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Dynamic financial constraints and innovation: Evidence from the UK Innovation Surveys

Henry Lahr[1], Andrea Mina[2]

Centre for Business Research and UK~IRC,
Cambridge Judge Business School, University of Cambridge,
Trumpington Street, Cambridge,
CB2 1AG, UK.
1) h.lahr@cbr.cam.ac.uk
2) a.mina@jbs.cam.ac.uk

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Author: Andrea Mina
Authors' contact: a.mina@jbs.cam.ac.uk
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Abstract

Does innovation cause financial constraints? And how do financial constraints affect firm innovation activities? In this paper we address the challenge of separating bi-directional causal effects in the relationship between innovation and financial constraints. Using the longest panel that can to date be derived from the UK Innovation Surveys, we construct novel simultaneous equations models with indicators for innovation, including expenditures for internal and external R&D, product innovation and process innovation, and for perceived financial constraints. The empirical analysis reveals a persistent impact of innovation inputs, and also outputs, on the likelihood that firms experience financial constraints. This effect is strongest for the observation of an R&D programme and relatively weak for R&D expenditures. Innovation outputs in the form of products new to the market seem to cause financial constraints – an important finding from a policy perspective. The reverse effect of financial constraints on innovation appears negligible.

Key words: Innovation; financial constraints; R&D; multivariate panel probit

JEL classification: O31, O32, C35

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1. Introduction

Innovation is a cornerstone of the knowledge economy and a fundamental driver of economic growth. The pathways to innovation are, however, varied and fraught with difficulties, with many obstacles posed by the fundamentally uncertain nature of innovation processes and their market outcomes. Access to capital is broadly recognised as a very significant barrier to innovation because it reduces investments in its core inputs (for example, R&D) which in turn may result in fewer new products and services and lower growth rates than would be the case in frictionless capital markets (OECD, 2009; NESTA, 2009). This problem clearly has special relevance in the aftermath of the recent financial crisis, during which the more innovative firms (and young and small firms in particular) might have been hit especially hard by a reduced availability or rising external cost of capital. This is a consequence of higher product market uncertainty and the stronger information asymmetries associated with it.

Despite a number of studies on the cash flow sensitivity of R&D investments (Hall, 1992; Himmelberg and Petersen, 1994; Harhoff, D., 1998; Mulkay et al., 2001; Bond et al., 2005), the extent to and the way in which innovation aggravates firm financial constraints have been significantly under-researched (Hall, 2010). This is partly due to a lack of cross-fertilisation between the innovation (Schumpeterian) economics and corporate finance research streams, and partly to the historical lack of suitable microeconomic data for the generation of robust empirical evidence. One of the empirically most challenging aspects of this research area is a potential feedback loop between innovation and financial constraints. Innovation induces risk, opaqueness and informational asymmetries into the relation between firms and investors, and this can lead to substantial additional financing costs if internal funds are not sufficient to sponsor R&D projects (Hall and Lerner, 2009). The existing literature offers no satisfactory solutions to this fundamental problem and yet the endogeneity of the relationship between firm financing and innovation can have serious implications for the validity of empirical findings and consequently also for the lessons that can be drawn from this body of evidence to inform policy.

In this paper we investigate the link between financial constraints and innovation through novel multivariate longitudinal analyses of innovation survey data. The paper advances our understanding of firms' innovation-financing behaviours by modelling comprehensively and simultaneously different dimensions of innovation, including inputs, processes and outputs, and not simply R&D. Our strategy is to treat financial constraints and innovation as a simultaneous dynamic system while accounting for firm-specific effects. We develop an original set of simultaneous equations models, suited to the treatment of endogeneity, and apply them to a panel of UK

Community Innovation Survey (CIS) data. The CIS data contain information on small and non-listed firms, which are not included in existing studies on the cash-flow sensitivity of investment (for example, Carpenter and Petersen, 2002). Our results provide a more comprehensive picture of the UK innovation-finance landscape than the one found in extant literature, in addition to the dynamic panel structure that is rarely modelled in the literature. It also allows us to compare results using a direct measure of financial constraints with prior findings of heterogeneous constraints based on cash flow sensitivities of R&D investment.

The objective of this paper is to join together theoretical insights from the innovation economics and corporate finance literatures and to contribute to a better understanding of the financial foundations of Schumpeterian economic dynamics. Our main results show that innovation inputs, and in part outputs, positively affect the probability that firms experience financial constraints. This effect is strongest for the observation of an R&D programme and relatively weak for R&D expenditures. Interestingly, innovation outputs in the form of products new to the market seem to cause financial constraints. The reverse effect of financial constraints on innovation appears negligible.

2. Measuring financial constraints and innovation

Studies of firm financial constraints have typically followed the approach developed by Fazzari, Hubbard and Petersen (1988) in regressing physical investment on cash flow and average Q (as a proxy for marginal Q) as a measure a firm's investment opportunities (Bond et al., 2003). This approach begins by separating firms into groups of a priori constrained and unconstrained firms. Differences in the sensitivity to cash flow between these groups are then used as a test for the existence of binding financial constraints. Models with R&D investments as an outcome variable were developed much later due to the limited availability of long R&D time series and methodological difficulties, such as those encountered in measuring the R&D capital stock.[1]

Empirical results usually reflected the existence of constraints on raising external finance (for example, Fazzari et al., 1988, 2000). This analytical framework – including the very identification of financial constraint and financial distress – has, however, been challenged in subsequent studies (Kaplan and Zingales, 1997, 2000; Cleary, 1999; Allayannis and Mozumdar, 2004; Schiantarelli, 1996). The use of conventional regressions of investment on cash flow has been criticized for neglecting the potential endogeneity of cash flow and for not controlling for external financing (Brown and Petersen, 2009). Hu and Schiantarelli (1998) recognise the methodological limitation of

[1] For extensive discussions of this literature see the reviews by Schiantarelli (1996), Hubbard (1998), Bond and Van Reenen (2007) and Coad (2010).

pre-classifying firms into constrained and unconstrained subpopulations and then estimating cash flow sensitivities for each. They estimate instead a switching regression model in the traditional Q investment model framework. In line with early studies, this approach mostly confirms findings of financial constraints to investment (Almeida and Campello, 2007). There also is some evidence of binding financial constraints for R&D investment, which nonetheless appear to vary considerably across time periods and countries (Hall, 1992; Himmelberg and Petersen, 1994; Harhoff, 1998; Mulkay et al., 2001; Bond et al., 2005; Cincera and Ravet, 2010; Brown et al., 2012), often not unlike physical investment (Carpenter et al., 1998; Bierlen and Featherstone, 1998).

In addition to the problem of endogeneity, this stream of contributions is severely limited by the reliance on R&D as the sole indicator of innovation. Following Schumpeter (1934), a series of key contributions to the economics of technical change (including Nelson and Winter, 1982; Pavitt, 1984; Kline and Rosenberg, 1986; Dosi, 1988; Freeman and Soete, 1997; Jaffe et al., 2002), have led to much deeper explorations of the different dimensions of innovation (Fagerberg et al., 2005). Innovation inputs (e.g. R&D) can be sharply distinguished from both intermediate outputs (e.g. patents) as well as final outputs (innovated products, processes and services). Moreover, each of these dimensions can be significantly affected by a range of practices and strategic choices about the sourcing of external knowledge, the acquisition of technologies and access to other complementary assets (Pisano, 1991; Teece, 1992; Powell et al., 1996; Ahuja, 2000; Stoneman, 2001; Baldwin and von Hippel, 2010). From an investment viewpoint, these facets of innovation are associated with different costs and risks and will be reflected in the patterns of demand and supply of external capital for innovative firms (Mina et al., 2013). The use of a broader and more precise range of innovation indicators has great potential for the refinement of our understanding of firms' financing behaviours.

The introduction and continued implementation of Community Innovation Surveys (CIS) has enabled the measurement of different stages and dimensions of innovations through time and on a large scale. The CIS also contains two specific questions on firms' perceived financial constraints (namely the extent to which 'access to' and 'cost of finance' constitute barriers to innovation). However, systematic research into the links between environmental constraints to the inputs, processes and outputs of innovation has only recently begun (Savignac, 2008; Canepa and Stoneman, 2008; Mohnen et al., 2008; Müller and Zimmermann, 2009; Czarnitzki and Hottenrott, 2011a, 2011b; Hottenrott and Peters, 2012). Despite the quality of these contributions, there are considerable margins for progress on theoretical, methodological and empirical grounds. The predominantly cross-sectional nature of the innovation data used so far in this stream of contribution does not help to address the problems of smoothing in R&D expenditures and state dependence in innovation activities. It also makes it extremely difficult to treat the potential reverse causality between financial constraints and innovation. Prior art on this topic typically models either constraints or innovation as exogenous or introduce simultaneity by adding contemporaneous error correlation without allowing for two-way causality.

Some econometric experimentation has recently taken place. Hajivassiliou and Savignac (2011) have used bivariate probit modelling with state dependency in both financial constraints and innovation variables in their study of French firms, although these analyses are severely limited by the use of only two CIS waves. Interestingly, however, this study finds a strong positive impact of innovative activities on the probability of financial constraints. In addition, and contrary to earlier studies, there is evidence of an insignificant effect of financial constraints on innovation for the full sample and positive and negative effects for contemporaneous and lagged financial constraints, respectively.

3. Data and methodology

3.1. Data

The Community Innovation Surveys (CIS) have made available a rich and direct source of information on firms' innovation activities and the economic environment in which these take place. CIS data are collected at the enterprise level. The CIS-UK 2011 sampled over 28 thousand UK enterprises.[2] The sampling frame includes all enterprises with 10 or more employees in sections C-K of the Standard Industrial Classification (SIC) 2003 or 2007 in the official business register, which include both manufacturing and service sectors. The original sample is stratified by region, industry sector and size, and weights are attached to responses according to the firm's weight relative to the number of firms in the stratum. For all enterprises with 250 or more employees, a census is used. Small and medium sized enterprises are sampled at random within each stratum. The survey is voluntary and conducted by means of a postal questionnaire and a telephone interview for non-responding businesses.

One important advantage of using a self-response measure over cash-flow sensitivities is that we can directly observe changes over time. In other words, instead of searching for latent financial constraints in different groups of firms, we can directly investigate their determinants and impact on innovation. We use four CIS-UK waves (CIS4-7, covering the periods 2002–2004, 2004–2006, 2006–2008 and 2008–2010) to assess British firms' perceived constraints in accessing capital

[2] Department for Business, Innovation and Skills, Office for National Statistics and Northern Ireland. Department of Enterprise, Trade and Investment, UK Innovation Survey, 1994-2010: Secure Data Service Access [computer file]. 2nd Edition. Colchester, Essex: UK Data Archive [distributor], October 2012. SN: 6699, Available at http://dx.doi.org/10.5255/UKDA-SN-6699-2

markets and their impact on innovation input and output. Individual cross sections contain about 15000 observations each. Data from the first wave are used as lagged dependent variables, reducing the maximum panel length to T=3. After linking four waves and excluding firms with incomplete time series (holes) in all dependent variables, we obtain an unbalanced panel dataset with 3218 firms. Due to missing variables in some dependent variables, individual analyses may have slightly fewer observations. For independent variables, there are 2659 two-period panels (2628 for CIS5-6 and 31 for CIS 6-7) and 559 three-period panels, 6995 firm-year observations in total. We match the CIS dataset with the Business Structure Database[3] (BSD) to obtain additional variables on firm age and legal form.

One feature of the data that needs special attention is a one-year overlap between consecutive surveys: each survey asks firms every two years about their activities over the previous three years. The serial correlation induced in the variables that are affected by this overlap has at least three implications for our modelling strategy. First, we use a dynamic model structure with lagged dependent variables to account for this serial correlation. Second, we choose appropriately lagged independent variables to construct economically meaningful models. Third, we test the robustness of our findings by incorporating a number of alternative measures of innovation inputs and outputs. For example, the survey question about R&D activities refers to a three-year period, whereas a similar question about R&D expenditures asks for the firm's expenditures in the last year of the survey period.

[Table 1 about here]

The distribution of firms in our sample is roughly comparable to the overall distribution of firms with 10 or more employees in the UK. We use SIC 2003 top-level classifications to construct industry dummy variables, which are presented in Table 1. To add a finer level of detail to our study of R&D and innovation activities, we split the manufacturing sector into high-tech and low-tech firms according to the OECD (2005) Science, Technology and Industry Scoreboard. Along the same line of reasoning, we separate R&D service firms from "other services". Manufacturing firms are overrepresented compared to the UK population of firms with more than 9 employees (32.7 percent vs. 19.3 percent) at the expense of other sectors, most notably hotels and restaurants (5.5

[3] Office for National Statistics, Business Structure Database, 1997-2011: Secure Data Service Access [computer file]. 3rd Edition. Colchester, Essex: UK Data Archive [distributor], October 2012. SN: 6697, Available at http://dx.doi.org/10.5255/UKDA-SN-6697-3

percent vs. 12.5 percent), trade (17.7 percent vs. 23.0 percent) and construction (7.6 percent vs. 11.2 percent).

3.2. Variables

Since we aim to simultaneously predict the occurrence of innovation activities and financial constraints in firms, all our dependent variables are binary indicator variables. We either use survey items directly or construct binary variables from them. Our six binary measures for R&D activities are based on two questions. First, "During the 3 year period [time period], did this business invest in any of the following, for the purposes of current or future innovation?" with answers "Internal Research and Development" and "Acquisition of external Research and Development", which translate into our dependent variables "R&D internal (activity)" and "R&D external (activity)". The binary variable "R&D any (survey)" equals unity whenever any of those two variables is answered positively by the firm. The second question is, "for each of the main innovation related investments in question [previous question], please ESTIMATE the amount of expenditure for the year [last year of survey period]". We treat positive amounts as indicators for internal and external R&D activities, which yields our dependent variables "R&D internal (expend.)", "R&D external (expend.)" and "R&D any (expend.)".

Dependent variables for innovation outputs correspond to survey items for the development of new products, services or processes. The questionnaire asks "During the 3 year period [survey period], did this business introduce a. new or significantly improved goods? […] b. new or significantly improved services?" and "did this business introduce any new or significantly improved processes for producing or supplying goods or services?" Additionally, we distinguish new goods and services that are new to the market from those that have been introduced by a competitor and are merely new to the firm. Finally, the variable "Innovation (any)" measures whether the firm introduced any type of innovation – good, service or process.

To assess financial constraints, firms answered the question, "how important were the following factors in constraining innovation activities: […] availability of finance". "Cost of finance" was another possible constraint in this block of items. We focus on the availability of finance, however, to stay close to the meaning of financial constraints as a *differential* between internal and external cost of finance that limits the availability of external finance. Whenever firms answer this items with any of "high", "medium" or "low", we code this answer as "experiencing financial constraints" and "unconstrained" otherwise. According to this measure, about half of the sample firms claim to be financially constrained to some extent. This proportion is largely driven by the two CIS waves in 2008 and 2010, as we show below. An important advantage of the UK

Innovation Survey relative to the innovation surveys of other European countries is that all firms were asked whether they experienced financial constraints, instead of only those that indicate some innovation activities. We find a substantial proportion of firms in all innovation and constraint regimes, including non-innovating firms that are financially constrained. Hence, potential selection problems within our sample are greatly reduced.

Independent variables in our analyses are related to a firms' innovative capacity and the likelihood of financial constraints. The range of variables is limited by their availability in official – and linkable – ONS datasets. We measure a firm's size as the natural logarithm of its turnover in the last year of each survey period. Firm age is calculated as (2010 – birth year) and thus does not vary over time. Since age changes in much the same way for all firms over time, the likelihood of detecting a time series effect in addition to the cross-sectional one is quite small given the short panel. However, treating age as firm-year specific would introduce four additional parameters (Wooldridge terms)[4], which remain insignificant in our tests. Whether a firm is a member of a group, is a subsidiary of a foreign firm and whether it has the legal status "company" can proxy for the availability of external finance and the availability of information about the firm. Similarly, the market scope of a firm can be related to information production, but also to competitiveness in the market and the constant need to be ahead of the competition by innovating. Finally, human capital is expected to have a positive impact not only on the likelihood to innovate, but also on the likelihood of financial constraints due to information asymmetries in firms with substantial intangible assets.

3.3. Model specification and estimation

We model the interaction between financing constraints and innovation as two simultaneous dynamic equations with concurrent error correlation between equations. The Community Innovation Survey's most recent wave enables us to specify a dynamic panel structure, combining several past waves to form a proper panel (T>2).[5] Linking four CIS waves allows us, in addition to incorporating first order dynamics, to use Wooldridge's (2005) approach to address the initial conditions problem in dynamic panels.

The system of equations for observed innovation activities (y_{it}^A) and financial constraints (y_{it}^B) is

[4] Wooldridge (2005)
[5] Prior studies often lose observations in their attempts to incorporate lagged dependent variables by merging several cross-sections and therefore have to restrict the scope of their analysis to cross-sections (Silva and Carreira, 2011; Hajivassiliou and Savignac, 2011).

$$y_{it}^A = I(X_{it}^A \beta^A + \lambda_A^A y_{i,t-1}^A + \lambda_B^A y_{i,t-1}^B + c_i^A + \epsilon_{it}^A > 0)$$
$$y_{it}^B = I(X_{it}^B \beta^B + \lambda_B^B y_{i,t-1}^B + \lambda_A^B y_{i,t-1}^A + c_i^B + \epsilon_{it}^B > 0), \quad (1)$$

where

$$\begin{pmatrix} \epsilon_{it}^A \\ \epsilon_{it}^B \end{pmatrix} \sim N\left[\mathbf{0}, \begin{pmatrix} 1 & \rho_{it} \\ \rho_{it} & 1 \end{pmatrix}\right] \quad (2)$$

and $I(\cdot)$ is the indicator function. Exogenous variables X_{it}^A and X_{it}^B can have the same content, since the model is identified by functional form. Coefficients can only be identified up to scale, since error variances need to be normalised to unity as in univariate probit models. Analogous to Wooldridge's (2005) panel probit estimator, we add random effects conditional on exogenous variables and initial values of both dependent variables.

These random effects can be written as

$$c_i^A = \alpha_0^A + \alpha_{1A}^A y_{i0}^A + \alpha_{1B}^A y_{i0}^B + \mathbf{x_i^A \alpha_2^A} + a_i^A$$
$$c_i^B = \alpha_0^B + \alpha_{1A}^B y_{i0}^A + \alpha_{1B}^B y_{i0}^B + \mathbf{x_i^B \alpha_2^B} + a_i^B, \quad (3)$$

where the row vectors $\mathbf{x_i^A}$ and $\mathbf{x_i^B}$ contain past, present and future observations for exogenous variables as well as time-constant variables. This implies that constant firm variables cannot be separately identified. Random effects are assumed to be independent from the idiosyncratic firm-year error component in equation (1). Their unobserved components are modelled as

$$\begin{pmatrix} a_i^A \\ a_i^B \end{pmatrix} \sim N\left[\mathbf{0}, \begin{pmatrix} \sigma_{a^A}^2 & \sigma_{a^A,a^B} \\ \sigma_{a^A,a^B} & \sigma_{a^B}^2 \end{pmatrix}\right]. \quad (4)$$

Since the likelihood function for both equations is analytically intractable, we use a maximum simulated likelihood (MSL) method to estimate this system of equations.[6] The error terms in all estimations are derived from 100 random draws. We tested smaller and larger sets of random errors and found that the added precision in larger samples is tiny compared to the increased computational cost of estimation. Standard errors shown in our results are based on the outer product of the gradient (OPG) method.

We do not intend to interpret this model strictly as a process view of innovation. In a well-known paper, Crépon, Duguet and Mairesse (1998) formulated a stepwise innovation process model including models for R&D, patents and innovative sales applied to Community Innovation Survey

[6] Gouriéroux and Monfort (1996) and Train (2009) provide excellent descriptions of estimation techniques and applications.

data. In this paper we take the view that financial constraints can affect firms' decisions and related productivity at any of these stages, and that firms may be simultaneously active in all of these stages with different projects. Instead of treating innovation outcomes and R&D expenditures as consecutive steps in an innovation process, we interpret them as indicators for innovative activities at a particular stage of development. Incorporating both input and output measures into a simultaneous multi-equation framework, in addition to simultaneous financial constraints, is beyond the scope of this paper.

4. Results

If we want to identify the dynamic effect of financial constraints on innovation and the reverse effect, we need to observe firms that switch from being constrained to unconstrained and from innovation-active to inactive or in the opposite direction. Table 2 shows the pattern of state transitions we observe in the data. A large number of firms remain inactive and unconstrained ("no/no" in the upper left corner in both panels). Many firms switch between the constrained and unconstrained states or remain constrained while not performing R&D or innovating. The innovation state seems to be less stable than the non-innovating state, unless firms are also financially constrained. If firms innovate in one period, the chances for all states in the next period are very similar. Only the innovation/constrained state ("yes/yes") shows high persistence, which indicates a strong relationship between these two variables. This relationship can also be seen in the small likelihood that a non-innovating, constrained firm starts innovating while also becoming unconstrained. Similarly, innovating firms that are unconstrained rarely become constrained and stop innovating in the same period. R&D activities are more stable than innovations for unconstrained firms (row "yes/no").

This highlights the stability of R&D programmes, in contrast to the relative randomness of innovations, although we do find a substantial number of serial innovators. Since all cells are occupied by a considerable number of firms, we are confident that a simultaneous bivariate binary model can produce meaningful results.

[Table 2 about here]

4.1. R&D models

Results from the estimation of simultaneous equation model with R&D and financial constraints (Table 3) reveal high persistence in both indicators over time. Financial constraints do not seem to affect R&D (Models 1-5), with the sole exception of one significant coefficient in a model for internal R&D indicating a positive effect (Model 6). On the contrary, and in line with earlier findings of increased financial constraints in technology firms with high R&D expenditures (Westhead and Storey, 1997), R&D increases financial constraints, but mainly in models using indicators of R&D activity (Models 2, 4 and 6), as opposed to R&D expenditures (Models 1, 3 and 5). This may suggest that firms engaging in informal R&D activities have more difficulties in attracting external finance relative to firms that engage in formal R&D, which is recorded in financial accounts. This is plausible from an asymmetric information perspective because informal R&D activities may be even harder for external investors to evaluate. An alternative explanation is that the 'true' level of investment risk is reflected in the R&D activity of a firm, independently of whether the firm allocate financial resources to a formal R&D budget or not.

Foreign ownership is negatively associated with R&D in four (Models 1, 2, 5, 6) out of six models, which implies that R&D investments may be overall closer to the firms' overseas headquarters. There are no regular and systematically strong effects across R&D indicators for other variables, including turnover, market scope, human capital, age, and company structure indicators. In two instances (Models 2 and 6), turnover seems to exert a negative effect on the likelihood of a subsequent internal R&D activity – a possible sign that growing firms slow down R&D in the following survey period. Operating on a more international market, a proxy for the scope of the firm's operations, has instead a plausible, although weak, positive effect on internal R&D in Model 6. Interestingly, time effects in the R&D equations reflect external macroeconomic conditions. Firms report R&D activities more frequently for CIS6 (2006-2008) relative to CIS5 (2004-2006), while engagement in R&D deteriorates significantly during the financial crisis. This can be explained in the light of the adverse climate in product markets characterising the last years of our sample period compared to the relatively more favourable climate of 2006 and the best part of 2007. Market demand fluctuations are a more appropriate explanation of these effects relative to the financial environment because we already control for the firms' financing conditions.[7]

[7] It is important to note that the presence of x_i in equation (3) prevents us from identifying time-constant variables, because we cannot separate the effect of these variables on both outcome variables from their correlation with the random effects in equation (3). For example, firms owned by a foreign parent seem to perform less internal R&D. Because the indicator for UK subsidiaries of foreign firms would also enter the conditional distribution of the random effects, including this variable in X_{it} would cause perfect collinearity with the one in x_i. Hence, instead of foreign ownership directly causing less R&D, it might be related to some unobserved quality which in turn is associated with

Among the determinants of firm financial constraints, beside the role of R&D, results show negative and significant effects for human capital and age, that is, both firm characteristics mitigate financial constraints. The effect of firm age is to be expected because information about older firms is more readily available than for younger firms, thus reducing information asymmetries and consequently the cost of external relative to internal capital.[8] The apparent negative effect of human capital is instead more difficult to interpret: intangible assets should in theory aggravate information asymmetries in the market for external capital, and prior cross-sectional evidence points toward an increased likelihood of financial constraints for firms with a high level of human capital (Hottenrott and Peters, 2012). On the one hand, variations in human capital over time seem unable to explain the likelihood of observing R&D activities. On the other hand, human capital is positively related to R&D through unobserved firm effects (Wooldridge terms in the R&D equation), which explains why we do not find a positive effect for time-varying human capital. Put differently, firms with a larger share of employees with a degree are more likely to face financial constraints, but only through unobservable firm characteristics related to human capital. Over time, instead, the effect of human capital on financial constraints is negative. A negative effect can be explained if we posit that increasing human capital can lead to higher productivity, which in turn – ceteris paribus – should be associated with growth and therefore also to more favourable financial prospects. It is also possible that after controlling for the adverse effect of R&D on constraints, human capital exerts a residual beneficial effect by helping to reduce information gaps between the firms and potential investors.

In addition, a relatively higher number of staff with degrees might help reduce informational asymmetries with external investors. After controlling for the adverse effect of R&D on constraints, this residual effect of human capital might well be beneficial for firms engaged in R&D activities.

4.2. Innovation models

The results generated by estimating models with innovation measures (Table 4) reveal, first of all, that not only R&D but also innovation is persistent through time and across indicators. The introduction of new goods, new services and new processes as well as products that are new to the firm or new to the market is strongly related to past success at innovating. Financial constraints do not appear to affect the likelihood of innovating (for all types of innovation). Among the variables that exert a significant effect on innovation, market scope has a positive effect, which means that

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less R&D without any implication of causality. It might even be the case that less research-intensive businesses are acquired by foreign firms more often.

[8] This result must however be interpreted with caution since age is constant across time periods and might also be correlated with unobserved random effects that reduce financial constraints.

operations on a larger market favour (in particular new-to-market) innovation; being part of a group seems instead to impede service innovation (Model 6), a possible sign that service innovation is highly concentrated within few units in large service firms or that being part of a group constrains firms' interaction with final users and their ability to change the process of service delivery. Finally, firms seem to have been relatively more innovative during the period 2006-2010. Both time dummies are both positive for new-to-market innovations (Models 1 and 2). This could indicate an effect of the time lag between R&D and innovation: adverse financial market conditions affect the firms' financial situation immediately, as reflected in time effects, but have a delayed impact on R&D investment, which in turn is translated with a time lag into innovation.[9]

While financial constraints do not affect innovation, inspection of the results in the lower half of Table 4 reveals that innovation has instead a strong impact on financial constraints. We find positive coefficients for new-to-market innovation (Model 2) – in line with Hottenrott and Peters' (2012) cross-sectional evidence – and for new goods (Model 4), and a lower but still positive coefficient for new services (Model 6). All coefficients for innovations are positive, but insignificant for new products that are only new to firm and not to the market and for new processes (Models 3 and 5).

This can be interpreted as an indication of financing needs not met by external sources of capital. It seems unlikely that new products, which are readily available for inspection by investors, should introduce asymmetries in financing relations that could lead to financial constraints. It is indeed interesting to see that that the indicators that determine financial constraints correspond to the most capital-intensive innovations: new-to-market and product innovations. This is compatible with the view that financial pressures increase in firms facing the costs associated with the scaling-up of production, the expansion of logistics operations and the early market diffusion of their new products. It is also possible that given the high variability in the quality of innovations, financial pressures increase because the market does not always respond positively to the introduction of new products. It is important to stress, however, that models in Table 4 employ innovation outputs as indicators for general innovative activities and thus might capture aspects of informationally opaque R&D projects that cause financial constraints. From an investor's point of view, innovation-by-imitation (innovation new only to the firm) and process innovation should be more transparent than uncertain product innovations. The interpretation that R&D projects feed into new products which are then correlated with financial constraints is also compatible with our results.

[9] An alternative explanation is that firms had to introduce new products to adapt to changes in demand.

5. Non-simultaneous estimations and unobserved heterogeneity

In order to validate our results we run a series of complementary and additional estimations. First of all we compare the results obtained from simultaneous modelling with results generated by simpler models that do not control for reverse causality. Secondly, we perform robustness checks on the estimation technique (by estimating bivariate probit models with lags instead of panel bivariate probit) and on our measure of financial constraints (by varying the cut-off points for the indicator's coding).

Table 5 and 6 show the results of independent estimations of the effects of financial constraints on R&D (Table 5: Models 1-6) and of R&D on financial constraints (Table 5: Model 7); and financial constraints on innovation (Table 6: Models 1-6) and of innovation on financial constraints (Table 6: Model 7). To demonstrate how different these results are, let us consider as an illustrative example the results presented in Table 5. These show positive effects of financial constraints on R&D, a counter-intuitive result which can be explained by observing the structure of error correlations. Correlation coefficients for firm-year errors between both equations are substantial and significant in all our specifications, supporting our modelling strategy. Interestingly, the effect of financial constraints on R&D or innovation is highest whenever the estimated between-equations correlation of random effects is insignificant. This suggests that the curious effects seen in these regressions are caused by unobserved heterogeneity that is correlated between equations. We are able to account for this correlation in our models, even though identification of this effect is challenging in small samples, as the corresponding Cholesky coefficient enters the estimation equation multiplicatively with the standard deviation of random effects in the R&D equation.

Controlling for initial conditions through Wooldridge (2005) terms in both equations helps produce sensible and stable results, but reduces many significant coefficients found in univariate models. Our modelling strategy reduces the likelihood of spurious results that are actually due to unobserved heterogeneity. For example, initial conditions (in CIS4) entering the conditional distribution of random effects in equation (3) turn out to be highly significant and positive in both the R&D and financial constraints equations. This finding also suggests that future research might benefit from investigating these unobservables that link a firm's financial environment and its innovation capabilities.

The inclusion of initial states for both outcomes in both equations, while retaining first-order dynamics, offers further insights into unobservable firm characteristics. Consider the positive coefficients for initial R&D conditions ("R&D (t=0)") in the financial constraints equation. R&D

activities are positively correlated with unobservables related to financial constraints, whereas R&D itself ("R&D (lag)") is less significant in most models. This suggests that being R&D active – interpreted as a firm effect – could lead to financial constraints, whereas observed year-on-year changes in R&D status are less important for financial constraints. Perhaps nothing has changed in the underlying characteristics of the firm, although it temporarily does not show any R&D activities. Capital market participants might thus be able to distinguish R&D performers, including those in a latent R&D-performing state without visible activities, from non-performers.

Similarly, success at innovating as a firm effect does not affect financial constraints ("Innovation (t=0)" in Table 4), as would be expected under standard theory, because innovation in itself does not cause information asymmetries. Another interpretation is that there is no such thing as a latent innovation state, e.g. there is no firm effect for innovation that adds to the overall firm random effect in the financial constraints equation. Innovations might be entirely random conditional on our observed variables. These interpretations are available under the normal interpretation of the financial constraints variable, that is to say a differential between external and internal financing costs and therefore a shortage of external funds. New goods and new-to-market innovations increase financial constraints, a result that standard theory would have difficulties to explain unless we interpret the survey question on constraints in more general terms as a signal of the demand for finance that usually follows successful innovations. Firms introducing novel products may find it necessary to approach external capital markets for expansion financing (ramping up production and marketing). This increase in the demand for finance produces, if unmet, a higher likelihood of financial constraints as detected in the Innovation Survey data.

Overall, past innovation success is more important for future success than past R&D is for future R&D when compared to the importance of initial conditions. In other words, coefficients for lagged innovation are about as large as coefficients for innovation at t=0, while R&D at t=0 has a much stronger effect on future R&D activities than lagged R&D. This again suggests that there are unobserved firm characteristics the predispose firms to constantly perform R&D. Innovation, on the other hand, depends less on constant firm characteristics, but rather on past success in innovating. In general, the link between innovation and financial constraints appears weaker than the one between R&D and financial constraints. Although both indicators for inputs or outputs in the innovation process explain financial constraints and are not affected by them, the relationship through cross-equation correlation and random effects is considerably weaker. Initial conditions of innovation and financial constraints in one equation are not significant in the other[10]. Hence, unobserved firm

[10] With the exception of product innovation, which seems to be affected by initial conditions of financial constraints.

heterogeneity in one variable seems to be unrelated to the other. The substantial correlation in unobserved firm effects nevertheless suggests the presence of unobserved firm characteristics that explain both innovation and financial constraints.

Would a simpler model without random effects or cross-equation error correlation be able to capture the same dynamic effects? To answer this question, we perform additional robustness tests. While estimation in Tables 5 and 6 assumed exogeneity of financial constraints, in Table 7 we develop a bivariate probit structure that contains all the features of our simultaneous models apart from a term that captures correlation between random effects. The key difference compared to results presented in Table 3 concerns the effect of past financial constraints on current research and development. All of these coefficients are positive and significant, suggesting an implausible increase of innovative activities in financially constrained firms. This effect can be found in univariate probit models, in univariate panel probit models and in models using innovation outputs as a dependent variable (similar to Table 4). If we allow for correlation between unobservables, this effect disappears. We conclude that specifying a sufficiently rich model is essential for modelling the dynamic relationship between innovation and financial constraints.

6. The identification of financial constraints

As a final robustness check, we code the indicator for firm financial constraints in a different way. A fundamental challenge for the constriction of binary models is combining precision in estimation with relatively small samples. Although our sample contains more than 3000 firms, many variables that are expected to have an impact on innovation or constraints cannot be distinguished from zero. There are only two alternatives. Either they are really zero or the estimation technique combined with sample size and data quality produces standard errors too large to see an effect. As a possible example for the latter explanation, firms' market scope increases the likelihood of innovative activities in all models, but not always significantly. Since a lack of precision can also affect our inferences about the determinants and effects of financial constraints as our main variable of interest, we must take measures to maximise the chance of finding an effect if it is there.

We therefore cut the indicator for financial constraints at the "low" level to maximise the information content in the resulting binary variable for our main analyses, since in so doing we obtain a ratio of constrained to unconstrained firms of about one. Increasing the threshold for financial constraints to the "medium" or "high" level would reduce the number of constrained firms, which might decrease the statistical power of the model. To test the effect of alternative thresholds when converting an ordinal survey item to our binary indicator for financial constraints, we repeat our analysis after cutting the constraints variable between the "low" and "medium" level. Innovation indicators are binary instead of ordinal by design. The inability to account for 'degrees of innovation' in the construction of this binary variable might explain the weak effects we find in models with few innovators and a large proportion of non-innovators.

A second reason for an alternative specification of financial constraints is that there might be a tendency among survey respondents to claim they faced some minor constraints in the availability of finance with respect to their innovation projects. If the relationship between true financial constraints and the observed ordinal survey item on financial constraints is not linear, results might differ depending on the cut-off threshold used for the binary indicator. We test this hypothesis by defining an alternative indicator for financial constraints, which equals zero for the *two* lowest categories in the survey item ("not applicable" and "low") and one for the two highest ones ("medium" and "high" financial constraints) instead of cutting below the "low" level.

Results for this alternative indicator for financial constraints support our main results for R&D (Table 8). Firms are more likely to be affected by financial constraints if they perform any R&D activity and internal R&D activities in particular. R&D expenditures in general do not cause financial constraints, although we now find a positive coefficient for expenditures on external R&D. Interestingly, the alternative definition of constraint leads to a slightly significant negative effect of being constrained on future external R&D activities, as is expected if constraints are binding.

Another interesting effect can instead be observed in our innovation models if we change the cut-off threshold (Table 9). Where innovation seemed to increase the likelihood of being financially constrained in the future, here these effects are reduced to insignificant levels. Innovation and constraints thus seem to be causally unrelated. How can this finding be reconciled with our previous results? A straightforward explanation can be derived if we allow for possible nonlinearity in the survey item's response scale. To see the effect of nonlinearity in the underlying (unobserved) financial constraint, consider the hypothesised relationships between survey responses and true constraints in Figure 1. If firms experiencing low financial constraints in the survey are almost unconstrained in reality (left panel), cutting the ordinal response scale at the 1/2 threshold maximises the difference between constrained and unconstrained firms in our binary dependent variable. Hence, we would expect to find an even stronger effect of innovation on constraints in our robustness test. This is not the case in our results. If, however, low financial constraints are closer to medium or high constraints (right panel), cutting at 0/1 would maximise the difference between groups. Since we do not find a stronger, but weaker, result for this alternative measure of constraints, the highest contrast between constrained and unconstrained firms must be in the lower region of the survey scale. This finding supports our choice for the construction of the financial constraints variable.

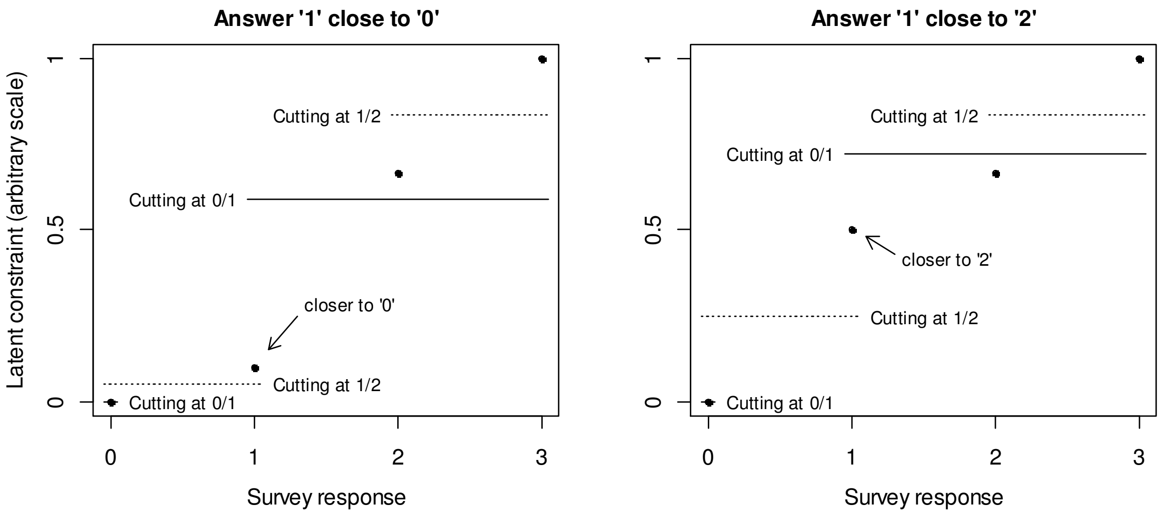

Figure 1. Effect of cutting ordinal financial constraints at different levels

This graph illustrates the effect of constructing a binary indicator for financial constraints from an ordinal survey item for two hypothetical unobserved relationships between the observed survey items and true (latent) financial constraints, which are represented by the black dots. The left panel shows a case in which true constraints at the "low" level ("1") are closer to those for the smallest answer ("0"). In this case, cutting between "1" and "2" maximises the mean difference between the constrained and unconstrained firms. Group means are represented by the red and blue horizontal lines. In the right panel, latent constraints at the "1" level are closer to those at the "medium" answer ("2"). Cutting between "0" and "1" maximises the mean difference. The first case is assumed in the robustness test, the latter in the main analysis.

Future research could address these issues of sample size and information content. An obvious improvement would be to increase sample size either in the time dimension or in the cross-section, although the UK sample is already fairly large compared to those available for most other countries that run Community Innovation Surveys. Adding future CIS waves would be highly desirable given that we are trying to estimate models with first order dynamics. This would not only increase the precision of coefficients for lagged variables, but also help us disentangle the direct effect of exogenous variables from their correlation with unobserved firm heterogeneity (in Wooldridge coefficients). While increasing sample size seems unlikely at least in the short term, increasing information extraction may be possible by refining the modelling strategy. Models could use the information contained the ordinal measure for financial constraints by estimating panel version of ordered response models.

Finally, even though we are able to construct a panel dataset and can take full account of endogeneity, one important limitation of CIS data is obviously that the information of firms' financial situation is limited compared to the wealth of information on R&D and innovation. This is important because the nature and scope of firm financial constraints is likely to vary together with the form of capital that might be demanded and supplied, and with the agents' ability to bridge information gaps in imperfect capital markets (Berger et al., 2001; Berger and Udell, 2006). Another avenue for further research could be the integration of a CDM framework with our modelling strategy, which would make it possible to control for the possible role of R&D in the relation between financial constraints and innovation.

7. Conclusion

This paper contributes to the debate on growth through innovation and on the problem of firms' limited access to capital markets by providing new and robust empirical evidence for the UK economy. We explore the nature and direction of the relationship between financial constraints and innovation in a longitudinal framework. To the best of our knowledge, this is the first paper on the relation between financial constraints and innovation that exploits the potential of the latest CIS panel. The CIS data cover small and non-listed firms, which are not included in existing studies on the cash-flow sensitivity of investment (for example, Carpenter and Petersen, 2002) and they provide direct information on the perception of financial constraints combined with detailed information on the innovative profile of firms (covering internal and external R&D, and innovation input and output). Hence, our results highlight new aspects of the UK innovation-finance landscape that cannot be easily observed through a traditional cash-flow sensitivity approach, which is usually tested on samples of listed large firms. To the best of our knowledge, this is also the first study that models the relation between financial constraints and innovation as a dynamic bivariate process capable of addressing the initial conditions problem through Wooldridge's (2005) method. This is a novel methodological contribution.

Our results contain no indications that past financial constraints affect R&D or innovation. While businesses might be affected by difficulties in raising finance in the short term, financing problems do not induce firms to stop their innovative activities. The reverse effect of R&D on financial constraints, which is expected from theory, can instead be clearly identified in our results. Interestingly, there is evidence that innovation, and in particular new-to-market and product innovation, cause financial constraints. This finding has especially important implications for policy: it highlights the fact that the financing challenges of innovation do not stop when firms introduce a new product or service, but continue – and may in fact intensify – in the early stages of diffusion. While support for the generation of new products may be vital in many sectors of the economy, support for early firm growth may be at least as important, in particular for SMEs, to build capacity and enable the full exploitation of their innovation activities.

In relation to the broader macroeconomic framework in which this study is set, time dummies reflect the impact of the recent financial crisis. Firms were significantly more often financially constrained during 2007-8 than in the preceding period. Financial pressure fell slightly after 2008, but remains high compared with pre-crisis years. While the crisis' effect can be found in concurrent time effects on financial constraints, investment in research and development lags the macroeconomic climate. Expenditures in R&D kept increasing until 2008 and only recently dropped below pre-crisis levels. This finding lends support to the theory that R&D investment becomes pro-cyclical when firms face tightening credit constraints (Aghion et al., 2012), even if the profiles of persistent innovators may generate heterogeneous behaviours (Archibugi et al., 2013).

The significant dynamic effects we find are only a fraction of the whole picture. R&D activities can explain financial constraints, but other firm characteristics correlated with innovation might offer richer insights into the causes of constraints. Unobserved heterogeneity as well as firm-year errors appear to be highly correlated, which explains implausible positive effects of financial constraints on innovation generated by simpler models. Future research could aim to address these hidden firm characteristics by collecting and merging additional information about firms' innovative capabilities and financial outlooks. Since innovation constraints as measured in Community Innovation Surveys might also capture financial distress, controlling for financial conditions can help separate financial distress from constraints caused by diverging internal and external cost of capital.

Identification of critical variables in the innovation process can help to address key difficulties through targeted policy measures for specific classes of firms. Our results suggest that while specific measures can be useful to alleviate the financial constraints of younger firms, support may be needed not only for formal R&D activities (typically covered by R&D tax credit schemes), but also informal R&D activities. Moreover, the costs of innovation are not limited to R&D expenditures but include a broader set of resource-intensive activities for successful innovators. Further research should focus on particular combinations of firm characteristics and the development through time of their innovation profiles in relation to their financial needs.

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ANNEXES

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Table 1. Descriptive statistics

This table shows summary statistics and definitions for the variables used in our analyses. Exact minimum, maximum and median values cannot be shown due to rules regulating statistical disclosure at the Secure Data Service/ONS. Instead, we provide frequency statistics for intervals containing the minimum and maximum under the "Min" and "Max" headings. The number of observations is the maximum number of observations for all time periods for panel variables (p) and cross-sectional variables (i). Due to missing variables in dependent variables, individual analyses may have slightly fewer observations. For independent variables, there are 2659 two-period panels and 559 three-period panels, 6995 observations in total. Dependent variables have more observations, since the first observation for each firm is used in lagged dependent variables.

Variable	Panel (p) or cross-section (i)	N	Min	Max	Mean	SD	Description
R&D internal (expend.)	p	10402	0	1	0.279		The firm's stated amount of internal R&D expenditures is positive in the last year of the survey period (e.g. in 2008 for the period 2006-2008). Dummy variable.
R&D external (expend.)	p	10402	0	1	0.104		The firm's stated amount of external R&D expenditures is positive in the last year of the survey period (e.g. in 2008 for the period 2006-2008). Dummy variable.
R&D any (expend.)	P	10402	0	1	0.296		The firm states positive internal or external R&D expenditures.
R&D internal (survey)	P	10266	0	1	0.345		The firm engaged in creative work on an occasional or regular basis to increase the stock of knowledge or used it to devise new and improved goods, services and processes. Dummy variable.
R&D external (survey)	P	10253	0	1	0.136		The firm engaged in external R&D activities; same as internal R&D, but purchased by the firm and performed by other companies (including other businesses within its group) or by public or private research organisations. Dummy variable.
R&D any (survey)	p	10259	0	1	0.363		The firm engaged in internal or external R&D activities.
Innovation new to market	P	10251	0	1	0.134		The firm introduced a new good or service onto the market before its competitors. Dummy variable.
Innovation new to firm	p	10249	0	1	0.128		The firm introduced a new good or service that was essentially the same as a product already available from its competitors. Dummy variable.
Innovation (good)	p	10382	0	1	0.190		The firm introduced new or significantly improved goods.
Innovation (process)	p	10385	0	1	0.186		The firm introduced any new or significantly improved processes for producing or supplying products.
Innovation (service)	p	10379	0	1	0.179		The firm introduced new or significantly improved services.
Fin. constraint	p	10258	0	1	0.511		The firm faced constraints in the availability of finance. This dummy variable is derived from the corresponding survey question "How important were the following factors as constraints on innovation activities in influencing a decision not to innovate?" All answers other than "Not experienced" are treated as being financially constrained.
Turnover (log)	p	6995	[0,7.5]	(9.5,18]	8.668	1.881	The firm's turnover in GBP (thousands, natural logarithm) for the last year of the survey period. This variable is lagged by one period. For a small number of firm, turnover was missing, but could be recovered from the corresponding entries in the Business Structure Database (BSD). Reading example: There are 2159 observation in the interval [0,7.5].
Observations in interval			2159	2185			
Market scope	p	6995	1	4	2.337	1.135	The largest geographic market in which a firm sells goods or services. Possible answers are 1="Local/regional within the UK", 2="UK", 3="Other Europe" and 4="All other countries".
Human capital	p	6995	[0]	(0.5,2]	0.137	0.237	The proportion of a firm's employees in the last year of the survey period that were educated to degree level or above. The maximum value is 2, since this variable adds the survey items "science or engineering subjects" and "other subjects". This variable is lagged by one period.
Observations in interval			2260	562			
Age (log)	i	6995	[0,2.5]	(3.8,4.1]	3.233	0.556	Firm age (natural logarithm) calculated as (2010 - birth year). Firm birth is censored at 1973 in the Business Structure Database. In order to avoid potential biases due to censored right-hand variables, we impute censored values using predicted values from a tobit regression of birth year on all other independent variables. This places many observations in the interval (3.8,4.1].
Observations in interval			796	1843			
Group member	i	6995	0	1	0.352		The firm is part of an enterprise group in the first period (CIS4). Dummy variable.
Company	i	6995	0	1	0.864		The firm has status "company" as opposed to sole proprietorship etc. in the Business Structure Database. Dummy variable.
Foreign ownership	i	6995	0	1	0.121		The firm is under foreign ownership (ultimately) in CIS5 (2004-2006). Dummy variable.
Sector: Construction	i	6995	0	1	0.076		SIC (1992, UK) codes beginning with: 45
Sector: Med./High-tech manuf.	i	6995	0	1	0.106		SIC (1992, UK) codes beginning with: 35, 24, 30, 32, 33, 31, 34, 29
Sector: Med./Low-tech manuf.	i	6995	0	1	0.221		SIC (1992, UK) codes beginning with: 25, 23, 26, 27, 28, 36, 37, 20, 21, 22, 15, 16, 17, 18, 19
Sector: Hotels, Restaurants	i	6995	0	1	0.055		SIC (1992, UK) codes beginning with: 55
Sector: Financial	i	6995	0	1	0.031		SIC (1992, UK) codes beginning with: 65, 67
Sector: R&D services	i	6995	0	1	0.031		SIC (1992, UK) codes beginning with: 72, 73
Sector: Other Services	i	6995	0	1	0.199		SIC (1992, UK) codes beginning with: 70, 71, 74, 90-99
Sector: Trade	i	6995	0	1	0.177		SIC (1992, UK) codes beginning with: 50-52
Sector: Transport	i	6995	0	1	0.082		SIC (1992, UK) codes beginning with: 60-63
Sector: Other	i	6995	0	1	0.021		SIC (1992, UK) codes beginning with: 10-14, 75, 80, 85 (Mining, Utilities, Education, Public Administration, Health)

Table 2. Transition matrices for dependent variables

This table shows the number of transitions between R&D and financial constraints states during the whole sample period. Each firm has two state variables that correspond to our dependent variables: whether it performs any research and development (or produces an innovation) and whether it experiences financial constraints in a given CIS round. For example, a firm can perform R&D and not experience financial constraint in period *t* ("Yes/No" in leftmost column) and transition to no R&D, but financial constraints in period t+1 (column "No/Yes"). This state transition would add one observation to the cell ("Yes/No", "No/Yes"). Cells represent the sum of all such transitions over all CIS rounds. The lower panel shows state transitions for the innovation variable that measures whether a firm produces any kind of innovation in period *t*.

Panel A	R&D (any) / Financial constraints in t+1				
R&D (any) / Financial constraints in t	No/No	No/Yes	Yes/No	Yes/Yes	Total
No/No	1626	689	215	273	2803
No/Yes	551	696	117	289	1653
Yes/No	179	119	236	312	846
Yes/Yes	224	300	187	937	1648
Total	2580	1804	755	1811	6950

Panel B	Innovation (any) / Financial constraints in t+1				
Innovation (any) / Financial constraints in t	No/No	No/Yes	Yes/No	Yes/Yes	Total
No/No	1669	736	185	261	2851
No/Yes	568	728	103	323	1722
Yes/No	236	153	205	253	847
Yes/Yes	268	364	164	812	1608
Total	2741	1981	657	1649	7028

Table 3. Research and Development - Simultaneous equations

This table presents results for bivariate panel probit models with six R&D measures and a financial constraints measure as dependent variables. All models are estimated using maximum simulated likelihood with 100 random draws and standard errors (in parentheses) based on the outer product of the matrix of contributions to the gradient. Intercepts and industry dummies are not shown. Wooldridge terms correspond to the coefficients in equation (3). Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Model	R&D any (expenditure)	R&D any (survey)	R&D external (expenditure)	R&D external (survey)	R&D internal (expenditure)	R&D internal (survey)
Dependent: R&D						
R&D (lag)	0.362 (0.089)***	0.378 (0.085)***	0.683 (0.071)***	0.372 (0.108)***	0.387 (0.092)***	0.398 (0.087)***
Fin. constraints (lag)	0.033 (0.071)	0.057 (0.067)	0.029 (0.082)	0.081 (0.076)	0.037 (0.070)	0.134 (0.067)**
Turnover (log) (lag)	-0.009 (0.043)	-0.085 (0.039)**	-0.028 (0.050)	0.013 (0.050)	-0.008 (0.045)	-0.093 (0.040)**
Market scope	0.031 (0.054)	0.076 (0.047)	0.051 (0.070)	0.064 (0.062)	0.027 (0.055)	0.089 (0.048)*
Human capital (lag)	0.028 (0.171)	0.016 (0.160)	-0.219 (0.192)	-0.154 (0.189)	0.101 (0.173)	0.026 (0.155)
Age (log)	0.027 (0.048)	0.001 (0.045)	-0.012 (0.045)	-0.056 (0.049)	0.013 (0.049)	0.006 (0.045)
Group member	-0.032 (0.059)	-0.035 (0.055)	0.051 (0.054)	0.021 (0.063)	-0.052 (0.061)	-0.071 (0.056)
Company	0.118 (0.086)	0.048 (0.077)	0.066 (0.086)	0.000 (0.093)	0.123 (0.088)	0.029 (0.078)
Foreign ownership	-0.297 (0.083)***	-0.170 (0.078)**	-0.040 (0.071)	0.037 (0.082)	-0.287 (0.086)***	-0.205 (0.079)***
Time dummy CIS6	0.111 (0.043)***	0.173 (0.042)***	-0.045 (0.050)	0.021 (0.048)	0.109 (0.044)**	0.185 (0.042)***
Time dummy CIS7	-0.189 (0.092)**	-0.250 (0.085)***	-0.085 (0.105)	-0.075 (0.106)	-0.231 (0.097)**	-0.293 (0.089)***
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Wooldridge terms						
R&D at t=0	0.892 (0.107)***	0.798 (0.100)***	0.499 (0.075)***	0.776 (0.120)***	0.910 (0.113)***	0.787 (0.102)***
Fin. constr. at t=0	0.198 (0.067)***	0.156 (0.062)**	0.089 (0.068)	0.077 (0.070)	0.190 (0.068)***	0.122 (0.063)*
Turnover (log), t0	-0.063 (0.022)***	-0.010 (0.020)	0.005 (0.022)	-0.022 (0.021)	-0.069 (0.022)***	-0.018 (0.021)
Turnover (log), t1	-0.030 (0.053)	0.056 (0.042)	0.005 (0.052)	0.024 (0.056)	-0.052 (0.054)	0.052 (0.042)
Turnover (log), t2	0.188 (0.046)***	0.127 (0.037)***	0.118 (0.041)***	0.109 (0.044)**	0.202 (0.049)***	0.137 (0.037)***
Market scope, t1	0.153 (0.048)***	0.106 (0.044)**	0.083 (0.054)	0.088 (0.053)*	0.162 (0.048)***	0.109 (0.045)**
Market scope, t2	0.076 (0.049)	0.059 (0.045)	0.008 (0.053)	0.025 (0.054)	0.086 (0.051)*	0.058 (0.046)
Market scope, t3	-0.001 (0.024)	-0.012 (0.023)	-0.020 (0.020)	-0.039 (0.024)	0.011 (0.025)	-0.001 (0.023)
Human capital, t0	-0.072 (0.160)	-0.159 (0.154)	0.179 (0.151)	0.160 (0.161)	-0.191 (0.163)	-0.215 (0.157)
Human capital, t1	0.079 (0.149)	0.106 (0.143)	0.075 (0.142)	0.037 (0.165)	0.041 (0.155)	0.073 (0.147)
Human capital, t2	0.669 (0.157)***	0.744 (0.152)***	0.271 (0.152)*	0.279 (0.170)	0.707 (0.165)***	0.806 (0.158)***
Dependent: Financial constraints						
R&D (lag)	0.106 (0.076)	0.175 (0.074)**	0.196 (0.101)*	0.181 (0.089)**	0.118 (0.077)	0.237 (0.077)***
Fin. constraints (lag)	0.382 (0.068)***	0.373 (0.069)***	0.339 (0.069)***	0.337 (0.070)***	0.406 (0.066)***	0.385 (0.070)***
Turnover (log) (lag)	0.013 (0.033)	-0.004 (0.033)	-0.006 (0.033)	0.004 (0.034)	0.009 (0.033)	-0.007 (0.034)
Market scope	0.041 (0.048)	0.040 (0.049)	0.040 (0.047)	0.032 (0.048)	0.041 (0.048)	0.040 (0.050)
Human capital (lag)	-0.279 (0.138)**	-0.302 (0.141)**	-0.289 (0.135)**	-0.290 (0.137)**	-0.280 (0.138)**	-0.323 (0.144)**
Age (log)	-0.076 (0.037)**	-0.078 (0.037)**	-0.080 (0.037)**	-0.084 (0.038)**	-0.078 (0.036)**	-0.077 (0.037)**
Group member	-0.032 (0.046)	-0.042 (0.046)	-0.041 (0.047)	-0.033 (0.048)	-0.037 (0.045)	-0.044 (0.047)
Company	0.102 (0.062)*	0.106 (0.062)*	0.109 (0.063)*	0.113 (0.064)*	0.093 (0.060)	0.099 (0.063)
Foreign ownership	-0.032 (0.069)	-0.035 (0.069)	-0.019 (0.070)	-0.023 (0.071)	-0.021 (0.068)	-0.014 (0.071)
Time dummy CIS6	0.665 (0.040)***	0.661 (0.040)***	0.657 (0.039)***	0.655 (0.040)***	0.664 (0.040)***	0.675 (0.042)***
Time dummy CIS7	0.556 (0.078)***	0.562 (0.080)***	0.560 (0.077)***	0.559 (0.078)***	0.553 (0.079)***	0.570 (0.082)***
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Wooldridge terms						
R&D at t=0	0.271 (0.068)***	0.237 (0.065)***	0.158 (0.092)*	0.074 (0.083)	0.251 (0.068)***	0.167 (0.067)**
Fin. constr. at t=0	0.439 (0.067)***	0.426 (0.066)***	0.483 (0.068)***	0.503 (0.070)***	0.423 (0.064)***	0.449 (0.069)***
Turnover (log), t0	-0.019 (0.017)	0.005 (0.016)	0.007 (0.017)	-0.013 (0.017)	-0.018 (0.017)	0.006 (0.017)
Turnover (log), t1	0.043 (0.036)	0.041 (0.037)	0.041 (0.036)	0.045 (0.037)	0.043 (0.036)	0.046 (0.037)
Turnover (log), t2	-0.007 (0.031)	-0.009 (0.031)	-0.007 (0.031)	0.001 (0.032)	-0.004 (0.030)	-0.011 (0.032)
Market scope, t1	0.054 (0.040)	0.055 (0.040)	0.063 (0.040)	0.065 (0.040)	0.054 (0.040)	0.058 (0.041)
Market scope, t2	-0.033 (0.042)	-0.038 (0.042)	-0.023 (0.042)	-0.015 (0.042)	-0.032 (0.041)	-0.033 (0.042)
Market scope, t3	-0.011 (0.020)	-0.012 (0.020)	-0.010 (0.020)	-0.012 (0.020)	-0.011 (0.019)	-0.017 (0.020)
Human capital, t0	0.113 (0.131)	0.124 (0.132)	0.139 (0.134)	0.123 (0.135)	0.103 (0.130)	0.144 (0.134)
Human capital, t1	0.284 (0.121)**	0.303 (0.122)**	0.289 (0.122)**	0.302 (0.123)**	0.296 (0.121)**	0.311 (0.124)**
Human capital, t2	0.265 (0.135)**	0.238 (0.138)*	0.305 (0.136)**	0.311 (0.138)**	0.262 (0.133)**	0.242 (0.139)*
Error correlation i,t	0.275 (0.044)***	0.303 (0.041)***	0.188 (0.053)***	0.242 (0.048)***	0.291 (0.044)***	0.364 (0.041)***
Error correlation i	0.402 (0.137)***	0.282 (0.141)**	0.346 (0.026)***	0.213 (0.156)	0.396 (0.135)***	0.121 (0.144)
SD random effect eq. A	0.716 (0.083)***	0.696 (0.080)***	0.120 (0.098)	0.569 (0.095)***	0.730 (0.086)***	0.700 (0.081)***
SD random effect eq. B	0.460 (0.073)***	0.450 (0.074)***	0.511 (0.069)***	0.514 (0.070)***	0.432 (0.073)***	0.451 (0.076)***
Observations	3218	3188	3189	3184	3218	3195
Log-Likelihood	-7227	-7491	-6089	-6386	-7108	-7431
Wald statistic	1988	2029	1946	1539	1960	1913
Wald p-value	0.000	0.000	0.000	0.000	0.000	0.000

Table 4. Innovation - Simultaneous equations

This table presents results for bivariate panel probit models with six innovation measures and a financial constraints measure as dependent variables. All models are estimated using maximum simulated likelihood with 100 random draws and standard errors (in parentheses) based on the outer product of the matrix of contributions to the gradient. Intercepts and industry dummies are not shown. Wooldridge terms correspond to the coefficients in equation (3). Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Model	Innovation any	Innovation new to market	Innovation new to firm	Innovation (good)	Innovation (processs)	Innovation (service)
Dependent: Innovation						
Innovation (lag)	0.465 (0.076)***	0.657 (0.105)***	0.451 (0.093)***	0.620 (0.092)***	0.484 (0.085)***	0.587 (0.079)***
Fin. constraints (lag)	0.105 (0.064)	0.006 (0.080)	0.104 (0.068)	0.074 (0.072)	0.068 (0.072)	0.065 (0.063)
Turnover (log) (lag)	-0.034 (0.038)	-0.019 (0.063)	-0.004 (0.050)	-0.044 (0.045)	0.009 (0.041)	-0.062 (0.043)
Market scope	0.124 (0.049)**	0.135 (0.069)**	0.018 (0.062)	0.052 (0.060)	0.097 (0.056)*	0.078 (0.053)
Human capital (lag)	-0.056 (0.144)	0.088 (0.217)	-0.080 (0.169)	0.021 (0.172)	-0.027 (0.178)	0.019 (0.163)
Age (log)	-0.034 (0.040)	-0.047 (0.053)	-0.010 (0.042)	-0.069 (0.045)	-0.040 (0.046)	-0.021 (0.041)
Group member	-0.085 (0.051)*	-0.076 (0.065)	0.005 (0.053)	-0.011 (0.056)	-0.105 (0.059)*	-0.145 (0.051)***
Company	-0.001 (0.066)	0.099 (0.098)	0.063 (0.077)	0.109 (0.086)	-0.066 (0.080)	0.111 (0.068)
Foreign ownership	0.037 (0.073)	0.026 (0.081)	0.013 (0.073)	0.015 (0.072)	0.016 (0.079)	-0.007 (0.070)
Time dummy CIS6	0.108 (0.039)***	0.346 (0.055)***	-0.042 (0.046)	0.054 (0.046)	0.033 (0.046)	-0.016 (0.043)
Time dummy CIS7	0.168 (0.079)**	0.286 (0.106)***	-0.003 (0.089)	0.049 (0.103)	0.072 (0.088)	0.001 (0.085)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Wooldridge terms						
Innovation at t=0	0.512 (0.081)***	0.699 (0.113)***	0.227 (0.087)***	0.596 (0.103)***	0.393 (0.087)***	0.429 (0.083)***
Fin. constr. at t=0	0.090 (0.058)	0.050 (0.071)	0.077 (0.061)	0.093 (0.063)	0.170 (0.065)***	0.075 (0.058)
Turnover (log), t0	-0.008 (0.017)	0.005 (0.021)	-0.022 (0.019)	0.027 (0.021)	-0.003 (0.019)	0.014 (0.021)
Turnover (log), t1	0.051 (0.044)	0.011 (0.071)	0.014 (0.056)	0.017 (0.050)	0.002 (0.051)	0.014 (0.048)
Turnover (log), t2	0.048 (0.034)	0.054 (0.052)	0.034 (0.039)	0.034 (0.039)	0.084 (0.040)**	0.078 (0.037)**
Market scope, t1	0.080 (0.041)*	0.007 (0.055)	0.086 (0.044)*	0.054 (0.049)	0.021 (0.043)	0.062 (0.043)
Market scope, t2	0.001 (0.044)	0.051 (0.059)	0.003 (0.050)	0.057 (0.051)	0.014 (0.051)	-0.012 (0.043)
Market scope, t3	-0.028 (0.020)	-0.022 (0.023)	-0.009 (0.021)	-0.018 (0.021)	-0.015 (0.022)	-0.028 (0.019)
Human capital, t0	0.092 (0.147)	0.010 (0.176)	0.195 (0.154)	0.133 (0.162)	-0.058 (0.160)	0.055 (0.141)
Human capital, t1	-0.037 (0.128)	-0.123 (0.190)	-0.099 (0.138)	-0.060 (0.141)	0.181 (0.150)	-0.077 (0.133)
Human capital, t2	0.375 (0.146)**	0.527 (0.183)***	0.078 (0.152)	0.221 (0.160)	0.214 (0.162)	0.462 (0.138)***
Dependent: Financial constraints						
Innovation (lag)	0.191 (0.069)***	0.267 (0.089)***	0.103 (0.080)	0.205 (0.086)**	0.100 (0.074)	0.129 (0.076)*
Fin. constraints (lag)	0.364 (0.067)***	0.347 (0.068)***	0.406 (0.069)***	0.445 (0.067)***	0.396 (0.067)***	0.350 (0.068)***
Turnover (log) (lag)	0.001 (0.032)	0.003 (0.032)	-0.003 (0.032)	-0.003 (0.032)	0.006 (0.032)	0.007 (0.032)
Market scope	0.042 (0.048)	0.033 (0.047)	0.037 (0.048)	0.043 (0.047)	0.039 (0.047)	0.038 (0.047)
Human capital (lag)	-0.286 (0.139)**	-0.287 (0.134)**	-0.274 (0.135)**	-0.272 (0.135)**	-0.292 (0.136)**	-0.274 (0.136)**
Age (log)	-0.074 (0.037)**	-0.081 (0.036)**	-0.080 (0.036)**	-0.075 (0.035)**	-0.079 (0.035)**	-0.081 (0.037)**
Group member	-0.040 (0.046)	-0.030 (0.046)	-0.035 (0.045)	-0.040 (0.044)	-0.043 (0.045)	-0.038 (0.046)
Company	0.113 (0.063)*	0.102 (0.061)*	0.111 (0.061)*	0.096 (0.059)	0.120 (0.060)**	0.103 (0.063)
Foreign ownership	-0.023 (0.069)	-0.025 (0.068)	-0.014 (0.068)	-0.021 (0.065)	-0.022 (0.067)	-0.012 (0.069)
Time dummy CIS6	0.677 (0.041)***	0.661 (0.039)***	0.649 (0.039)***	0.653 (0.040)***	0.654 (0.039)***	0.652 (0.039)***
Time dummy CIS7	0.584 (0.079)***	0.555 (0.077)***	0.538 (0.077)***	0.535 (0.078)***	0.541 (0.078)***	0.553 (0.077)***
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Wooldridge terms						
Innovation at t=0	0.104 (0.061)*	0.070 (0.078)	-0.034 (0.074)	0.091 (0.077)	0.116 (0.063)*	0.055 (0.071)
Fin. constr. at t=0	0.448 (0.066)***	0.469 (0.067)***	0.443 (0.067)***	0.401 (0.065)***	0.432 (0.065)***	0.473 (0.067)***
Turnover (log), t0	0.003 (0.016)	0.004 (0.016)	0.002 (0.016)	0.005 (0.015)	0.000 (0.016)	0.003 (0.016)
Turnover (log), t1	0.044 (0.036)	0.041 (0.035)	0.048 (0.035)	0.038 (0.035)	0.040 (0.035)	0.045 (0.036)
Turnover (log), t2	-0.014 (0.031)	-0.011 (0.030)	-0.011 (0.030)	-0.004 (0.029)	-0.013 (0.030)	-0.014 (0.031)
Market scope, t1	0.052 (0.040)	0.057 (0.039)	0.061 (0.039)	0.049 (0.038)	0.054 (0.038)	0.064 (0.040)
Market scope, t2	-0.027 (0.042)	-0.019 (0.041)	-0.014 (0.041)	-0.027 (0.040)	-0.017 (0.041)	-0.027 (0.042)
Market scope, t3	-0.014 (0.019)	-0.012 (0.019)	-0.015 (0.019)	-0.009 (0.018)	-0.014 (0.019)	-0.014 (0.020)
Human capital, t0	0.132 (0.132)	0.161 (0.130)	0.172 (0.128)	0.156 (0.127)	0.155 (0.129)	0.168 (0.130)
Human capital, t1	0.284 (0.123)**	0.290 (0.121)**	0.275 (0.120)**	0.266 (0.117)**	0.315 (0.119)***	0.287 (0.122)**
Human capital, t2	0.315 (0.133)**	0.254 (0.134)*	0.280 (0.131)**	0.286 (0.126)**	0.289 (0.129)**	0.271 (0.134)**
Error correlation i,t	0.270 (0.039)***	0.103 (0.050)**	0.233 (0.040)***	0.267 (0.044)***	0.223 (0.043)***	0.182 (0.040)***
Error correlation i	0.378 (0.141)***	0.410 (0.176)**	0.125 (0.242)	0.093 (0.273)	0.509 (0.151)***	0.441 (0.173)**
SD random effect eq. A	0.554 (0.073)***	0.498 (0.101)***	0.311 (0.104)***	0.394 (0.104)***	0.575 (0.083)***	0.359 (0.091)***
SD random effect eq. B	0.474 (0.070)***	0.484 (0.070)***	0.443 (0.075)***	0.380 (0.081)***	0.441 (0.071)***	0.495 (0.069)***
Observations	3208	3179	3177	3212	3214	3209
Log-Likelihood	-7693	-6024	-6587	-6599	-6820	-7010
Wald statistic	2044	1765	1161	2094	1792	1927
Wald p-value	0.000	0.000	0.000	0.000	0.000	0.000

Table 5. Research and Development - Panel Probit Models

This table presents random effects probit models for six R&D measures and financial constraints as dependent variables. Heteroskedasticity-robust standard errors are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Model	R&D any (expend.)		R&D any (survey)		R&D external (expend.)		R&D external (survey)		R&D internal (expend.)		R&D internal (survey)		Financial constraints	
R&D any (expend.) (lag)	1.052	(0.04)***											0.320	(0.04)***
R&D any (survey) (lag)			0.997	(0.04)***										
R&D external (expend.) (lag)					1.005	(0.06)***								
R&D external (survey) (lag)							0.962	(0.05)***						
R&D internal (expend.) (lag)									1.087	(0.04)***				
R&D internal (survey) (lag)											1.018	(0.04)***		
Fin. constraints (lag)	0.164	(0.04)***	0.153	(0.04)***	0.121	(0.05)***	0.138	(0.04)***	0.155	(0.04)***	0.154	(0.04)***	0.684	(0.03)***
Turnover (log) (lag)	0.061	(0.01)***	0.059	(0.01)***	0.084	(0.01)***	0.091	(0.01)***	0.053	(0.01)***	0.052	(0.01)***	0.024	(0.01)**
Market scope	0.199	(0.02)***	0.190	(0.02)***	0.144	(0.02)***	0.142	(0.02)***	0.206	(0.02)***	0.199	(0.02)***	0.056	(0.02)***
Human capital (lag)	0.307	(0.08)***	0.261	(0.08)***	0.148	(0.10)	0.134	(0.09)	0.289	(0.08)***	0.248	(0.08)***	0.099	(0.08)
Age (log)	-0.017	(0.03)	-0.023	(0.03)	-0.032	(0.04)	-0.073	(0.04)*	-0.021	(0.04)	-0.019	(0.03)	-0.088	(0.03)***
Group member	-0.013	(0.04)	-0.019	(0.04)	0.086	(0.05)	0.047	(0.05)	-0.031	(0.04)	-0.041	(0.04)	-0.029	(0.04)
Company	0.101	(0.06)	0.052	(0.06)	0.061	(0.08)	-0.011	(0.07)	0.111	(0.06)*	0.056	(0.06)	0.075	(0.05)
Foreign ownership	-0.182	(0.06)***	-0.078	(0.06)	-0.040	(0.07)	0.025	(0.06)	-0.176	(0.06)***	-0.103	(0.06)*	0.011	(0.06)
Sector: Construction	-0.151	(0.14)	-0.340	(0.13)***	-0.359	(0.17)**	-0.411	(0.15)***	-0.106	(0.14)	-0.325	(0.13)**	-0.111	(0.12)
Sector: Financial	0.188	(0.15)	0.135	(0.14)	-0.008	(0.18)	-0.074	(0.16)	0.186	(0.15)	0.141	(0.14)	-0.388	(0.14)***
Sector: Hotels, Restaurants	-0.225	(0.15)	-0.278	(0.14)**	-0.313	(0.18)*	-0.374	(0.16)**	-0.208	(0.15)	-0.292	(0.14)**	-0.184	(0.13)
Sector: R&D services	0.445	(0.16)***	0.311	(0.15)**	-0.037	(0.18)	-0.089	(0.17)	0.498	(0.16)***	0.329	(0.15)**	-0.050	(0.15)
Sector: Med./High-tech manuf.	0.341	(0.13)**	0.188	(0.12)	0.022	(0.15)	-0.049	(0.14)	0.382	(0.13)***	0.198	(0.13)	0.132	(0.12)
Sector: Med./Low-tech manuf.	0.215	(0.13)*	0.078	(0.12)	-0.091	(0.14)	-0.144	(0.13)	0.248	(0.13)*	0.080	(0.12)	0.228	(0.11)**
Sector: Other Services	-0.047	(0.13)	-0.170	(0.12)	-0.202	(0.14)	-0.258	(0.13)*	-0.018	(0.13)	-0.150	(0.12)	-0.049	(0.11)
Sector: Trade	-0.216	(0.13)*	-0.317	(0.12)***	-0.283	(0.14)*	-0.401	(0.13)***	-0.231	(0.13)*	-0.325	(0.12)***	-0.129	(0.12)
Sector: Transport	-0.211	(0.14)	-0.324	(0.13)**	-0.390	(0.16)**	-0.481	(0.15)***	-0.167	(0.14)	-0.302	(0.13)**	0.017	(0.12)
Time dummy CIS6	0.080	(0.04)**	0.108	(0.04)***	-0.088	(0.05)*	-0.017	(0.04)	0.078	(0.04)**	0.110	(0.04)***	0.591	(0.03)***
Time dummy CIS7	-0.185	(0.07)**	-0.290	(0.07)***	-0.150	(0.08)*	-0.153	(0.08)*	-0.197	(0.07)***	-0.298	(0.07)***	0.423	(0.06)***
Intercept	-2.127	(0.19)***	-1.702	(0.17)***	-2.415	(0.23)***	-2.090	(0.21)***	-2.144	(0.19)***	-1.717	(0.18)***	-0.794	(0.16)***
Std.dev. (u_i)	0.002		0.002		0.002		0.002		0.003		0.003		0.002	
P-value for u_i	0.490		0.491		0.494		0.491		0.488		0.490		0.491	
Observations	6872		6872		6872		6872		6872		6872		6872	
Log-Likelihood	-3154		-3497		-1917		-2284		-3033		-3424		-4159	
Chi-sq. test	1727		1745		686		822		1741		1745		1079	
P-value	0.000		0.000		0.000		0.000		0.000		0.000		0.000	

Table 6. Innovation - Panel Probit Models

This table presents random effects probit models for six innovation measures and financial constraints as dependent variables. Heteroskedasticity-robust standard errors are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Model	Innovation any	Innovation new to market	Innovation new to firm	Innovation (good)	Innovation (processs)	Innovation (service)	Financial constraints
Innovation (any) (lag)	0.865 (0.04)***						0.294 (0.04)***
Innovation new to market (lag)		1.178 (0.05)***					
Innovation new to firm (lag)			0.646 (0.05)***				
Innovation (good) (lag)				1.048 (0.05)***			
Innovation (process) (lag)					0.796 (0.05)***		
Innovation (service) (lag)						0.873 (0.04)***	
Fin. constraints (lag)	0.194 (0.04)***	0.137 (0.05)***	0.156 (0.04)***	0.112 (0.04)***	0.238 (0.04)***	0.186 (0.04)***	0.682 (0.03)***
Turnover (log) (lag)	0.038 (0.01)***	0.033 (0.02)**	0.023 (0.01)*	0.026 (0.01)*	0.069 (0.01)***	0.023 (0.01)*	0.024 (0.01)**
Market scope	0.175 (0.02)***	0.179 (0.02)***	0.085 (0.02)***	0.151 (0.02)***	0.126 (0.02)***	0.118 (0.02)***	0.061 (0.02)***
Human capital (lag)	0.129 (0.08)	0.206 (0.10)**	0.031 (0.09)	0.182 (0.09)*	0.114 (0.09)	0.215 (0.08)**	0.106 (0.08)
Age (log)	-0.043 (0.03)	-0.070 (0.04)	-0.016 (0.04)	-0.080 (0.04)**	-0.042 (0.04)	-0.036 (0.04)	-0.081 (0.03)***
Group member	-0.046 (0.04)	-0.047 (0.05)	0.016 (0.05)	0.026 (0.05)	-0.078 (0.05)	-0.103 (0.05)**	-0.029 (0.04)
Company	-0.012 (0.06)	0.060 (0.08)	0.047 (0.07)	0.097 (0.08)	-0.068 (0.07)	0.095 (0.06)	0.091 (0.05)*
Foreign ownership	0.047 (0.06)	0.034 (0.07)	-0.011 (0.07)	0.009 (0.06)	0.032 (0.07)	0.008 (0.06)	0.011 (0.06)
Sector: Construction	-0.372 (0.13)***	-0.592 (0.19)***	-0.084 (0.16)	-0.012 (0.17)	-0.722 (0.16)***	-0.351 (0.14)**	-0.108 (0.12)
Sector: Financial	0.021 (0.14)	-0.156 (0.19)	0.273 (0.17)	-0.181 (0.19)	-0.069 (0.16)	0.066 (0.15)	-0.382 (0.14)***
Sector: Hotels, Restaurants	-0.255 (0.14)*	-0.443 (0.19)**	-0.081 (0.16)	-0.051 (0.17)	-0.573 (0.16)***	-0.180 (0.14)	-0.189 (0.13)
Sector: R&D services	0.122 (0.15)	-0.022 (0.18)	0.160 (0.17)	0.319 (0.18)*	-0.046 (0.16)	0.176 (0.15)	-0.037 (0.15)
Sector: Med./High-tech manuf.	0.125 (0.12)	0.146 (0.15)	0.036 (0.15)	0.625 (0.15)***	-0.058 (0.14)	-0.383 (0.13)***	0.142 (0.12)
Sector: Med./Low-tech manuf.	0.063 (0.12)	-0.001 (0.15)	0.088 (0.14)	0.516 (0.15)***	-0.078 (0.13)	-0.372 (0.12)***	0.225 (0.11)**
Sector: Other Services	-0.168 (0.12)	-0.263 (0.15)*	0.001 (0.14)	-0.329 (0.16)**	-0.336 (0.13)**	-0.096 (0.12)	-0.058 (0.11)
Sector: Trade	-0.220 (0.12)*	-0.287 (0.15)*	-0.089 (0.14)	0.021 (0.15)	-0.463 (0.14)***	-0.245 (0.13)*	-0.134 (0.12)
Sector: Transport	-0.242 (0.13)*	-0.323 (0.17)*	0.030 (0.15)	-0.257 (0.17)	-0.506 (0.15)***	-0.151 (0.13)	0.004 (0.12)
Time dummy CIS6	0.091 (0.04)**	0.354 (0.05)***	-0.047 (0.04)	0.012 (0.04)	0.033 (0.04)	-0.057 (0.04)	0.605 (0.03)***
Time dummy CIS7	0.093 (0.07)	0.213 (0.09)**	-0.052 (0.08)	-0.037 (0.08)	0.042 (0.08)	-0.106 (0.07)	0.447 (0.06)***
Intercept	-1.460 (0.17)***	-2.180 (0.23)***	-1.741 (0.21)***	-1.918 (0.22)***	-1.807 (0.21)***	-1.430 (0.19)***	-0.854 (0.16)***
Std.dev. (u)	0.003	0.002	0.022	0.001	0.263	0.002	0.002
P-value for u	0.489	0.493	0.492	0.494	0.083	0.493	0.493
Observations	6872	6872	6872	6872	6872	6872	6872
Log-Likelihood	-3592	-1931	-2465	-2413	-2645	-2839	-4161
Chi-sq. test	1337	1001	288	1463	799	719	1077
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 7. Research and Development – Bivariate probit models

This table presents bivariate probit models for six R&D measures and financial constraints as dependent variables. The rightmost column shows results for the financial constraints equation in the model presented in the first column ("R&D any (expend.)"). Estimation results for financial constraints equations corresponding to the remaining R&D measures are not shown, as they are quantitatively and qualitatively similar. Heteroskedasticity-robust standard errors are in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Model	R&D any (expend.)	R&D any (survey)	R&D external (expend.)	R&D external (survey)	R&D internal (expend.)	R&D internal (survey)	Financial constraints
R&D any (expend.) (lag)	0.758 (0.05)***						0.211 (0.05)***
R&D any (survey) (lag)		0.761 (0.05)***					
R&D external (expend.) (lag)			0.692 (0.07)***				
R&D external (survey) (lag)				0.666 (0.06)***			
R&D internal (expend.) (lag)					0.795 (0.05)***		
R&D internal (survey) (lag)						0.798 (0.05)***	
Fin. constraints (lag)	0.111 (0.05)**	0.090 (0.04)**	0.098 (0.06)*	0.116 (0.05)**	0.105 (0.05)**	0.099 (0.04)**	0.533 (0.04)***
Turnover (log) (lag)	-0.034 (0.04)	-0.079 (0.04)**	-0.029 (0.04)	-0.014 (0.04)	-0.031 (0.04)	-0.084 (0.04)**	-0.006 (0.03)
Market scope	0.032 (0.05)	0.077 (0.05)	0.052 (0.06)	0.070 (0.06)	0.028 (0.05)	0.087 (0.05)*	0.043 (0.04)
Human capital (lag)	-0.026 (0.15)	-0.038 (0.15)	-0.228 (0.18)	-0.161 (0.17)	0.037 (0.15)	-0.032 (0.15)	-0.277 (0.14)**
Age (log)	0.006 (0.03)	-0.001 (0.03)	-0.013 (0.04)	-0.054 (0.04)	-0.001 (0.03)	0.000 (0.03)	-0.075 (0.03)**
Group member	-0.034 (0.04)	-0.038 (0.04)	0.052 (0.05)	0.013 (0.05)	-0.059 (0.04)	-0.064 (0.04)	-0.031 (0.04)
Company	0.087 (0.06)	0.039 (0.06)	0.064 (0.09)	-0.002 (0.08)	0.093 (0.07)	0.037 (0.06)	0.082 (0.05)
Foreign ownership	-0.234 (0.06)***	-0.124 (0.06)**	-0.043 (0.07)	0.029 (0.06)	-0.221 (0.06)***	-0.145 (0.06)**	-0.028 (0.06)
Time dummy CIS6	0.120 (0.04)***	0.153 (0.04)***	-0.037 (0.05)	0.037 (0.04)	0.117 (0.04)***	0.159 (0.04)***	0.609 (0.03)***
Time dummy CIS7	-0.155 (0.08)**	-0.229 (0.07)***	-0.090 (0.09)	-0.055 (0.08)	-0.183 (0.08)**	-0.252 (0.07)***	0.473 (0.07)***
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wooldridge terms							
R&D at t=0	0.430 (0.05)***	0.372 (0.05)***	0.484 (0.07)***	0.459 (0.06)***	0.424 (0.05)***	0.346 (0.05)***	0.158 (0.05)***
Fin. Constraints at t=0	0.096 (0.04)**	0.088 (0.04)**	0.048 (0.06)	0.038 (0.05)	0.099 (0.05)**	0.090 (0.04)**	0.262 (0.04)***
Turnover (log), t0	-0.016 (0.01)	-0.007 (0.01)	0.005 (0.02)	0.008 (0.02)	-0.020 (0.01)	-0.011 (0.01)	0.005 (0.01)
Turnover (log), t1	-0.020 (0.04)	0.048 (0.04)	0.006 (0.04)	0.024 (0.04)	-0.036 (0.04)	0.044 (0.04)	0.037 (0.03)
Turnover (log), t2	0.138 (0.03)***	0.107 (0.03)***	0.117 (0.04)***	0.089 (0.03)**	0.145 (0.03)***	0.112 (0.03)***	-0.010 (0.03)
Market scope, t1	0.108 (0.04)***	0.070 (0.04)*	0.080 (0.04)*	0.065 (0.04)	0.115 (0.04)***	0.068 (0.04)*	0.039 (0.03)
Market scope, t2	0.059 (0.04)	0.041 (0.04)	0.008 (0.05)	0.010 (0.05)	0.066 (0.04)	0.039 (0.04)	-0.036 (0.03)
Market scope, t3	-0.002 (0.02)	-0.011 (0.02)	-0.020 (0.02)	-0.033 (0.02)*	0.004 (0.02)	-0.002 (0.02)	-0.011 (0.02)
Human capital, t0	-0.021 (0.12)	-0.099 (0.12)	0.185 (0.16)	0.173 (0.14)	-0.111 (0.12)	-0.142 (0.12)	0.115 (0.12)
Human capital, t1	0.091 (0.11)	0.106 (0.11)	0.077 (0.14)	0.039 (0.13)	0.049 (0.11)	0.084 (0.11)	0.257 (0.10)**
Human capital, t2	0.499 (0.12)***	0.561 (0.12)***	0.261 (0.14)*	0.232 (0.13)*	0.525 (0.12)***	0.612 (0.12)***	0.217 (0.11)*
Intercept	-2.385 (0.19)***	-1.987 (0.19)***	-2.727 (0.23)***	-2.395 (0.21)***	-2.379 (0.20)***	-1.971 (0.19)***	-0.961 (0.17)***
Fin. constraints equation	See rightmost column	not shown	not shown	not shown	not shown	not shown	
Observations	6995	6928	6995	6916	6995	6942	
Log-Likelihood	-7249	-7511	-6100	-6406	-7129	-7456	
Wald statistic	2765	2799	1821	1898	2775	2780	
P-value	0.000	0.000	0.000	0.000	0.000	0.000	
Rho	0.311	0.309	0.220	0.248	0.314	0.314	
Wald statistic for rho	170.736	186.642	52.200	78.083	167.800	189.599	
P-value	0.000	0.000	0.000	0.000	0.000	0.000	

Table 8. Alternative specification of financial constraints – R&D models

This table presents results for bivariate panel probit models corresponding to table 3. Results for the R&D equation is not shown, as these are qualitatively identical to those in the main tables. Financial constraints as the binary dependent variable are derived from the survey measure by cutting the ordinal scale between "low" and "medium" financial constraints, not below the "low" level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Model	R&D any (expenditure)	R&D any (activity)	R&D external (expenditure)	R&D external (activity)	R&D internal (expenditure)	R&D internal (activity)
Dependent: Financial constraints; R&D equation not shown						
R&D (lag)	0.028 (0.074)	0.211 (0.077)***	0.299 (0.091)***	0.122 (0.088)	0.007 (0.076)	0.189 (0.077)**
Fin. constraints (lag)	0.454 (0.071)***	0.487 (0.072)***	0.518 (0.067)***	0.490 (0.072)***	0.457 (0.071)***	0.534 (0.063)***
Turnover (log)	0.043 (0.038)	0.044 (0.039)	0.043 (0.038)	0.045 (0.038)	0.043 (0.038)	0.043 (0.038)
Market scope	0.100 (0.050)**	0.106 (0.052)**	0.105 (0.051)**	0.096 (0.051)*	0.099 (0.050)**	0.105 (0.051)**
Human capital	-0.258 (0.142)*	-0.295 (0.146)**	-0.278 (0.143)*	-0.277 (0.143)*	-0.257 (0.141)*	-0.299 (0.145)**
Age (log)	-0.110 (0.036)***	-0.108 (0.036)***	-0.113 (0.035)***	-0.112 (0.036)***	-0.111 (0.036)***	-0.106 (0.035)***
Group member	-0.097 (0.046)**	-0.106 (0.047)**	-0.097 (0.045)**	-0.101 (0.046)**	-0.100 (0.047)**	-0.102 (0.045)**
Company	0.084 (0.063)	0.098 (0.064)	0.087 (0.062)	0.104 (0.063)*	0.082 (0.063)	0.088 (0.062)
Foreign ownership	-0.003 (0.066)	-0.001 (0.067)	0.002 (0.065)	0.002 (0.066)	-0.002 (0.066)	0.002 (0.065)
Time dummy CIS6	0.556 (0.040)***	0.560 (0.041)***	0.559 (0.040)***	0.553 (0.040)***	0.555 (0.040)***	0.557 (0.041)***
Time dummy CIS7	0.458 (0.077)***	0.465 (0.079)***	0.455 (0.078)***	0.459 (0.078)***	0.457 (0.077)***	0.458 (0.079)***
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Wooldridge terms						
R&D in t=0	0.131 (0.064)**	0.061 (0.062)	-0.097 (0.079)	-0.012 (0.075)	0.167 (0.066)**	0.086 (0.062)
Financial constraints in t=0	0.503 (0.070)***	0.482 (0.070)***	0.469 (0.067)***	0.483 (0.070)***	0.500 (0.070)***	0.442 (0.062)***
Size (log(turnover)), Lag, t1	-0.002 (0.015)	-0.001 (0.015)	-0.001 (0.015)	-0.003 (0.015)	-0.001 (0.015)	0.001 (0.015)
Size (log(turnover)), Lag, t2	0.020 (0.039)	0.022 (0.041)	0.019 (0.039)	0.021 (0.039)	0.020 (0.039)	0.022 (0.040)
Size (log(turnover)), Lag, t3	-0.069 (0.030)**	-0.074 (0.031)**	-0.070 (0.030)**	-0.071 (0.030)**	-0.068 (0.030)**	-0.073 (0.030)**
Market scope, t1	0.022 (0.037)	0.014 (0.038)	0.020 (0.037)	0.023 (0.038)	0.022 (0.037)	0.014 (0.037)
Market scope, t2	-0.094 (0.044)**	-0.103 (0.045)**	-0.090 (0.044)**	-0.085 (0.044)*	-0.093 (0.044)**	-0.101 (0.044)**
Market scope, t3	-0.027 (0.019)	-0.027 (0.019)	-0.026 (0.018)	-0.026 (0.019)	-0.027 (0.019)	-0.028 (0.018)
Human capital, Lag, t1	0.052 (0.129)	0.054 (0.131)	0.080 (0.129)	0.083 (0.129)	0.047 (0.128)	0.060 (0.127)
Human capital, Lag, t2	0.235 (0.122)*	0.267 (0.123)**	0.251 (0.120)**	0.261 (0.121)**	0.237 (0.121)*	0.264 (0.120)**
Human capital, Lag, t2	0.086 (0.135)	0.043 (0.138)	0.082 (0.133)	0.081 (0.135)	0.083 (0.134)	0.045 (0.133)
Error correlation i,t	0.070 (0.045)	0.232 (0.044)***	0.213 (0.048)***	0.146 (0.051)***	0.079 (0.047)*	0.236 (0.045)***
Error correlation i	0.440 (0.187)**	-0.128 (0.262)	-0.312 (0.480)	0.387 (0.343)	0.390 (0.189)**	-0.286 (0.426)
SD random effect eq. A	0.724 (0.083)***	0.715 (0.080)***	-0.420 (0.109)***	-0.557 (0.102)***	0.766 (0.086)***	0.732 (0.082)***
SD random effect eq. B	0.316 (0.027)***	0.267 (0.027)***	0.213 (0.023)***	0.274 (0.027)***	0.314 (0.027)***	0.175 (0.020)***
Model statistics						
Log-Likelihood	-6639.610	-6908.922	-5422.919	-5734.777	-6513.938	-6850.619
Observations	3218	3188	3218	3184	3218	3184
Wald statistic	1821.185	1785.845	1289.600	1416.538	1744.472	1812.716
Wald df	66	66	66	66	66	66
Wald P	0.000	0.000	0.000	0.000	0.000	0.000

Table 9. Alternative specification of financial constraints – Innovation models
This table presents results for bivariate panel probit models corresponding to table 4. Results for the innovation equation is not shown, as these are qualitatively identical to those in the main tables. Financial constraints as the binary dependent variable are derived from the survey measure by cutting the ordinal scale between "low" and "medium" financial constraints, not below the "low" level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Model	Innovation any	Innovation new to market	Innovation new to firm	Innovation (good)	Innovation (processs)	Innovation (service)
Dependent: Financial constraints; innovation equation not shown						
Innovation (lag)	0.052 (0.071)	0.114 (0.086)	-0.077 (0.084)	0.080 (0.086)	0.071 (0.075)	0.073 (0.078)
Fin. constraints (lag)	0.436 (0.074)***	0.511 (0.063)***	0.475 (0.075)***	0.480 (0.073)***	0.495 (0.068)***	0.433 (0.074)***
Turnover (log)	0.050 (0.038)	0.047 (0.037)	0.043 (0.038)	0.048 (0.037)	0.050 (0.037)	0.053 (0.038)
Market scope	0.107 (0.051)**	0.101 (0.050)**	0.103 (0.051)**	0.109 (0.051)**	0.101 (0.050)**	0.109 (0.052)**
Human capital	-0.261 (0.144)*	-0.266 (0.140)*	-0.260 (0.142)*	-0.248 (0.142)*	-0.254 (0.141)*	-0.263 (0.144)*
Age (log)	-0.108 (0.037)***	-0.106 (0.035)***	-0.110 (0.036)***	-0.106 (0.036)***	-0.111 (0.035)***	-0.113 (0.037)***
Group member	-0.101 (0.047)**	-0.103 (0.044)**	-0.104 (0.047)**	-0.104 (0.046)**	-0.095 (0.045)**	-0.100 (0.048)**
Company	0.104 (0.065)	0.099 (0.061)	0.107 (0.065)*	0.092 (0.063)	0.095 (0.062)	0.101 (0.066)
Foreign ownership	0.000 (0.068)	0.006 (0.064)	-0.001 (0.067)	0.000 (0.066)	0.001 (0.064)	0.002 (0.068)
Time dummy CIS6	0.565 (0.041)***	0.556 (0.039)***	0.560 (0.040)***	0.560 (0.040)***	0.554 (0.040)***	0.559 (0.040)***
Time dummy CIS7	0.478 (0.079)***	0.452 (0.077)***	0.464 (0.079)***	0.456 (0.079)***	0.456 (0.078)***	0.470 (0.078)***
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Wooldridge terms						
R&D in t=0	0.095 (0.059)	0.064 (0.073)	0.048 (0.072)	0.108 (0.073)	0.059 (0.061)	0.052 (0.069)
Financial constraints in t=0	0.521 (0.072)***	0.447 (0.061)***	0.500 (0.074)***	0.490 (0.071)***	0.468 (0.066)***	0.526 (0.073)***
Size (log(turnover)), Lag, t1	-0.004 (0.016)	-0.005 (0.014)	-0.005 (0.015)	-0.004 (0.015)	-0.004 (0.015)	-0.004 (0.016)
Size (log(turnover)), Lag, t2	0.020 (0.040)	0.015 (0.038)	0.023 (0.040)	0.020 (0.039)	0.018 (0.039)	0.022 (0.040)
Size (log(turnover)), Lag, t3	-0.075 (0.031)**	-0.062 (0.029)**	-0.064 (0.031)**	-0.070 (0.030)**	-0.072 (0.030)**	-0.075 (0.031)**
Market scope, t1	0.019 (0.038)	0.019 (0.036)	0.026 (0.038)	0.016 (0.038)	0.020 (0.037)	0.021 (0.038)
Market scope, t2	-0.092 (0.045)**	-0.091 (0.043)**	-0.085 (0.045)*	-0.096 (0.044)**	-0.084 (0.044)*	-0.093 (0.045)**
Market scope, t3	-0.030 (0.019)	-0.026 (0.018)	-0.031 (0.019)	-0.027 (0.019)	-0.030 (0.018)	-0.029 (0.019)
Human capital, Lag, t1	0.048 (0.130)	0.067 (0.124)	0.079 (0.129)	0.067 (0.127)	0.066 (0.124)	0.070 (0.130)
Human capital, Lag, t2	0.249 (0.123)**	0.236 (0.116)**	0.235 (0.121)*	0.233 (0.120)*	0.243 (0.118)**	0.249 (0.124)**
Human capital, Lag, t2	0.095 (0.137)	0.034 (0.129)	0.069 (0.137)	0.087 (0.133)	0.085 (0.130)	0.077 (0.138)
Error correlation i,t	0.149 (0.043)***	0.017 (0.049)	0.128 (0.042)***	0.161 (0.047)***	0.096 (0.045)**	0.122 (0.045)***
Error correlation i	0.344 (0.253)	0.643 (0.239)***	0.313 (0.438)	0.167 (0.366)	0.480 (0.312)	0.373 (0.234)
SD random effect eq. A	0.505 (0.076)***	0.466 (0.110)***	0.330 (0.104)***	0.409 (0.108)***	0.524 (0.087)***	0.510 (0.086)***
SD random effect eq. B	0.348 (0.030)***	0.210 (0.020)***	0.312 (0.030)***	0.288 (0.028)***	0.248 (0.024)***	0.355 (0.031)***
Model statistics						
Log-Likelihood	-7106.110	-5361.254	-5915.784	-5943.039	-6201.673	-6358.396
Observations	3208	3179	3177	3212	3214	3209
Wald statistic	1816.683	1586.352	1026.803	1942.458	1483.246	1414.555
Wald df	66	66	66	66	66	66
Wald P	0.000	0.000	0.000	0.000	0.000	0.000