MACROECONOMIC CONDITIONS AND THE DETERMINANTS OF COMMERCIALISATION

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PAPER PRESENTED TO WIPO, 2 APRIL 2012.

In this paper, we focus on the effects of macroeconomic conditions on commercialisation. Using survey data on the activities of Australian inventors who attempted to commercialise 3,736 inventions over the period 1986-2005, we find evidence that macroeconomic conditions have a pro-cyclical effect on commercialisation activities. Such a finding has important policy implications since it suggests that recessions have both short-term effects (on employment, income) *and* long-term effects (on productivity). However, the magnitude of the supply-side effects – the cost of finance and level of public sector research – are estimated to be larger than the growth in aggregate or industry demand.

Key words: Innovation, Commercialisation, Invention, Appropriation
JEL Classification: O31, O34

1. Introduction

Around the world, there is increasing interest in understanding the causes and effects of commercialising inventive activity. Our particular focus in this paper is on the effects of macroeconomic conditions on commercialisation. Establishing that there is a pro-cyclical relationship between innovation and macroeconomic conditions, for instance, suggests that recessions have both short-term effects (on employment, income, etc) *and* long-term effects (on productivity) since innovation is the primary engine of long-run productivity growth. Although the relationship between innovative activity and macroeconomic conditions has been studied extensively (see Geroski and Walters, 1995; Saint-Paul, 1997), this is the first study to focus on commercialisation rather than other proxies for innovation such as R&D expenditure or counts of innovations/patents. Our analysis of this issue has previously been impossible because of the paucity of good data on commercialisation activities. In this paper, we take advantage of new survey data relating to 3,736 Australian inventions that were the subject of an attempt at commercialisation over the period 1986-2005.

Scholars who argue that innovation is pro-cyclical (Griliches, 1990; Guellec and Ioannidis, 1997; Fatás, 2000; Piva and Vivarelli, 2007) have suggested that a positive economic outlook provides the incentive to invest in innovative activities (Geroski and Walters, 1995), while high profit levels provide the means (Himmelberg and Petersen, 1994). However, some have questioned whether this pro-cyclical relationship holds across the whole innovation process, and in particular to activities further down the value chain. For example, Francois and Lloyd-Ellis (2003) argue that since official R&D data is biased towards measured efforts of research, it typically excludes the entrepreneurial functions that occur during development. They argue that if the complete set of innovative activities were accounted for – R&D, in-house managerial time, the withdrawal of labour from direct production, *inter alia* – observed innovation would actually be counter-cyclical (see also Saint-Paul, 1997). Wälde and Woitek (2004) qualify this line of argument by formally separating research from development in order to identify the effects of the business cycle on 'basic research', 'applied research' and 'development'. In the USA between 1953 and 1998, they found that the observed pro-cyclical nature of aggregated R&D expenditure was driven by the more entrepreneurially-orientated ‘development’, while expenditure on ‘basic’ and ‘applied’ research was in fact weakly countercyclical.[1]

Our approach hones in on this issue and considers whether macroeconomic conditions have differing effects on the phases of commercialisation from development through to mass production. To do so, we rely on survey responses from a sample of Australian inventors who between them filed 3,736 patent applications with the Australian Patent Office between 1986 and 2005. In this survey, inventors were asked a range of questions relating to their experiences with commercialisation of specific inventions. Since some inventors have many inventions, we asked inventors about their commercialisation efforts relating each invention, up to a maximum of 5 inventions. Thus, the unit of analysis in this paper is the invention. In addition, the questionnaire asked a series of questions regarding inventor- and invention-specific characteristics. Following Palmberg (2006) and Nerkar and Shane (2007), we model the decision to attempt commercialisation using duration analysis. We employ a multiple event model and define the ‘event’ as an attempt made at one of a number of distinct commercialisation stages including: development, licensing, transferring to a spin-off company, make and sell, mass production and export. The main contribution of our study is to reveal how the effects of macroeconomic vary across these different dimensions of the commercialisation process.

In our results, we find clear evidence that macroeconomic conditions matter for commercialisation and that they are pro-cyclical. We separately identify the effects of demand-side factors (e.g. business confidence and growth in demand) and supply-side factors (e.g. commercial lending rates, the tax price of R&D, and changes in the level of government R&D expenditure) on commercialisation and conclude that the supply-side effects are larger than the effects of growth in aggregate (or industry) demand. In particular, the overdraft rate was found to have the largest effect followed by the tax price of R&D and changes to the level of public sector R&D. These results have important implications for the relative effects of ‘demand-pull’ and ‘supply-push’ factors on commercialisation.

The outline of our paper is as follows. In Section 2, we summarise the determinants of commercialisation with particular emphasis on macroeconomic forces. We then outline the

[1] Francois and Lloyd-Ellis (2003) also do not find any correlation between applied research and GDP in the US from 1953 to 1999.

data collated from the Australian Inventor Survey and provide some descriptive statistics. In Section 4, we provide the estimating model and analyse the results. Section 5 presents some robustness checks based on a set of different assumptions relating to the timing of commercialisation decisions. Section 6 concludes.

2. Determinants of commercialisation

Economists have long since understood the market failure involved in the production of new knowledge (see Nelson, 1959; Arrow, 1962). Since information has a marginal cost of zero, the unfettered market will not produce the socially-optimal level of knowledge. However, it is also become apparent that – over and above the problems associated with the creation of new knowledge – there are some acute problems associated with the commercialisation of new knowledge. For instance, taking a new pharmaceutical from the laboratory and investing in clinical trials may require hundreds of millions of dollars and take 20 years before a final product is observed in the pharmacist's shelves. Numerous studies have previously examined policies directed at assisting technology transfer from universities to the private sector (see Mowery *et al.*, 2001 for the seminal contribution) and more generally the determinants of invention commercialisation (see Nerkar and Shane, 2007 and Decheneaux *et al.*, 2008 for recent contributions).

In this paper, we examine the determinants of decisions to commercialise an invention *conditional* upon the invention's creation. Our specific focus is on the role of macroeconomic conditions upon commercialization decisions, in particular the decision to attempt one of a series of distinct stages along the commercialisation pathway including: development, licensing, transferring to a spin-off company, 'make and sell', mass production and export. However, we should make it clear at this juncture that the study does not consider feedback from the state of the macro-economy to the decision to invent, which makes it quite different to other studies in the literature.[2] Both R&D and downstream commercialisation activities are

[2] Studies that incorporate the complete innovation decision, such as Geroski and Walters (1995), endogenise both the decision to invent *and* the state of the macro-economy and are thus able to consider whether the innovations are caused by business cycle fluctuations or cause these fluctuations. The latter forms the basis of the 'real business cycle' theories of Lucas, Kydland and Prescott and (in a very different way) the evolutionary theories of Nelson and Winter (1982).

investments from the point of view of the firm, and we would expect the determinants of the commercialisation decision to parallel those for the decision to invest in plant and equipment.

Almost all theories of firm investment behaviour are pro-cyclical. The aggregate theories of (tangible) investment dating from Keynes (1936), and successors, Lundberg (1937), Samuelson (1939) and Harrod (1939), and their somewhat unconnected contemporaries, Schumpeter (1934, 1943) and Kalecki (1939, 1968), believed that the macro-economy had both a push and pull effect, both of which are pro-cyclical. Schumpeter and Kalecki modelled firms' investment demand as a function of both the capacity to finance (from retained earnings and external intermediaries) and the expectation of profits (as represented by current sales and exogenous embodied 'innovation').[3] Almost all of these theories comprised elements which are both endogenous to and exogenous from the macro-economy. In Kalecki's 1968 model, central banks' cash rate is the exogenous force determining the availability of external finance and the rate of exogenous 'innovation' (which we would call public sector scientific output) conditions the expectation of profits. Endogenous retained earnings are both the source of finance and are also the collateral against which banks extend credit. Endogenous (current) sales are the mainstay upon which firms base their future expectations of sales.

Since then, investment theories have expanded into the intangible realm and become more nuanced by distinguishing between the up- and down-stream stages of the innovation pathway (Wälde and Woitek, 2004) and between product and process innovations (Brown and Eisenhardt, 1995; Martinez-Ros, 1999; Krishnan and Ulrich, 2001). Consistent with other areas of applied economic research, the unit of analysis has shifted from the economy or industry to the individual firm or invention. Following Mansfield and Wagner (1975), many of these firm-level studies have focused on the role that technological and organisational characteristics play in shaping commercialisation outcomes.

[3] Schumpeter goes further than Kalecki and assumes that firms' demand functions and existing conditions of markets are made malleable by firms' innovation decisions. Innovation is the prime weapon of competition. Furthermore, Schumpeter extends Kalecki's 'principal of increasing risk' (Kalecki 1939, Ch 4) to highlight the central role of retained earnings for highly uncertain investments such as innovation investments.

3. Data and descriptive statistics

For this study, data were drawn from the 2007 Australian Inventor Survey which surveyed every Australian inventor who a submitted patent application to the Australian Patent Office between 1986 and 2005.[4] The unit of analysis of the survey is the individual invention. That is, inventors were asked questions about commercialisation activities relating to a specific invention which was identified at the start of the questionnaire. All inventors listed on a patent application were sent a survey. In instances where there was a response from more than one inventor listed on the same patent application, we randomly selected a single response. To eliminate repeat observations in our sample, inventors with more than one patent application over the period 1986-2005 – which accounted for about 24 per cent of the inventors in the population – were asked about a maximum of 5 randomly-selected inventions.[5]

A unique characteristic of our survey is that inventors whose patent applications were unsuccessful along with successful applicants. This is the major point of departure from other inventor surveys from around the world who only surveyed patent owners (such as the PatVal-EU survey, as described in Gambardella *et al.*, 2008). One major advantage of this survey design is that it provides us with a unique cross-section of different commercialisation pathways utilized by entrepreneurial inventors. That is, some of the inventors in our sample relied on patents to aid their attempts to license their inventions to third parties who would make, market, distribute and sell their inventions, while others relied on alternative commercialisation pathways.

The questionnaire included a comprehensive set of inventor- and technology-specific characteristics and a range of outcomes at different stages of commercialisation. In particular, we collected information on whether or not each of five different stages of the commercialisation pathway – development; make and sell; mass production; export; and licensing and spin-off – were attempted. All respondents were asked about whether an

[4] An alternative strategy would be to send the survey to the assignee (rather than the inventor). However, we believe the inventor should have a more intimate knowledge of the lifecycle of the invention than his or her organization. Mattes *et al.* (2006) use a sample of 136 inventors to show a correlation between inventor and owners responses on patent outcomes of about 90 per cent.

[5] A complete description of the survey population and the survey method is provided in the Appendix.

attempt was made to license or spinoff the invention and whether the invention had been developed. The latter related to 'proof of concept', 'testing and validation', and 'prototype'. Respondents who indicated that an attempt had been made to develop the invention were also asked about whether the invention was manufactured. The latter included 'gathering market intelligence', 'validating the commercial opportunity', 'trialling the manufacturing process' and 'market launch'. Only those respondents who had attempted the 'make and sell' stage were asked about attempts to mass produce and export the product.

Ideally, one might imagine that successful commercialisation should be measured using the discounted stream of profit generated by the investment in the invention. However, this is difficult to measure without a project–specific record of accounts. As a consequence, most studies of commercialisation focus on proxies of commercialisation success such as break-even times (see Palmberg, 2006) or duration of sales (Astebro and Michela, 2005). In this study, our measure of success is whether a specific stage of the commercialisation process was attempted. We acknowledge that measuring commercialisation in this way has its limitations. However, it does have one major benefit: since the questions are structured in a sequential manner, the further down the commercialisation process the invention proceeds – toward mass production and export, for example – the more the measure of attempted commercialisation embodies an element of success.

In total, there were 43,200 inventor-application pairs in the population with a complete address and inventor name. These applications related to 31,313 unique patent applications (i.e. inventions). On the basis of the number of surveys returned to us unopened (and a post enumeration survey of non-respondents), we estimate that there are 5,446 inventions with currently-valid addresses (see the Appendix for more details). Survey responses came from inventors in a wide range of employment arrangements covering: small-medium sized enterprise (SME) (36.4 per cent), large companies (10.5 per cent), and public-sector research organisations (6.6 per cent). The residual (46.6 per cent) were individual inventors.[6] The inventions in the sample covered a broad cross-section of technology areas, which were classified using the OST-IPC technology concordance.[7] The distribution by technology area

[6] Employment status was determined by the name of the applicant.
[7] OST refers to the UK Office of Science and Technology classification. IPC is the International Patent Classification.

was: electricity and electronics (10.4 per cent), instruments (10.4 per cent), chemicals and pharmaceuticals (9.9 per cent), mechanical engineering (27.9 per cent), process engineering (11.1 per cent), and 'other' (30.3 per cent).

Additional variables are also available from the survey on the inventors' age, sex, highest level of post-school qualification, research motivations and the sources of knowledge and funds used in their research. In addition to the applicant- and technology-specific characteristics summarised above, we have information on how radical the invention is and how many previous patent applications the inventor had made.[8] However, none of these variables were significant in the hazard estimations outlined below.

In order to consider any potential response bias, the population in-scope was compared with the sample of survey respondents by the following characteristics: year of application; organisation type; whether the patent was granted (at the end of 2007); and technology area. In all cases, the chi-squared test rejected the hypothesis of independence (at the 5 per cent level) between those that did and did not respond to the survey but the degree of bias was not large.

Table 1 presents some descriptive statistics on the sample of survey respondents used in the analysis presented here. It shows that 91.0 per cent of firms attempted one or more development stage (proof of concept; testing and validation; prototype; or 'other'); and 72.3 per cent attempted the make and sell stage (gathering market intelligence; validating commercial opportunity; trialling the manufacturing process; market launch and 'other'). While about 40 per cent attempted to licence the invention, only 14.2 per cent attempted to place the invention in a spin-out company. For mass production and export the percentages were 7.0 and 21.4 respectively.[9]

Table 1. *Descriptive statistics*

Commercialisation event	Number	%
Apply for a patent	3,736	100.0
Attempt at least one development stage	3,399	91.0

[8] For a more thorough discussion of the details of the Australian Inventor Survey, see Webster and Jensen (2009).
[9] The survey also collected information on the demographic and research background of inventors but since they had no explanatory power in the estimations we do no present them here.

Attempt to license	1,525	40.8
Attempt to spinout	531	14.2
Attempt at least one make and sell stage	2,700	72.3
Attempt mass production	1,383	37.0
Export	798	21.4
Total	3,736	100.0

Notes: the sum of each section may not add to 3,736 if some observations are missing a reported characteristic.
Source: Australian Inventor Survey 2007

Six independently sourced time-varying datasets were used to construct the explanatory variables used in this paper (see the following section for more details on the empirical model). Most of these data were collated from the Reserve Bank of Australia or the Australian Bureau of Statistics. Only the industry-value added measure is sector specific – being 2-digit level for all industries except for Machinery and Equipment Manufacturing which is disaggregated at the 3-digit level. All other variables are aggregated at the economy level. While simple charts of these data are given in the Appendix, we note here that most series involve considerable variation over time. Table 2 presents the correlations between the commercialisation events (coded as 0/1) and the set of (continuous) explanatory variables. While there are generally low correlations overall, the highest correlation is between the small business overdraft rate and the B-index (0.710), and between the overdraft rate and the change in the real level of GERD (0.524). Almost all other correlations are below 0.1.

Table 2. *Correlation between dependent variables (commercialisation event) and explanatory variables*

	Commercialisation event	Annual rate of growth in real wages	Annual rate of growth in industry value-added	Business confidence	Small business overdraft rate	B-index	Change in the real level of GERD
Commercialisation event	1						
Annual rate of growth in real wages	-0.052	1					
Annual rate of growth in industry value-added	0.032	0.080	1				
Business confidence	0.012	0.103	0.185	1			
Small business overdraft rate	-0.075	-0.212	-0.123	-0.573	1		
B-index	0.083	0.118	0.079	0.096	-0.710	1	
Change in the real level of GERD	-0.054	0.253	-0.091	-0.300	0.524	-0.517	1

4. Estimation model and results

In this paper, we model the effects of macroeconomic conditions on commercialisation using event history analysis and assume an attempt at each stage of the commercialisation process is an ‘event’. The main problem with utilising this technique to interrogate our data is that apart from the date of lodgement of a patent application, we do not observe the timing of any commercialisation decisions. That is, although we asked the inventors about *whether* they attempted each commercialisation stage, we did not ask them *when* such an attempt occurred. Ideally, calendar year information would be used to match the attempted commercialisation stage with date-relevant, time-varying industry and macroeconomic variables. However, this is clearly not possible in this instance.

In order to take account of the timing of commercialisation decisions, we take advantage of the fact that the many of the commercialisation stages are sequential[10]: that is, development occurs before make and sell, and make and sell occurs before mass production, and so forth. This enables us to place a logical ordering of the commercialisation stages: for example, we can state categorically that an attempt to make and sell an invention must come after a successful attempt to develop the product. The issue we must address is however the length of

[10] We say ‘primarily’ here because a couple of the commercialisation stages are independent of the others. For example, licensing does not require that the invention go through the ‘make and sell’ or ‘mass production’ stages. Similarly, exporting does not require that the invention first be mass produced.

the lag between the two decisions. To deal with this, we have introduced some assumptions about the relevant lags over the entire commercialisation process. Specifically, we introduce the following lags between the year the patent application was filed (which we observe) and attempts (if made) at each of the five commercialisation stages: development (1 year); licensing (3 years); spin-off a company (4 years); make and sell (5 years); mass production (7 years); and export (9 years).[11] Given the ad hoc nature of these assumptions, we undertook a comprehensive sensitivity analysis – where we allow the length of these lags to vary – in the following section. The results suggest that our results are robust to varying assumptions.

Time-related events are typically modelled as a hazard function. The hazard function defines the probability that an event occurs at time *t* conditional on the unit having survived up until time *t*.[12] Formally, the hazard, which is denoted as $h_i(t \mid \mathbf{x})$, can be written as:

$$h_i(t \mid \mathbf{x}) = h_0(t)\exp(\mathbf{x}_{it}'\boldsymbol{\beta}) \qquad (4)$$

where $h_0(t)$ is the baseline-hazard function, and $\mathbf{x}_i$ is a vector of explanatory variables which impose a proportional characteristic-specific shift on the baseline hazard. The hazard rate is defined with respect to time since the invention's patent application with the baseline hazard h_0 written as a flexible function. This avoids potential mis-specification bias resulting from choosing an inappropriate parametric specification for the baseline hazard.[13]

The vector $\mathbf{x}$ in our empirical model includes a range of time-varying explanatory variables relating to the factors affecting intent to commercialise. Similar to Guellec and Ioannidis (1997), we employ a parsimonious model based on a set of demand-side variables (growth in demand; business confidence) and a set of supply-side variables (the cost of borrowing; business R&D subsidies; level of public sector R&D). In the following, we explain the construction of both sets of variables. Since commercialisation activity is a

[11] Note that we are implicitly assuming here that the lags do not vary across industry. Of course, this is a restrictive assumption to impose since it is quite possible that there is substantial inter-industry heterogeneity in the commercialisation process – it is well know, for instance, that commercialising an invention in the pharmaceutical industry can take much longer (20+ years) than in other industries. If we could observe the timing of commercialisation decisions for individual inventions, we could control for this. We thank an anonymous referee for pointing this out to us.
[12] The use of the term 'hazard' in this context derives from its literal meaning of an obstacle or something which may potentially lead to failure, which reflects the fact that hazard functions are typically used to model adverse events such as death and disease. However, in our context, we define 'hazard' in a positive light since it is associated with success.
[13] Many attempts were made to include an invention-specific effect (frailty model) but they all failed to estimate.

derived demand function, we use the same logic used to model input demand functions. That is, we estimate the firm's 'demand' for commercialisation as a function of a set of exogenous prices and external events. As such, even though commercialisation activity may be correlated with other forms of firm investment demand – such as the purchase of new plant and equipment – they are actually endogenous to the commercialisation decision and are not included in our model. While we have a number of variables that describe the characteristics of the applicant (whether a small or large company, an individual or a public sector research organisation) and the invention (whether radical or incremental, technology class), these were not significant when included in the estimation.

4.1 Demand-side variables

In our specification, we include a set of two demand-side variables: *Demand Growth* and *Business Confidence*. The *Demand Growth* variable is measured in two alternative ways: by the annual rate of growth in real wages[14] and the annual rate of growth in industry value-added.[15] These two variables are meant to be alternative proxies for the same underlying phenomenon, so each version of the estimating model includes one variable or the other. The variable *Business Confidence* is measured by a quarterly index of confidence in the Australian investment and business community that is published by one of Australia's retail banks, the National Australia Bank.[16]

4.2 Supply-side variables

The set of supply-side variables used in the estimated model include: *Cost of Commercial Borrowing*, *Business R&D Subsidies* and *Public R&D*. The first of these variables is measured using the official small business overdraft rate published by the Reserve Bank of Australia.[17] The variable *Business R&D Subsidies* is measured by the B-index, which is the

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[14] Earnings; Persons; Full Time; Adult; Ordinary time earnings deflated by the Consumer Price Index (all groups). Source G06 LABOUR COSTS.xls and GO2HIST.xls Reserve Bank of Australia, Downloaded 7/08/2008.

[15] 5206.0 Australian National Accounts: National Income, Expenditure and Product, Table 6. Gross Value Added by Industry, Australia: Chain volume measures.

[16] National Australia Bank business confidence index, Source G08HIST.xls Reserve Bank of Australia. Downloaded 7/08/2008.

[17] Small Business Overdraft Rate. Source F05HIST.xls Reserve Bank of Australia. Downloaded 7/08/2008.

proportion of (before tax) R&D cost paid by the firm as a ratio of the proportion of (before tax) profit received by the firm. It includes general incentives available to all firms such as depreciation and allowable tax credits. The B-index is the standard way in the literature to proxy the cost of R&D (see Warda, 2001; Guellec and van Pottelsberghe, 2003; Falk, 2006; Thomson, 2009).[18] The final supply-side variable is *Public R&D*, which is measured by the annual change in the level of Government Expenditure on R&D (GERD) deflated by the GDP deflator.[19]

4.3 Results and analysis

In Table 3, we present alternative specifications of our parsimonious model. In total, we present three variations of the estimating model, based on the different combinations of demand- and supply-side variables. Overall, the results provide strong evidence that the state of the macro-economy does matter for commercialisation. Across all models, we find robust evidence that both demand- and supply-side variables are strongly statistically significant. With regard to the demand-side variables, there appears to be a considerable 'pull' effect, regardless of whether we use real wages (Model 1) or real industry value-added (Models 2 and 3) as a measure of the growth in demand. Contrary to expectations, the effect of business confidence is negative. This could be explained by the fact that this measure of business confidence is based on subjective beliefs about the future – and is therefore a noisy indicator of the investment climate – rather than hard objective data.

On the supply side of the equation, the cost of doing business appears to have a fairly clear effect on the success of commercialisation. As expected *a priori*, an increase in either the small business overdraft rate or the B-index has a strong negative effect on the commercialisation success rate. At the same time, the annual change in the level of GERD (government R&D expenditure designed for economic development) had a positive and significant effect in all five models estimated, which is strong support for the theory that 'supply push' factors are important determinants of successful commercialisation.

[18] We thank Russell Thomson for his estimate of the B-index, which is outlined in Thomson (2009).

[19] 81090DO003_200607 Research and Experimental Development, Government and Private Non-Profit Organisations, Australia, 2006-07 and cat 8109.0 various years. Downloaded 7/08/2008.

Table 3. *Results from the estimated hazard of (multiple) 'success'*

	MODEL 1	**MODEL 2**	**MODEL 3**	**MODEL 4 (extra lags chemicals)**
Demand-side variables				
Annual rate of growth in real wages	0.097***			
	(0.011)			
Annual rate of growth in industry value-added		0.777***	0.715**	1.372***
		(0.273)	(0.271)	(0.395)
Business confidence	-0.003	-0.005**		
	(0.002)	(0.002)		
Supply-side variables				
Small business overdraft rate	-0.059***	-0.097***	-0.080***	-0.068***
	(0.014)	(0.014)	(0.012)	(0.015)
B-index	-1.127***	-1.788***	-1.373***	-0.985**
	(0.338)	(0.355)	(0.292)	(0.390)
Change in the real level of GERD	1.373***	1.777***	1.903***	2.581***
	(0.341)	(0.346)	(0.340)	(0.460)
Observations	9467	8389	8389	4923
Estimation method	Cox Hazard	Cox Hazard	Cox Hazard	Cox Hazard
No. of subjects	3601	3232	3232	3206
No. of events ('successes')	7503	6516	6516	3050
Log likelihood	-53761	-45856	-45858	-23372

Notes: Absolute value of z statistics are presented in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%

Model 4 uses the specification of Model 3 but introduces an additional 2-year lag for the license, spin-out, make and sell, mass production and export stages in the 2-digit industry which includes pharmaceuticals (the whole 2-digit industry comprises Petroleum, Coal, Chemical and Associated Product Manufacturing). We have given special treatment to this industry because it is well-known that pharmaceuticals can have longer commercialisation lags than other fields. The results, which are presented in the last column, are similar to Model 3 except that the coefficients on the industry value-added and GERD variables are larger and the B-index is smaller.

In Table 4, we provide an estimate of the economic importance of the independent variables. To do this, we present the change in the estimated linear prediction of the hazard model if we change each independent variable from being on one standard deviation below the mean to one standard deviation above the mean while holding all other independent variables at their means (using the coefficients from Model 3, where the business confidence index is excluded from the estimation). These estimates show that variation in the rate of interest has the largest effect on the propensity to successfully commercialise inventions. The absolute magnitude, 0.306, is nearly twice the size for the cost of conducting R&D (the B-index) and the change in the level of GERD. The impact of the rate of growth of industry value added is about half as small as these variables again. These relative impacts remain even if we use relative real wage growth instead of industry value-added as a proxy for growth in demand.

Table 4. *Effect of a change in independent variable from (mean less one standard deviation) to (mean plus one standard deviation) on the linear prediction $X\beta$*

	Change in the linear prediction $\mathbf{X\beta}$
Annual rate of growth in industry value-added	0.067
Small business overdraft rate	-0.306
B-index	-0.170
Change in GERD	0.164

5. Robustness check and comparison with other studies

Logically several of our commercialisation stages are sequential: development has to precede 'make and sell', 'make and sell' has to precede manufacture and so on. However, as mentioned, we do not know the actual real world time intervals between stages and our assumed lag structure is based only upon anecdotal information. To assess how sensitive our results are to our assumed lag structure, we undertook a series of alternative estimations using different lag structures. Rather than assume a 1-year lag between each commercialisation stage, we experimented with seven other lag structures which involved 21 other estimated models (that implied both compressions and extensions of time between commercialisation stages). Compared with the case presented above in Table 2, we found the results to be robust with the following exceptions: the real wage growth variable was statistically insignificant in one of the 21 estimations; the change in industry value added was not significant in 2 of the 21 estimations; the small business overdraft rate remained significant and negative in all 21 estimations; the B-index was not significant in 4 of the 21 estimations; and the change in GERD was not significant in 6 of the 21 estimations. There are a finite number of different lag structures that could be employed here since the co-variates are year specific and there are a limited number of combinations of year lags that are consistent with the sequential nature of the commercialisation stages.[20]

In addition, we have assumed in our estimations that the development stage had been undertaken if any of the four activities identified in the part of the questionnaire that dealt with 'development' – proof of concept, testing or validation, prototype or 'other' – had been conducted. As an alternative, we could have treated these as four separate events rather than combine them as one event. A similar issue arises for the 'make and sell' stage. When we estimated the hazard model using these more finely graded definitions of an event, we found similar results to Table 2.

While our results confirm the importance of macroeconomic conditions – from both the demand and supply-side – on the decision to commercialise inventions, the magnitude of the supply-side effect is estimated to be larger than the growth in aggregate or industry demand. In particular, the overdraft rate was found to have the largest effect followed by the level of tax incentives for R&D and changes to the level of public sector R&D. This supports the earlier findings of Guellec and Ioannidis (1997) who use an 18 country dataset from 1972 to 1995 and find that measures of overall level of economic activity (GDP), public-sector funded research, and long-term interest rates[21] have a significant (with an *a priori* consistent sign) effect on the level of R&D spending. While the effects of aggregate or industry demand are clearly significant, they are also pro-cyclical, which stands in contrast to the findings of Francois and Lloyd-Ellis (2003) and Saint-Paul (1997).

These findings should not be confused with microeconomic studies which also investigate the relative effect of demand versus supply-side factors on commercialisation (Schmookler, 1962; Stoneman, 1979; Cainelli *et al.*, 2006, von Hippel, 1978; Buenstorf, 2003; Geroski and Walters, 1995; Fontana and Guerzoni, 2008).[22] In these studies, the research questions – which are quite different from the question posed here – address the effects on innovation of

[20] The explanatory variables are year-specific and therefore there is a limit to how many variations on the lag structure are useful. For example – it does not matter whether a lag is 6 or 10 months after application year, since both lags fall within the same calendar year. In addition, only some lag structures are sensible – we cannot have export or mass production occurring before the development or make and sell stage.

[21] The negative effect of interest rates on R&D was predominantly apparent for the G12 OECD countries (Australia, Austria, Belgium, Denmark, Finland, Iceland, Ireland, Netherlands, Norway, Spain, Sweden and Switzerland).

[22] The first two studies are industry-level while the others are firm-level. For a critical review of earlier microeconomic studies see Mowery and Rosenberg (1979).

organisational capabilities, managerial style and the firm's marketing strategy. This is not the same as the effect on innovation of the broad macroeconomic environment. The outcomes from our study and these internal managerial practices studies do not have the same implications for policy. Nonetheless, it is interesting to note that these microeconomic studies tend to find supply-side effects to be the more important than demand-side effects.[23]

6. Conclusions

In many respects the question of whether demand- versus supply-side factors determine the level of commercialisation activity is a false dichotomy. Both factors are necessary but not sufficient. A new product or process would not be commercialised if it clearly had no market. Nor would it be commercialised if funding was unavailable. The real question for policy makers is: what constitutes the short side of the market? That is, which factor is the bottleneck? This question is not easily answered. While we have found that the cost of funds has the biggest impact on the commercialisation decision, we are not able to say that a one standard deviation reduction in the rate of interest will have a greater impact than a one standard deviation rise in aggregate demand.

Nonetheless, our findings are consistent with previous work that concludes that the overall level of economic activity, wages, public-sector funded research, and long-term interest rates have a significant pro-cyclical effect on the level of R&D spending. Contrary to other studies (e.g. Thomson 2009), we also conclude that total R&D tax treatment does appear to influence commercialisation decisions.

[23] Cainelli *et al.* (2006) use a 1995 cross-section of approximately 700 Italian firms and find support for positive effect of past firm productivity (but not sales growth) on process innovations (R&D, ICT development) in the service sector firms. Geroski and Walters (1995) use patent and (SPRU) innovation count data and find that evidence that while change in sales stimulates investments into inventions and innovation, that unobserved supply-side determinants (from say, scientific breakthroughs) are more important. In their review of eight industry- and firm-level studies, Mowery and Rosenberg (1979) argue that the role of demand had been overplayed and that both demand and supply-side forces are important.

Appendix: Australian Inventor Survey

The Australian Inventor Survey was mailed out in two waves between July and December 2007 by the Melbourne Institute of Applied Economic and Social Research at the 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 address. Of the 31,313 applications, 76.2 per cent had only one inventor and almost all (99.3 per cent) had 5 or less inventors (see Table 5). Of the 31,947 inventors, the vast majority (82.5 per cent) had only filed one application between 1986 and 2005 (see Table 6). To avoid administrative burden, inventors were asked about each invention, up to a maximum of 5 patent applications.

Table 5. *Number inventors per application, 1986 to 2005*

Inventors per application	Number of applications	%
1	23,866	76.2
2-5	7,225	23.1
6-10	218	0.7
>10	4	0.0
Total applications	31,313	100.0

Table 6. *Number of applications per inventor, 1986 to 2005*

Applications per inventor	Number of inventors	%
1	26,360	82.5
2-10	5,506	17.2
11-20	66	0.2
>20	15	0.0
Total inventors	31,947	100.0

There was no initial screening of applications and 47.0 per cent 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 and manually looked the applicant up by name and address in both the telephone book and internet. This search revealed that only 11.7 per cent 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. Given we received completed questionnaires for 3,736 inventions, our effective response rate was 68.6 per cent.

The following four tables show the pattern of survey response by year of application across various characteristics. According to Table 7, there is a clear rise in the percentage of completions over time. Response rates also varied according to whether the inventor was employed by a large company (63.2 per cent), SME (64.3 per cent), public research organisation (71.2 per cent), or an individual (73.5 per cent), as demonstrated in Table 8.

Table 7. *Number of patent applications with a complete survey response by year, 1986 to 2005*

Year	Number of patent applications			
	Complete	Estimated non-complete[a]	Total	% Completed
1986-1990	254	245	499	50.9
1991-1995	553	385	938	58.9
1996-2000	1124	541	1665	67.5
2001-2005	1805	538	2343	77.0
Total	3736	1710	5446	68.6

Note: [a] Number of non-completes exclude surveys that were returned as 'return to sender' and the estimated 65.7% of non-responses which we estimated, through a post-enumeration survey, to have had an invalid address.

Table 8. *Number of patent applications with a complete survey response by organisation type, 1986 to 2005*

Organisation	Number of patent applications			
	Complete	Estimated non-complete[a]	Total	% Completed
Large company[b]	391	228	619	63.2
SME[b]	1361	756	2117	64.3
Public sector research	247	100	347	71.2
Individual	1737	626	2363	73.5
Total	3736	1710	5446	68.6

Note: [a] Number of non-completes exclude surveys that were returned as 'return to sender' and the estimated 65.7% 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.

The grant rate (as of the end of 2007) for the entire population of applications lodged at the Australian Patent Office between 1989 and 2000 was 68.4 per cent.[24] Table 9 presents a comparison by major technology class between respondents and the total population. It shows that there is a modest level of variation in the response rate across technology groups comprising a slightly lower response rate from the electricity and electronics area and 'Other'.

Table 9. *Number of patent applications with a complete response by technology area, 1986 to 2005*

OST technology area[b]	**Number of patent applications**			
	Complete	Estimated non-complete[a]	Total	% Completed
I Electricity and electronics	329	181	511	64.4
II Instruments	440	175	617	71.3
III Chemicals, pharmaceuticals	410	166	579	70.8
IV Process engineering	447	187	638	70.1
V Mechanical engineering	1061	476	1542	68.8
VI Other	1048	524	1578	66.4
Total	3736	1710	5446	68.6

Note: [a] Number of non-completes exclude surveys that were returned as 'return to sender' and the estimated 65.7% 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

Six independently sources time-series explanatory variables were used in the estimations. Figures 1 to 6, which present summaries of these variables, show considerable variation in the series over the period of analysis.

[24] We exclude applications lodged between 1986 and 1988 as the high percentage of grants suggests that some non-granted applications are missing from the database.

Fig. 1: *Industry value-added – constant prices (weighted average over all industries)*

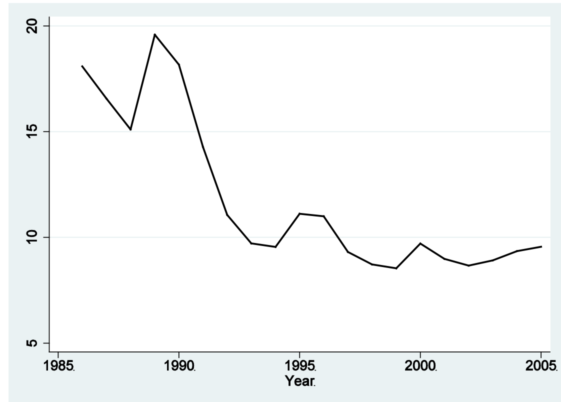

Fig. 4: *Small business overdraft rate (%)*

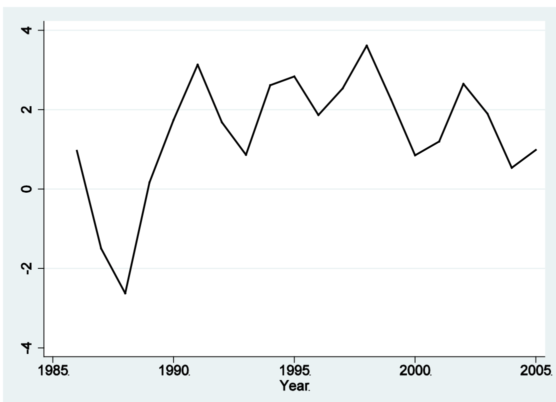

Fig. 2. *Rate of growth of real wages (annual %)*

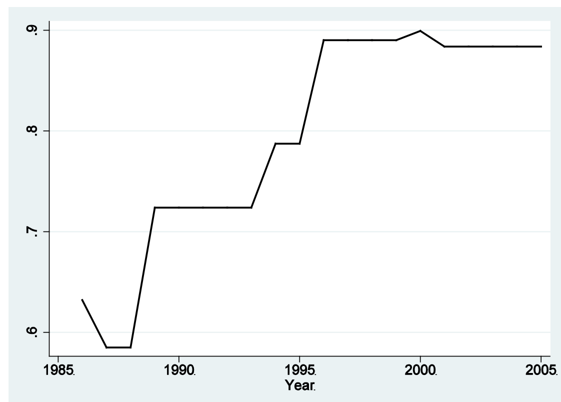

Fig. 4. *B-index*

Fig. 3. *Business confidence (index)*

Fig. 6. *Government R&D expenditure (level)*

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