THE UNIVERSITY OF MELBOURNE

FACULTY OF BUSINESS & ECONOMICS

Melbourne Institute Working Paper Series

Working Paper No. 19/11

External Ventures: Why Firms Don't Develop All Their Inventions In-house

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Melbourne Institute Working Paper No. 19/11

ISSN 1328-4991 (Print)

ISSN 1447-5863 (Online)

ISBN 978-0-7340-4251-4

July 2011

* The term 'external ventures' is taken from Cassiman and Ueda (2006). The authors are grateful to Bruno Cassiman, Reinhilde Veugelers, Michele Cincera, Kartin Hussinger, Paul Jensen, Owen Malone, Jefferson Harcourt, Deborah Cobb-Clark and participants from the Melbourne Institute, Competition and Innovation Summer School (Turkey 2010) and IPRIA seminars, Kay Collins and Sean Applegate for advice and assistance with the IP Australia patent database; and Chris Bird, Anne Leah and Annabelle O'Bryan for assisting with the survey. Funding for this research comes from an Australian Research Council (ARC) Linkage Grant with IP Australia (LP0989343). All errors remain our responsibility.

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Abstract

In this paper we consider why firms sometimes choose an external development path for their own inventions, despite the costs of contracting and the risks of opportunistic behaviour and expropriation. We model the probability that firms adopt an external development strategy using survey data from over 2700 Australian inventions. Our results indicate that firms pursue external development strategies in response to perceived project-level risk about the technical feasibility of the invention, especially when suported by confidence in the patent system. Our findings also confirm that small to medium size enterprises, highly leveraged large firms and firms with few co-specialized assets are more likely to pursue an external development strategy.

JEL classification: O32, O33

Keywords: Outsourcing R&D, managing technological risk, licensing innovation

1. Introduction

The transformation of an invention from the initial idea into a new commercial product can take place either wholly within one firm, or through a series of different firms, each contributing a different stage in the development pathway. In this paper, we aim to quantify factors determining this choice, focusing on the juncture between the identification of an invention and its subsequent development. From a theory-of-the-firm perspective, deciding to develop externally is puzzling given the advantages of scale, notably abnormal profits Griffiths *et al.* (2010), and the disadvantages of using external parties, notably contracting and transaction costs (Coase 1937), pernicious opportunistic behaviour (Williamson 1979) and expropriation of intellectual property (Arrow 1962).

Our focus is on the role of project-specific risk and uncertainty, conditioned on the degree of IP protection. Our conjecture is that incorporating external parties into the development pathway is partly a response to owners' uncertainty over the feasibility of the technology. As argued by Arrow and Lind (1970), risk-averse firms try to minimise the cost of uncertain risk (in contrast to actuarial risk) by spreading responsibility for the activity across multiple entities.[1] In this paper, we use survey measures of technological risk to assess their effect on the decision to develop externally. In so doing, we also control for two additional well-known determinants of "going external" – lack of liquidity and lack of complementary capabilities.

To date, no studies have directly considered the role of project risk. Furthermore, those studies of the external development decision that exist have focussed either on a single industry (Kollmer and Dowling 2004);[2] university inventions (Shane 2001);[3] or start-ups receiving government support (Gans *et al* 2002).[4] The adjacent literature on licensing typically does not distinguish between licenses for mature versus developing technologies (e.g., Anand and Khanna 2000; Arora and Ceccagnoli 2006; Gambardella *et al.,* 2007).

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[1] We presume that the risks associated with inventions will be weighted towards uncertain rather than actuarial risk since inventions are by definition something that is in essence something new.

[2] Kollmer and Dowling (2004) investigate a sample of 70 biotechnology firms.

[3] Shane (2001) considers the mode of exploitation of 1,397 patents assigned to the Massachusetts Institute of Technology. However, since his analysis considers only patents assigned to a university (which is not generally in the business of commercializing inventions in house) the results are conditional on licensing being the mode of commercialization.

[4] Gans et al (2002) considers 118 small firms which either received VC funding or funding under a specific government programme.

However, the evidence is that most licensing activity involves mature technology (Kollmer & Dowling 2004; Anand and Khanna 2000). While existing studies have confirmed the influence of complementary assets, intellectual property protection and other market characteristics on the decision to 'go external', the role of project-level uncertainty remains unexamined. We extend the nascent existing literature by addressing this gap.

Our estimations use invention-level data on 2600 Australian private-sector inventions. The core of the dataset is the population of patent applications filed at the Australian patent office between 1986 and 2005. The dataset used for the estimations was created by linking data from an inventor survey; company accounts; and technology-specific information from the US. We find support for the hypothesis that firms pursue an external development strategy in response to perceived technological risk. In addition, our results confirm that other more general sources of business risk, which cause liquidity-constraints and provide a premium for firms with complementary assets, are also influential. This is consistent with the well-known risks associated with highly leveraged positions and the separate and distinct risks associated with expanding capabilities.

The paper is organised as follows. Section two discusses the relevant theory of the firm which identifies our principal hypothesis. Section 3 outlines our data and the empirical approach undertaken in this study. Our results are outlined in section 4 and section 5 concludes.

2. Background

Why does a firm forego an opportunity for internal growth and instead engage and share returns with another firm? Early theories of firm boundaries typically held that internal expansion is preferred over external development.[5] [6] Internal expansion avoids many transaction costs (Coase 1937; Williamson 1979); facilitates the appropriation of project-level spillovers; and by diversifying the firm's portfolio, can offer more options for within-firm risk

[5] Many authors over time have articulated reasons for the superiority of large firms in developing new technologies. For a recent summary of the arguments, see Cohen (1995) and Symeonidis, (1996).

[6] We abstract from the inconsistent accounting treatment of in-house versus bought intangible assets and how this affects CEO incentives to buy rather than make, see He and Wang (2009).

management.[7] Added to this it is well-recognised that firms risk expropriation through copying when they incorporate external partners (Arrow 1963).

While there are some advantages of being small and nimble (via focus, high-powered incentives and flexibility), large firms can opt for these advantages by operating as a holding company over a set of smaller self-governing subsidiaries (See for example, Rosenberg 1994 and Branscomb and Auerswald 2001).[8] Small-firm advantages can therefore be mimicked by the large firm and it seems possible for large firms to access the 'best of both worlds'. Static analysis does not reveal clear reasons for pursuing an external venture.

The reasons for external development instead relate to the costs of expansion, not size per se. A firm's propensity to pursue an external venture depends on the limits to its rate of internal growth, which we argue arise out of a firm's willingness to bear and manage risk. Not only are there certain risks associated with the "normal" expansion of a firm, but these risks are aggravated when the expansion involves an R&D-based venture. Three types of risk exist, of which the first two have been comparatively well-researched. The first type is the financial risk firms take when they expand. Access to debt is limited by realisable collateral (i.e. owners' capital) and the more leveraged the business, the greater the risk of bankruptcy. New capital raisings are also limited if owners want to minimise the risk of losing control (Kalecki 1939; Carreira and Silva 2010). There is a view, and supporting evidence, that funding innovation via debt is particularly difficult because inventive and innovative activities typically produce uncertain and distant collateral which, more often than not, are absent from balance sheets (Schumpeter 1943; Hall 2005; Scellato 2007; Canepa and Stoneman 2008; Carreira and Silva 2010).

The second type of risk is the uncertainty associated with successfully increasing the capabilities and skills of a firm (Penrose 1959; Brozen 1971; Demsetz 1973; Lippman and Rumelt 1982). External development may be preferred if there is a strong need for assured and rapid access to development capabilities or co-specialized assets (Richardson 1972; Teece

[7] A contrary view is offered by Coase (1937) who proposed that "decreasing returns to the entrepreneur function" imposes a limit to the optimal firm size.
[8] Branscomb and Aueswald (2001) discuss attempts by Exxon Enterprises and IBM to develop small technology enterprises within their corporate umbrella. The authors suggest that, while affording innovating business units complete autonomy is desirable in theory, the temptation to intervene, monitor or support proves too strong to resist in practice.

1986; 1992; Cassiman and Ueda 2006).[9] External development strategies may be options when the inventing firm cannot quickly buy or copy the capabilities it lacks (Demsetz 1973; Lippman and Rumelt 1982).

There have been a number of extensions to this basic idea. Teece (1986), for example, maintains that where technological change is rapid, a single firm, even a large firm, will be even less likely to possess the required technological expertise to bring a new technology completely to market. In addition, Chan, Nickerson and Owan (2007) argue that because co-specialized assets involve considerable fixed (and sunk) costs, their economic price depends on the size of the internal pipe-line of inventions within the firm. Hence, a firm with a long pipe-line and fully utilized co-specialized assets will be inclined to seek additional support from external partners.

It is however the last type of risk – project risk – has been least explored in the literature. Each project or activity carries its own individual risk over and above general firm-level risks. With respect to invention, these risks are largely uncertain risks since inventions embody a high degree of novelty. While pooling can be a successful strategy for projects subject to actuarial risk, Arrow and Lind (1970) have argued that the only effective strategy to minimise exposure to uncertain risk is to spread responsibility across multiple entities. As a corollary, we expect that firms will seek to contain their total exposure to uncertain risk by externalising the commercialisation process of the most risky inventions regardless of the status of their internal capabilities and their available funds for expansion.

All the while, the firm still confronts the normal costs associated with using external parties for intangible transactions (contracting and transaction costs, opportunistic behaviour and expropriation). According to Richardson (1972), Arora and Ceccagnoli (2006), Chan, Nickerson and Owan (2007) and Novak and Stern (2008) confidence in the power of the patent system can be an enabling factor that affects whether firms use an external partner.

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9 The importance of complementary assets in determining development and commercialization choices of inventing firms is supported by a growing body of evidence. Kollmer and Dowling (2004) find that among the 70 biotechnology firms they analyse, licensing is a main commercialization strategy for firms which lack requisite complementary assets ('non-integrated firms'). Similarly, Gans et al (2002) find some evidence that difficulty in acquiring complementary assets drives firms to cooperate with incumbents.

To summarise, the discussion above identifies three characteristics of the invention or its owner that will influence the probability that a given invention will be developed externally: the project-specific technological riskiness of the invention ; the owners' collateral and access to liquidity; and the owners' possession of co-specialized commercialisation skills and capabilities. Finally, confidence the owner has in their IP protection is anticipated to moderate the costs and risks associated with external development, thereby making it a more attractive proposition.

3. Survey Data and Descriptive Statistics

The main data source for this study is the Australian Inventor Survey 2007, which involved sending a questionnaire to every Australian inventor who submitted a patent application to the Australian Patent Office between 1986 and 2005. The survey included questions relating to inventor- and technology-specific characteristics such as whether development was attempted (including proof-of-concept, testing and validation and prototype) and whether the invention was developed in-house, by an affiliate or by an external company. In addition, the questionnaire asked respondents to rate on a 1-7 Likert scale their assessment of the uncertainty they feel over the feasibility of the technology and their confidence that the legal system would prevent the invention from being copied.

Every inventor listed on a patent application was sent a survey, with the proviso that inventors with multiple applications were limited to 5 randomly selected questionnaires. The inventor was surveyed rather than the assignee since we believed the inventor should have a more intimate and long-standing knowledge of the lifecycle of the invention than the owner(s) or their employees. Mattes, Stacey and Marinova (2006) found a high correlation (0.90) between inventor and owner responses in their survey of patent outcomes.

Firm, or applicant (assignee), information was obtained by matching the applicant by name to the IBISWorld database, a private database which includes approximately 2000 of the largest firms in Australia.[10] Public-sector applications were removed from the dataset. Micro-businesses were identified directly from patent records as non-company applicants. That is, following Gambardella et al (2007 p. 1169), we interpret assignment as to individuals as

[10] The IBISWorld database covers the years 1989 to the present.

being akin to micro-firms, however, we confirm the robustness of our findings to a sample which excludes individual (non-firm) inventors.

In total, there were 43,200 inventor-application pairs in the population which had a complete Australian address and inventor name.[11] These relate to 31,313 unique patent applications (i.e. inventions). On the basis of the number of surveys returned to us unopened (and two post-enumeration surveys of non-respondents), we estimate that there were 5,446 inventions with valid addresses. We received completed questionnaires relating to 3,740 unique inventions, of which 3,271 were companies.[12]

The distribution of responses by technology area was: electricity and electronics (9.3 percent), instruments (11.4 percent), chemicals and pharmaceuticals (7.7 percent), process engineering (12.3 percent), mechanical engineering (29.8 percent) and “other” (29.5 percent). To gauge how technologically representative our sample is, we compare our sample with the population of US Patent and Trademark Office (USPTO) granted patents. This reveals that USPTO patents are more heavily weighted towards electricity and electronics and instruments and less towards mechanical engineering and “other” patents than our sample.

Table 1: Technology Group of US Patent and Trademark Office and Australian Inventor Survey Respondents

Technology group	*Australian Inventor Survey 1986-2005 (%)*	*US Patent and Trade Mark Office 1986-2005 (%)*
I Electricity and electronics	9.3	30.4
II Instruments	11.4	16.9
III Chemicals, pharmaceuticals	7.7	12.5
IV Process engineering	12.3	12.1
V Mechanical engineering	29.8	19.4
VI Other	29.5	8.8
TOTAL	100.0	100.0

Source: Australian Inventor Survey 2007 and NBER USPTO database, 1976-2006 from https://sites.google.com/site/patentdataproject/Home.

In order to consider any potential survey response bias, the survey population was compared with survey respondents according to the following characteristics: year of application; organisation type; whether the patent was granted (at the end of 2007); and technology area. A comparison of the patent application outcomes for survey respondents and non-respondents shows that more recent inventors where more likely to respond. Response rates also varied

[11] 8,413 applications did not have an inventor name and 37 did not have an address.
[12] More information on the population, sample and survey method is provided in the Appendix.

according to whether the inventor was employed by a large company (63.6 percent of those with an estimated valid address), SME (64.6 percent), public sector organisation (70.6 percent), or filed as an individual (73.4 percent). Inventors whose applications were still pending were more likely to respond, followed by inventors whose applications were granted, rejected and withdrawn respectively.[13] The distribution of responses by technology area shows that there is a modest level of variation in the response rate across technology groups: there was a slightly lower response rate from the electricity and electronics area and "Other". Summary statistics on survey respondents (and non-respondents) are presented in the Appendix.

4. Empirical Model and Estimation

4.1 Dependent Variable

Our dependent variable (denoted DevExternal) is a survey question which asks inventors: "Once this invention was conceived, was it developed in-house (= 0) or by an affiliated organisation, an external organization under license, an external organisation under contract or other (= 1)?"[14] In the regression sample, 21.0 percent of inventions were developed externally (but this falls to 12.4 percent if we exclude those developed by an affiliated organisation).

As mentioned, we expect that the decision to develop externally is contingent on the size of the firm's financial capital and its leverage position; its possession of co-specialized skills and capabilities; and the confidence it has that the patent will prevent copying. The conjecture of our paper is that, in addition to these established reasons, the invention's technological risk profile is relevant. The construction of these explanatory variables are outlined below.

[13] However, this is partly due to the fact that recent applications have not yet been examined. For applications lodged between 1989 and 2000, the response rate is 12.6 percent for non-grants and 18.6 percent for granted applications.
[14] We could alternatively define the dependent variable to exclude "developed by an affiliate organisation" but since the results with this alternate dependent variable did not materially differ from the DevExternal model and we limit ourselves to presenting results for the latter only.

4.2 Explanatory Variables

Project risks. One of our key contributions is to consider the role of project specific risk. The survey asked inventors to assess the technological risk of the invention. The question was asked twice: once the development stage and again at the "make and sell" stage of innovation. Assessments were recorded on a 1 (= "not a problem") to 7 (= "severe problem") Likert scale. The variable used in the regressions, denoted as Technology Risk, are the means of responses at both stage for each invention.

Financial capital and leverage. Large, unleveraged firms are least likely to be capital constrained, both in terms of external sources of capital and having more internal revenues available for funding development. We model these financial variables as a series of four binary variables, indicating a typology of firms. The first is SME =1 (=0 otherwise) if the firm has less than 200 employees and AUD$50 million total revenue. The second (denoted as Large-owner funds low) indicates if it is a large firm in the bottom third of IBISWorld owners' funds for their 2-digit industry. The third (denoted by Large-high leverage) =1 (=0 otherwise) if it is a large firm in the top third of IBISWorld ratio of non-current liabilities to total assets for their 2-digit industry. Note that the second and third class are not mutually exclusive. The final group of firms, which is omitted from the regression model (and forms the base case) are large firms who are neither highly leveraged nor have low owner's funds.[15]

Co-specialized skills & technologies. We have limited information on the organisational capabilities and co-specialized assets of the firms in our sample. However, we conjecture that both the firm's patenting experience and the speed of change in the relevant technological field are correlated with their capacities for internal development. Specifically, we conjecture that (a) more experienced firms are more likely to have the resources to develop their inventions in-house; and (b) where technological change is rapid firms are more likely to outsource to supplement their own resources (essentially following Teece 1986). Two measures were included in the model. The first variable is the total number of domestic patent applications made by the firm (either parent or subsidiary) in the invention's IPC subclass, prior to the patent application filing date.[16] Alternate specifications of the experience variable

[15] In this dataset, 4.2 percent of large firms did not have financial data and these were included in the base case of large unconstrained firms. The sensitivity of results to this allocation was assessed.
[16] To calculate this, we used the complete IP Australia administrative patent database from 1986.

according to whether past applications were aggregated at the OST or all technology levels. To capture 'experience' the log of the count of patents is used, which reduces the sensitivity to extremely large values. To capture the influence of the speed of technological change, we include a variable, denoted Technology cycle time, which is the median age of US patents cited in the same technology class over the period 1980-2001 (compiled by Chi research, see Narin 1995; Kayal and Waters 1999). An advantage of this measure is that it is exogenous from the Australian R&D environment.[17] Note that a higher cycle-time variable implies a slower rate of technological change so we expect this variable to be negatively related to the propensity for external development.

IP confidence. Clear and (relatively) certain patent protection should moderate some concerns firms have about the contracting, opportunistic and expropriation costs caused by dealing with external partners. As above, respondents rated the confidence they had in the patent's ability to prevent copying on a 1 (= "severe problem") to 7 (= "not a problem") Likert scale. These questions were asked twice: once at the development stage and again at the 'make and sell' stage of innovation. The model includes a measure (denoted as IP confidence) which is the mean of inventors' responses pertaining to both stages.

Table 2 presents a summary of the variables used in the regression according to whether the inventions were developed in-house or externally. It shows that overall, 6.4 percent of firms in the estimating sample were Large-owner funds low and 4.1 percent were Large-high leverage (note these categories are not mutually exclusive). 40.0 percent were SMEs and 44.1 were micro-businesses. The average number of cumulative past patents in the same IPC subclass for each firm was 8.8 and the mean age of backward citations in the related OST class was 9.5. Both average felt technology risk (at 2.57) and average IP confidence (at 4.92) were closer to "not a problem" than "severe problem".

[17] Additionally, the data to construct this variable is not available from the Australian patent database.

Table 2 Summary of Descriptive Statistics for Variables Used in Regression Analysis (excludes micro-businesses)

	Mean value for developed In-house, N= 2,192	*Mean values for developed external, N= 435*	*Mean values for full sample, N= 2,627*
Financial capital and leverage			
Large-owner funds low (%)	6.4	6.2	6.4
Large-high leverage (%)	4.1	4.6	4.1
Large-unclassified (%)	2.4	2.3	2.4
SME (%)	39.1	45.1	40.0
Micro-business (%)	44.5	42.1	44.1
Co-specialized skills & technologies			
Experience subclass (no.)	9.0	7.8	8.8
Technology cycletime (years)	9.6	9.4	9.5
Project risks			
Technology risk (Likert scale 1…7)	2.51	2.87	2.57
IP position			
IP confidence (Likert scale 1…7)	4.93	4.89	4.92

Appendix contains details of exact question asked and summary statistics of the responses used in the regressions.

In summary, the model we estimate using DevExternal as the dependent variable is represented as:

$$DevExternal_i = const + \beta X_j + \gamma Y_k + \theta W_{jk} + \tau Z_i + \varepsilon_i$$

Where *X*= Large-owner-funds-low, Large-high-leverage, SME, Micro-business; *Y*=Technology cycletime; *W*= Experience-subclass; *Z*=, Technology risk and IP Confidence, for each invention *i* in firm *j* and technology *k*. The coefficients are β, γ, θ and τ, and ε is the error term.

4.3 Estimation and results

The main estimation issue we have is that respondent's responses regarding degree of felt project risk – Technology Risk– are likely to be moderated if development is pursued by an external firm that has a strong history of successful product development. Risk therefore is likely to be endogenous due to simultaneity.

Fortunately, we have a promising candidate for an instrumental variable: the inventor's assessment of importance of 'science' as a source of knowledge. The rationale is that inventors who draw more heavily on new basic science, such as academic literature and university research, are more likely to be developing technologies that are subject to greater technological risk. The data come from the Inventor Survey which asked inventors to report the importance of eight different possible sources of knowledge to their most recent invention. In practice, our instrument consists of the unweighted average of the nominated importance of four 'basic science' sources including universities and scientific literature.[18] While we believe our choice of instrument is based on sound a priori reasoning, we also undertake a range of statistical tests to confirm the validity of our instrument.

OLS estimates of our model are presented in column (1) of Table 3. The IV linear probability model is presented in column 2 and the IV probit is presented in column 3. Not only are the linear IV results consistent estimates of local average "treatment" effect (of felt risk) (Angrist and Kreuger 2001) but the coefficients are straightforward to interpret and linear IV allows for a range of statistical diagnostics not available in IV probit (such as regarding weak instruments). These diagnostics, discussed below, support the validity of the instrument.

To begin with we note that the OLS results presented in column 1 indicate a significant correlation between project-specific technical risk and external development (the estimated coefficient is 0.0212). However, as discussed, we are concerned that the act of external development might allay inventors concerns regarding technical risk and thereby mask the true magnitude of the hypothesised relationship. This suspicion is confirmed by a Durbin-Wu-Hausman test (over 24), which strongly rejects the null that perceived technological risk is exogenous. IV estimates, which account for the masking effect, are presented in column (2). Further confirming our hypothesis, the IV estimates of the relationship between project risk and the decision to develop externally is an order of magnitude greater than those estimated using OLS (c.f., 0.0212 from column 1 and 0.221 from column 2).

The validity of our instrument is investigated using a range of approaches, suggested by Angrist and Pischeke (2009). First, since IV estimates are consistent but not unbiased, it is important to consider the potential magnitude of this bias, which depends primarily on the strength (and number) of chosen instrument(s). The first-stage F-test (=34.50), presented in

[18] The eight categories include: (1) Universities, (2) Other public sector research bodies, (3) Technical conferences and workshops, (4) Scientific literature, (5) Patent literature, (6) Customers or product users, (7) Suppliers and; (8) Competitors. Factor analysis confirmed that these fall naturally into two groups (1-4) which we associate with science and 'push factors' and (5-8) which are associated with market factors or demand.

the penultimate row of Table 3, indicates that the instrument Science, is closely correlated with the endogenous variable. The first stage regression results are presented in Table A6 in the appendix. The significance of our instrument was also confirmed in a reduced-form regression of DevExternal on the instrument in place of the endogenous variable (presented in Table A7, column 1 in the appendix). Finally, we note that the bias in the estimated coefficient of two-stage least squares is approximately zero where the equation is just identified, that is, in our case when we have only one instrument (Angrist and Kreuger 2001).

Table 3 Regression estimates: Dependent variable = DevExternal

VARIABLES	(1) *OLS*	(2) *Linear IV*	(3) *IV Probit*	(4) *Marginal effects from (3)* *(0/1 – discrete variables; μ-σ/μ-σ – continuous variables)*
Financial capital and liquidity				
Large- owner funds low	0.0443	0.00402	0.0690	0.018
	(0.0413)	(0.0545)	(0.155)	
Large-high leverage	0.101**	0.121**	0.365**	0.098
	(0.0451)	(0.0573)	(0.166)	
SME	0.0659*	0.140***	0.404***	0.102
	(0.0384)	(0.0482)	(0.142)	
Micro-business	0.0357	0.159***	0.447***	0.112
	(0.0418)	(0.0583)	(0.151)	
Co-specialized skills & technologies				
Ln(Experiencesubclass)	-0.0192**	-0.0331***	-0.0856***	-0.051
	(0.00897)	(0.0121)	(0.0313)	
Ln(Technology cycle time)	-0.101***	-0.109**	-0.264**	-0.025
	(0.0371)	(0.0509)	(0.129)	
Project risks				
Technology risk (instrumented)	0.0212***	0.221***	0.532***	0.525
	(0.00445)	(0.0508)	(0.0423)	
IP position				
IP confidence	0.00336	0.0408***	0.0979***	0.096
	(0.00376)	(0.0110)	(0.0150)	
Constant	0.286***	-0.468**	-2.213***	
	(0.0973)	(0.226)	(0.350)	
F test (tech_rsk)		34.50		
Observations	2,702	2,627	2,627	

The second requisite attribute of a valid instrument is that it is uncorrelated with our dependent variable (except through the variable it is instrumenting). While we believe the *a* *priori* case that Science is exogenous is well founded, we would like additional statistical reassurance. To test over-identification, we employed two additional instruments. The first is the average risk for each OST technology class;[19] and second is a dummy variable which indicates whether the invention was radical (versus incremental) relative to the state-of-the-art. Both variables were obtained from the Inventor Survey. We argue that these instruments should be uncorrelated with external development except via their correlation with project specific risk. While Average risk and Radical are not our preferred instruments, they allow us to use the over-identification test to support to our original choice of instrument. The Hansen-J statistic (over-identification test), which is reported in Table A7, column 2 in the appendix, has a P-value = 0.1823. This means we cannot reject the hypothesis that the instruments are valid (i.e., that our preferred instrument Science is exogenous).

Column 3 presents IV Probit estimates of the same model, employing Science as the sole instrument of Technical risk. The probit estimator avoids the out of range predictions and is more efficient if the distributional assumptions are correct. The IV Probit estimates are consistent with the linear IV.

Our key hypothesis is that project level uncertainty about the feasibility of the technology is an important influence in determining a firm's decision to pursue external development. In addition to the careful assessment regarding the validity of our identification strategy we undertook a range of other robustness testing. While our preferred results include patents assigned to micro-firms, we test the robustness of these results to a sample excluding patents assigned to individuals and find little difference in the estimates (presented in Table A7, column 3 in the appendix). In fact, the relationship is also robust to firm-level fixed effects,[20] that is, a statistically significant relationship between project risk and external development can be observed within a firm's portfolio of projects.

Our estimates also provide evidence on other determinants of a firm's decision to pursue an external development pathway. We find that Large-high leverage and SME variables are significant and positive, indicating that more leveraged firms (relative to their industry

[19] Using a grouped within sample variable is a method used by Daniela Del Boca in labor economics.
[20] In this case IV was not an option because our instrument ('science') is collected at the inventor level, which corresponds to a considerable degree to the firm level, and is therefore unable to identify variation from the firm mean.

average) were significantly more likely to develop externally. This result was robust across all specifications. While the role of liquidity constraints in the external development decision has been subject to some empirical scrutiny, this evidence is novel in that it is based on a large systematic sample. Recall that the excluded category is large firms which are neither highly leveraged or in the category of having low shareholder funds.

Both of the variables representing *Co-specialized skills and technologies* and Technology cycle time are significant and correctly signed. Firms with either less accumulated experience in patenting in the same subclass or producing inventions in fast changing technologies were more likely to develop externally. In unreported results, we also included a variable reflecting whether the firm's primary technological focus is in the same area as the given patent. Specifically, the ratio of experience in the given subclass to all experience (cumulative patents). This variable was never significant in any specification.

IP confidence is significant and also exhibits the anticipated sign. That is, the more confident the firm is, the more likely it is to use or seek an external development partner. We expect IP confidence to have an interactive effect with the other explanatory variables, that is, without strong IP protection, firms will typically not pursue external development even in the face of other factors which may encourage it.

As an extension to the above analysis, we consider this interactive affect using two approaches. First, we estimate a model which incorporates the degree of felt risk interacted with confidence over IP position. Results are presented in column 1 of Table 4 and these confirm a statistically significant positive interactive effect indicating that *Technology risk* has a greater impact when confidence in the intellectual property system is high. To allow for the possibility that other parameters may also vary with IP confidence, we divided the sample in half into firms which indicated that they had less confidence in IP protection and those which had more. The division approximately balanced the numbers of observations in each group. This sample splitting approach avoids the high demands of multiple interacted terms (i.e., a nested model). Results on the split sample, which are presented in Table 4 column 2, show that the coefficient for technological risk is higher the greater the degree of confidence in IP. The statistical significance of some other coefficients was sensitive to the number of observations in each group.

The simulated marginal effects presented in Table 3 are based on full-sample IV Probit. These effects can be compared to indicate the economic importance of the independent variables, as distinct from their statistical importance. The binary Financial capital and liquidity variables are evaluated at 0 or 1, while the continuous Co-specialised skills and technologies, Project risks and IP Position variables are evaluated at one standard deviation below and one standard deviation above the mean. Column 4 shows that the variation in the degree of felt technological risk has the largest impact on whether or not the inventing firm decides to develop externally. Being a micro-business, SME or highly leverage large firm all have a comparable effect on the probability of developing externally relative to other large firms.

Table 4: Regression estimates, split sample: Dependent variable = DevExternal IV Probit

	(1)	(2)	(3)
	IV Probit	*IV Probit*	*IV Probit*
VARIABLES	Full sample	Less confident about IP	More confident about IP
Financial capital and liquidity			
Large-owner funds low	-0.000	0.00389	-0.00273
	(0.0582)	(0.0762)	(0.0778)
Large-high leverage	0.113*	0.154*	0.0629
	(0.0603)	(0.0869)	(0.0824)
SME	0.149***	0.0549	0.186***
	(0.0516)	(0.0697)	(0.0652)
Micro-business	0.174***	0.0608	0.188**
	(0.0625)	(0.0773)	(0.0806)
Co-specialized skills & technologies			
Ln(Experiencesubclass)	-0.0329***	-0.0547***	-0.0177
	(0.0124)	(0.0160)	(0.0160)
Ln(Technology cycle time)	-0.106**	-0.143**	-0.0601
	(0.0517)	(0.0693)	(0.0716)
Project risks			
Technology risk*IP Confidence (instrumented)	0.0166***		
	(0.00446)		
Technology risk (instrumented)	0.150***	0.149***	0.272***
	(0.0352)	(0.0499)	(0.0835)
Constant	-0.301	0.0286	-0.465*
	(0.193)	(0.227)	(0.270)
F test (tech_rsk)	72.09	21.42	19.20
Observations	2,627	1,287	1,431
Cases			

5. Conclusion

In this paper, we test whether firms limit their internal growth in order to share uncertain risk with other entities using a dataset of 2700 inventions. In so doing, we revisit one of the classic questions of industrial economics – what determines the boundary of the firm? Our evidence supports the view that using external partners is one way firms spread the risk associated with uncertain technologies. In addition, we found new systematic evidence confirming the widely held belief that external development is often undertaken in response to liquidity constraints. Finally, the important role of the IP system in facilitating external development was confirmed, most notably in that firms are more likely to act on underlying need to pursue external development where they are confident in their IP protection.

Prior studies on the determinants of the vertical disaggregation of the commercialization pathway have focused on firm-level capacities and specialization and expropriation risk. In this paper, we find that, once these factors are controlled for, managing project level risk is a key driver and advantage of external development. Confidence in IP rights enables firms to optimally allocate risk between partners.

Our results also highlight that opportunities lost through liquidity constraints and a shortage of internal capabilities may be diminished by a smooth functioning market for technology. An IP system which provides clarity and certainty is important in facilitating the optimal industrial structure of innovative industries.

Appendix: Australian Inventor Survey

The Australian Inventor Survey was mailed out in two waves between July and December 2007 by researchers at the Melbourne Institute of Applied Economic and Social Research, University of Melbourne. The recipients of the survey constituted the population of Australian inventors who filed a patent application at the Australian Patent office – IP Australia – during the period 1986-2005. The survey recipients were identified by the country of applicant (Australia) and their postal address.

The inventor-invention relationship is a many-to-many relationship. That is, one inventor can have many patent applications, and one patent application can have many inventors. In total, there were 43,200 inventor-application pairs in the population with a complete inventor name and Australian address.[21] Of the 31,313 applications, 76.2 percent had only one inventor and almost all (99.3 percent) had 5 or less inventors. Of the 31,947 inventors, the vast majority (82.5 percent) had only filed one application between 1986 and 2005. To avoid administrative burden, inventors were asked about each invention, up to a maximum of 5 patent applications.

There was no initial screening of survey recipients and 47.0 percent of surveys were returned to us (as "return to sender") unopened, presumably because the address was no longer valid. To estimate the number of non-responses which also had invalid addresses, we selected a random sample of 600 non-respondents (both those from the "return to sender" and "no response" groups) and manually looked the applicant up by name and address in both the telephone book and internet. People with a valid telephone number were then called to confirm that they were the correct person. This search revealed that only 11.7 percent of the sample of non-respondents had a complete address and were still at the listed address (some had moved while others had apparently disappeared). Assuming that this is representative of all non-respondents, we can infer that we had a valid inventor address for 5,446 of our original population of inventions. We received completed questionnaires for 3,740 inventions.

The following four tables show the pattern of survey response by year of application across various characteristics.

[21] 8413 applications did not have an inventor name and 37 did not have an address.

Table A1: Number of Patent Applications with a Complete Survey Response by Year, 1986-2005

Year	***Number of patent applications***			
	Complete	Est. address valid[a] & not complete	Est. address not valid	Total
1986-1990	254	245	3,705	4,204
1991-1995	554	385	5,831	6,770
1996-2000	1,125	541	8,186	9,852
2001-2005	1,807	537	8,143	10,487
Total	3,740	1,708	25,865	31,313

Note: [a] Excludes surveys that were returned as 'return to sender' and the estimated 88.3% of non-responses which we estimated, through a post-enumeration survey, to have had an invalid address.

Table A2: Number of Patent Applications with a Complete Survey Response by Organization Type, 1986-2005

Organization	***Number of patent applications***			
	Complete (response %)	Est. address valid[a] & not complete	Est. address not valid	Total
Large company[b]	588 (63.6%)	337	5,097	6,022
SME[b]	1,175 (64.6%)	643	9,727	11,545
Public sector research	269 (70.6%)	112	1,697	2,078
Individual	1,704 (73.4%)	618	9,346	11,668
Total	3,736 (68.6%)	1,710	25,867	31,313

Notes: [a] Excludes surveys that were returned as 'return to sender' and the estimated 88.3% of non-responses which we estimated, though a post-enumeration survey to have had an invalid address. [b] A company is 'Large' where it, or its highest Australian-located parent company, has a turnover greater than A$50m per annum. Otherwise the company is defined as an SME.

Table A3: Number of Patent Applications with a Complete Survey Response by Patent Application Outcome, 1986-2005

Patent grant status	***Number of patent applications***			
	Complete	Est. address valid[a] & not complete	Est. address not valid	Total
Withdrawn	572	331	5,006	5,909
Pending	731	167	2,535	3,433
Rejected	382	232	3,512	4,126
Granted	2,051	979	14,815	17,845
Total	3,736	1,710	25,867	31,313

Note: [a] Excludes surveys that were returned as 'return to sender' and the estimated 88.3% of non-responses which we estimated, though a post-enumeration survey to have had an invalid address.

Table A4: Number of Patent Applications with a Complete Survey Response by Technology Area, 1986-2005

OST technology area[b]	***Number of patent applications***			
	Complete	Est. address valid[a] & not complete	Est. address not valid	Total
I Electricity and electronics	329	181	2,739	3,249
II Instruments	440	175	2,654	3,269
III Chemicals, pharmaceuticals	410	166	2,516	3,092
IV Process engineering	447	187	2,825	3,459
V Mechanical engineering	1,061	476	7,204	8,741
VI "Other"	1,048	524	7,927	9,499
Total	3,736	1,710	25,867	31,313

Notes: [a] Excludes surveys that were returned as 'return to sender' and the estimated 88.3% of non-responses which we estimated, though a post-enumeration survey to have had an invalid address. [b] OST refers to the Office of Science and Technology classification which is based on the International Patent Classification system

Table A5: Summary of Descriptive Statistics for Variables used in Regression Analysis

Variable	*Concept*	*Measure/survey question*	*Source*	*Mean*	*SD*
DevExternal	Invention developed by an external partner	Once the invention had been conceived, was it developed…In-house, By affiliated organisation, By external organisation under license, By external organisation under, contract, Other/Not applicable.	AIS-2007	0.170	0.376
Large-owner funds low	Large firm with few mortgagable assets.	Large firm (>$50m turnover pa). Owner funds in bottom third of 2-digit industry mean. Deflated by CPI.	IBISWorld	0.114	0.318
Large-high leveraged	Large firm highly leveraged	Large firm (>$50m turnover pa). Owner funds in top third of 2-digit industry mean. Deflated by CPI.	IBISWorld	0.075	0.263
SME	Small and medium enterprise	Not large, micro business or pubic research organisation.	Default	0.715	0.451
Experiencesubclass	Firm's experience commercialising patents	The inverse of the cumulative number of Australian patent applications by firm in same IPC subclass	IP Australia	2.826	1.245
Technology cycle time	Rate of technological change	The inverse of the median age of the backward citations on US patents in the same OST technology as the invention over 1980-2001.	Chi research	0.110	0.024
Technology risk	Uncertainty over technology	How severe were the following problems in the development & make and sell stages…Uncertainty over feasibility of technology (rated on two 7 point Likert scales, 7 is most uncertain).	AIS-2007	2.716	1.634
IP confidence	Confidence in IP	How severe were the following problems in the development & make and sell stages… Lack of confidence in legal protection from copying of the invention (rated on two 7 point Likert scales, 1 is least confident).	AIS-2007	5.19	1.806
Instrumented variables					
Mean technology risk	Uncertainty over technical feasibility	Mean Technology risk for OST technology relating to the invention.	AIS-2007	2.641	0.278
Science	Riskiness of invention	How important were the following sources of knowledge for research on your last patent application? Universities, other public sector research bodies, technical conferences and workshops and scientific literature (mean of ratings on four 7 point Likert scales).	AIS-2007	2.730	1.505
Radical	How technologically radical the invention was.	Relative to state of art at time of application, did the invention reflect …an Incremental improvement, Radical improvement, Unsure.	AIS-2007	0.578	0.494

Note: AIS-2007 is the Australian Inventor Survey 2007.

Table A6: First stage regression estimates for estimation (2) Table 3: Dependent variable = Technology risk

	(1)
	First stage Linear IV
VARIABLES	Full sample
Financial capital and liquidity	
Large-owner funds low	0.215
	(0.188)
Large-high leverage	-0.050
	(0.190)
SME	-0.342**
	(0.157)
Micro-business	-0.572***
	(0.171)
Co-specialized skills & technologies	
Ln(Experiencesubclass)	0.052
	(0.038)
Ln(Technology cycle time)	0.124
	(0.156)
Instruments	
Science	0.133***
	(0.023)
IP position	
IP Confidence	-0.187***
	(0.017)
Constant	3.215
	(0.409)
F(8, 2618)	30.30
Observations	2,627

Table A7 Supplementary regression estimates: Dependent variable = DevExternal

VARIABLES	(1) Reduced form OLS	(2) Three instruments	(3) Ex-micro-businesses	(4) Fixed effects
Financial capital and liquidity				
Large- owner funds low	0.0511	0.0116	-0.0125	
	(0.0414)	(0.0498)	(0.0654)	
Large-high leverage	0.110**	0.117**	0.128*	
	(0.0451)	(0.0537)	(0.0660)	
SME	0.0621	0.131***	0.165***	
	(0.0384)	(0.0439)	(0.0588)	
Micro-business	0.0321	0.145***		
	(0.0416)	(0.0518)		
Co-specialized skills & technologies				
Ln(Experiencesubclass)	-0.0217**	-0.0320***	-0.0381***	-0.0628***
	(0.00898)	(0.0112)	(0.0143)	(0.0223)
Ln(Technology cycle time)	-0.0678*	-0.105**	-0.169**	0.188**
	(0.0366)	(0.0481)	(0.0732)	(0.0844)
Project risks				
Technology risk		0.198***	0.285***	0.0260***
		(0.0397)	(0.0818)	(0.00873)
Science	0.0304***			
	(0.00472)			
IP position				
IP confidence	0.000521	0.0359***	0.0599***	0.0113
	(0.00356)	(0.00898)	(0.0180)	(0.00967)
Constant	0.202**	-0.395**	-0.617*	-0.291
	(0.0964)	(0.188)	(0.354)	(0.200)
Hansen J Test, Chi-sq(2) P-val		0.1823		
Under-Identification, KP rk LM				
F test (tech_rsk)		21.15	18.92	
F test that all u_i=0: F(379, 652)				2.66
Observations	2,729	2,614	1,468	1,036
Cases				380

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