 'green innovation' over the last three years.

	No. of obs.	Mean	Std. Dev	
Difficulties in protecting or defending green products/services from copying	151	2.34	1.31	
Possibility of other competing green products/services being introduced	151	2.30	1.24	Avg. covariance = 1.09
Possibility of other 'breakthrough' green products destroying the market	150	2.13	1.19	Cronbach Alpha = 0.881
Possibility of intense price competition	151	2.77	1.42	

(*continued*)

Perceived Environmental Uncertainty – macro-economic dimension.
Thinking first about the situation in the UK generally. How important is each of the following factors for your business:

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