R&D spending intensity of private versus public firms: the role of cash flow, leverage, and information quality

Abstract

Purpose: This study provides a large sample comparison of R&D spending intensity in private and public firms and the extent to which these firms' unique characteristics affect their R&D spending rate.

Design/method/approach: The study compares both private and public data from UK firms for the period 2006-2016, generating a total matched 232,029 firm-year observations, and applies a probability model technique to our large panel datasets.

Findings: We uncover that private firms show lower R&D spending intensity compared to their public counterparts. Our evidence also shows that privately owned firms in the technological (non-technological) sector display higher (lower) probability of R&D spending intensity. Compared with public firms, we further observe that the intensity of private firms' R&D spending increases with higher internal cash flow, leverage, and industry information quality. Our results remain robust to alternative econometric models.

Originality/value: By combining both private and public firms' datasets, we are able to provide new evidence to suggest that the intensity of private firms' R&D spending is dependent on internal cash flow, leverage and the industry information level. In fact, to the best of our knowledge, this is the first study that explores these relationships.

Key words: Research and development, private firms, public firms, UK

1. Introduction

Research and development (R&D) investment by both private and public firms has received growing academic interest (see e.g., Ahn *et al*., 2020; Boeing, 2016; He and Wintoki, 2016; Brown and Petersen, 2011; Ishibashi and Matsumura, 2006). Evidence suggests that R&D is critical in driving firm innovation and performance (Liu *et al*., 2021; Alam *et al*., 2020; Belderbos *et al*., 2004). For instance, Falk (2012) observes that firm-level R&D drives firm growth. A similar view is shared by many other authors (see e.g., Lee and Min, 2015; Hung and Chou, 2013; Sher and Yang, 2005). In the same vein, R&D is seen as an important businesses strategy for maintaining a firm's competitiveness in the market (Boiko, 2021). Thus, firms that engage in R&D should have superior performance and competitive advantage over those that engage less in R&D. Broadly, there is an overwhelming acknowledgment in the literature of the importance of R&D in driving firm-level innovation and performance.

Despite this critical role played by R&D, existing evidence on whether private firms invest more in R&D activities than public firms are mixed. Comparatively, very limited numbers of studies examine the spending pattern of both private and public firms on R&D activities. Also, we are unsure whether industry-level information matters in firms' R&D spending. Thus, in this study, we examine R&D spending intensity in private and public firms. To the best of our knowledge, no past study has explored the R&D intensity of private and public UK firms. Indeed, examining the R&D intensity of these two categories of firms is essential in that it provides important insight into the extent to which firms commit resources into this course. In addition, since private firms are more likely to face financial constraints than public firms (Acharya and Xu, 2017; Gao *et al.*, 2013), private firms are more likely to sponsor R&D activities from their internally generated funds than public firms are. Thus, we investigate the extent to which internal cash flow and leverage affect the R&D spending intensity of both private and public firms. Additionally, we seek to understand the extent to which industry information quality drives private – public firms' R&D intensity behaviour. Indeed, evidence depicts that public firms are seen to operate in a more transparent environment and disclose more information than their private counterparts (Aggarwal and Hsu, 2014). In line with this, private firms operating in a more informational flow environment or industry are more likely to respond quickly to anticipated investment opportunities in that industry (Badertscher *et al.*, 2013). Thus, the level of industry information can facilitate private firms' engagement in innovation (R&D) intensity.

In addressing the above objectives, we use data from both private and public firms from the UK for the period 2006-2016 and conduct our analysis by using probit regression model. Our result from this study indicates that private firms are less likely to aggressively engage in R&D intensity. This result remains qualitatively similar to alternative econometric modelling. Next, our results indicate that private firms in the technology sector are more likely to allocate greater resources into investment in R&D than their non-technology counterparts. Further, we observe that private firms are likely to rely more on internal cash flow and leverage to sponsor R&D intensity than their public counterparts. Finally, our study shows that private firms operating in an industry with high public firms' presence (information quality) are more likely to engage in innovation (R&D) intensity.

We make primary contributions to the literature in the following ways. First, we contribute to the literature on R&D investment (see e.g., Leung and Sharma, 2021; Adomako *et al.*, 2019; Padgett and Galan, 2010). While our paper builds on the R&D investment literature, to the best of our knowledge, it is one of the first attempts to explore how R&D investment varies across both private and public firms. Second, we demonstrate that private firms are more likely to finance R&D intensity from the internally generated cash flow compared to the public ones. This supports private firms' financial inflexibility problem (e.g., Acharya and Xu, 2017; Badertscher *et al.*, 2013; Rajan, 2012). In other words, private firms are more likely to experience higher costs in raising external finance for innovative activities than public firms. Thus, our study shows that private firms are more likely to increase innovation (R&D) intensity when they hold more internal cash. We further demonstrate that, with only debt as their main external source of financing, private firms show a high likelihood to increase R&D intensity with debt than their public peers. This is inconsistent with Rajan's (2012) assertion that private entrepreneurs have a low desire to finance innovative activity with debt for fear of losing collateral security. Our final contribution stems from the importance of an information quality environment in driving firm innovative activities among private firms. In industries with large public firms' presence, information disclosure is more likely to be in greater detail than in industries with less public firms' presence. Thus, private firms in an information quality environment are likely to leverage on this to respond quickly to innovative activities. Thus, in this study, we demonstrate that private firms operating in an environment with greater public firms' presence (i.e., which captures information quality) are more likely to rapidly respond to innovation intensity and have a better innovation profile than their counterparts in industries with less public firms' presence. By doing this, we show that industry-level information plays an important role in explaining the heterogeneity of innovation intensity among firms.

We structure the remainder of this article as follows: Section 2 offers a review of the related literature, Section 3 focuses on data and empirical methods, Section 4 presents and discusses results, and, finally, Section 5 concludes the study.

2. Related literature

The theoretical literature offers different explanations relating to the investment in research and development (R&D) of both private and public firms (see e.g., Ishibashi and Matsumura, 2006; Hall and Lerner, 2010; Rajan, 2012; Acharya and Xu, 2017; Edmans *et al*., 2017). The first explanation suggests that, compared to private firms, public firm managers are forced to meet the short-term earnings performance target imposed by the equity market (Porter, 1992; Graham *et al*., 2005). One way to achieve or establish such a market performance record is to disinvest in long-term innovation (R&D) activity (Gopalan *et al.*, 2014; Acharya and Lambrecht, 2015; Edmans *et al*., 2017). Acharya and Lambrecht (2015) further suggest that the under-pressured public firm managers have limited motivations to undertake long-term investment in innovation. Relatedly, Ferreira *et al*. (2014) shared a similar sentiment in their no tolerance for failure model. They argue that managers of publicly listed firms are rationally biased against innovation projects, especially those projects with higher failure rates. The authors further argue that private firm shareholders have no such short-term incentives because the lack of stock liquidity forces these shareholders to take a long investment horizon. Thus, short-term performance pressure is much weaker in private firms than in public ones.

Contrary to the short-termism model, others suggest that the social welfare responsibility of firms influences their innovation activities. For instance, in their market presence model, Clausen (2009) and Ishibashi and Matsumura (2006) indicate that the welfare-maximising public firms tend to invest more in R&D activities than their private counterparts. The low social welfare mandate of private firms suggests that these firms only invest in R&D for profit maximisation purposes. The model shows that the externality of R&D resulting from the social welfare motive of public firms stimulates more R&D spending compared to private firms.

Moreover, financing advantages is another view that has been suggested in the literature (see e.g., Acharya and Xu, 2017; Rajan, 2012; Brown *et al*., 2012; Aghion *et al*., 2010). Being a publicly listed firm as opposed to a privately held one is associated with some benefits which can potentially impact corporate R&D strategy. Under the financing model, private firms have limited financing options compared to public ones, i.e., they rely mainly on debt financing whenever internally generated cash flow is inadequate (Acharya and Xu, 2017; Gao *et al*., 2013; Brav, 2009). Given that debt financing does not encourage R&D behaviour (Atanassov *et al*., 2007; Aghion *et al*., 2004), it may become problematic for private firms to achieve optimal R&D investment.

In contrast, public firms' easier access to the equity markets enables the financing of risky innovative activities (Allen and Gale, 1999). That is, because the firms' stocks are freely traded in the market, it allows shareholders to achieve the benefit associated with portfolio diversification and risk sharing, which in turn encourages managers to make more corporate decisions (Faccio *et al*., 2011). Extending this view, Nohria and Gulati (1996) suggest that the easy accessibility of public equity markets generates financial slack which protects these firms from the uncertainty associated with innovative activities, and this consequently encourages a culture of experimentation. As firms become motivated and engage in experimentation, the pursuit of long-term R&D projects is encouraged (Aghion *et al*., 2010). Relatedly, Rajan (2012) also shares similar sentiment when he argues that the ability of listed firms to secure equity capital alters the intensive innovation of these firms. In his model, he argues that the equity market plays an important role in providing the capital and incentives that entrepreneurial firms need to innovate, transform, develop, create, and generate profits. Thus, with easy access to the equity market, public firms are more likely to conduct capital-intensive innovation. Extending this assumption, Hall and Lerner (2010) suggest that the unattractiveness of intangible assets to the debt market makes equity financing a preferred option. That is, because innovative activities are often uncertain and volatile, they become unattractive to many creditors to accept as collateral (Stigliz, 1985). Moreover, pointing to the collateral argument, Rajan (2012) shows that the possibility of entrepreneurial firms losing their critical assets to creditors in the event of project failure discourages them from being innovative. However, through the equity market, publicly listed firms can easily finance innovative projects without needing collateral security. Consequently, listed firms may enjoy a lower cost of capital as their investors' portfolios become more liquid and diversified (Pagano *et al*., 1998).

Overall, given the contrasting predictions on how a firm's listing status (private & public) is likely to impact its innovative (R&D) activities, it becomes an empirical question as to how privately held firms' R&D behaves. Additionally, we further conjecture that the R&D behaviour of privately held firms may vary based on the firms' internal and external sources of financing. Simply put, because private firms often have limited financing options, those with R&D intensive activities may rely more on internal financing and may only use debt (second choice) when internally generated cash flow is insufficient (Acharya and Xu, 2017; Gao *et al*., 2013; Brav, 2009). However, the exposure to stock market short-termism (i.e., to satisfy annual earnings growth) could prevent public firm managers using internally generated funds to sponsor R&D. Further, the infusion of public equity benefits makes them less dependent on internal cash and external debt to finance R&D activity (Acharya and Xu, 2017). Noting the implications of the various theoretical models, we argue that the impact of firm status (private vs public) on R&D activity varies with the degree of internal and external finance dependence.

Lastly, we also argue that the information environment within which (private) firms operate may affect their R&D activities. Thus, listed firms disclose more information to the markets and, given that they are closely monitored by their peers, including private ones, (Aggarwal and Hsu, 2014; Bhattacharya and Ritter, 1983), these monitoring firms may tend to respond promptly to any investment opportunity they identify in the information disclosed. For instance, while Asker *et al.* (2012) observe that private firms are more responsive to growth opportunities than their public counterparts, Badertscher *et al.* (2013) assert that the responsiveness of private firms to investment growth opportunities is linked to the firms' prompt reaction to the industry information. Given the above proposition, we provide further analysis on the extent to which private firms' R&D behaviour is driven by the industry information level.

3. Method

3.1. Data

The data for the firms examined in this study was obtained from the Amadeus database supplied by Bureau van Dijk, which covers both private and public UK firms for the period 2006–2016. Amadeus database provides financial statement data for a large set of European firms including UK private and public firms and it is compiled from several well-established national information collectors (Burgstahler et al., 2006; Badertscher et al., 2013). The database's unique coverage of financial information on private and public firms enables us to measure firm-year R&D intensity and other characteristics. Consistent with prior empirical studies (e.g., Acharya and Xu, 2017), we exclude financial and utilities firms from our sample because investment models are not suited for these firms. Again, we also drop firms with fewer than two years of complete data, and each observation requires non-missing data on total assets (Brown *et al*., 2012). After these processes, the full sample contains 61,278 private firms with 604,369 firm-year observations and 1,358 public firms with 12,356 firm-year observations operating in 10 industries over a 10-year period.

3.2. Measurement of variables

3.2.1. Dependent variable

The research and development (R&D) intensity is our main dependent variable, and this variable is defined as the total annual R&D expenditure scaled by total assets, similar to prior research (e.g., see Brown *et al*., 2012; Hall and Lerner, 2010). Because our reported R&D expense have large missing values, we use a dummy to represent R&D intensity if the value is positive (Gonzalez and Pazo, 2008; Arrighetti *et al*., 2014). Again, we also use the ratio of R&D measure for robustness purposes.

3.2.2. Independent variable

As suggested, the listing status of a firm affects the level of its R&D investment intensity. To capture this effect, we use indicator variables for private firm and public firm to represent our independent variable. Specifically, private firm (*PRIV = 1 or 0*) is a dummy variable that takes the value of 1 and 0 otherwise (i.e., 0 represents a public firm), similar to Acharya and Xu (2017).

3.2.3. Control variables

Similar to previous studies (e.g., Acharya and Xu, 2017; Arrighetti *et al*., 2014), we control for the following variables in our R&D intensity model. Thus, cash flow (*CF*) is captured as the sum of income before extraordinary items (interest, taxes) and depreciation and amortisation deflated by the book value of total assets. Sales growth (*SGR*) is used as our proxy for investment opportunities and it is measured as log of sales scaled by lagged sales to proxy for growth. Logarithm of total assets is used to proxy for firm size (*SZ*); cash and cash equivalents are scaled by total assets to proxy for cash holdings (*CH*); leverage (*LEV*) is measured as total debt scaled by total assets; profitability is defined as profit for the period scaled by total assets (*PR*); firm years of operation are used to proxy for firm years (*FY*); and long-term debt that matures after one year is divided by total debt (*DMAT*). Further, it is suggested that the information environment of firms affects how they invest (Badertscher *et al*., 2013; Aggarwal and Hsu, 2014). Consistent with Badertscher *et al.* (2013), we further include an information quality (*IQ*) variable, and it is measured as the ratio of public firms' sales to total industry sales. Lastly, we include fixed effect variables to account for industry and time fixed effects in the probit model. The acronyms and definitions of all the variables are provided in Table I.

[Table I about here]

3.3. Matched sample

Ideally, to achieve the aim of this study, we would need to compare R&D intensity behaviour of two identical firms that differ only in their listing status. To get close to this aim, we need to find firms both private and public that are observably similar to each other. We adopt a matching technique, and our preferred match is based on size and industry. This is because investment behaviours (R&D intensity) among private and public firms are found to differ substantially across industries and size (Acharya and Xu, 2017; Asker *et al*., 2015). To minimise the differences in industry and size distributions, we identify a sample of industry and size matched private and public firms. For each private firm of the sample period, we match it with a public firm closest in size and in the same SIC industry code, similar to prior research (see Acharya and Xu, 2017; Asker *et al*., 2015). Thus, we use size (log of total assets) and industry to estimate propensity score with a 5% caliper, consistent with Asker *et al.*'s (2015) nearest-neighbour matching. The time series observations for the matched pair are kept, preserving the panel structure of the data. This procedure results in 232,029 matched private and public observations.

3.4. Model specification

Our prediction is that a firm's R&D intensity is likely to be determined by its listing status (private versus public). To test this, we employ probit regression model where both our dependent variable (*R&D intensity*) and independent variable (*PRIV*) are a dummy equal to 1 and 0 otherwise. Thus, *R&D intensity*$_{ij}$ represents that a firm (i) may belong to an outcome (j) (i.e., committing an *R&D intensity* if j =1, or not committing *R&D intensity* if j=0) as a function of the firm's status (private - *PRIV* = 1 and 0 = public) and a vector of measured firm-specific characteristics (*controls*). Our adopted approach is similar to Acharya and Xu (2017). Specifically, we estimate the following probit regression model to test our prediction:

$$R\&D\ Intensity_{ijt} = \alpha + \beta_1 PRIV_{ijt} + \beta_2 Controls_{ijt-1} + \phi_j + \zeta_t + \varepsilon_{ijt} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Private$_i$ (*PRIV*) = {1 if Private$_i$ > 0 or Private$_i$ ≤ 0. }   OR

Private$_i$ (*PRIV*) = {if Private$_i$ = 1 if Public$_i$ = 0 }

In equation (1), where *R&D intensity*$_{ijt}$ is the probability of firm (i) committing innovation intensity, while *PRIV* is also a dummy of 1 and 0 otherwise if a firm is a private one, *Controls* are other investment-related determinants, and $\phi_j,\ \zeta_t\ and\ \varepsilon_{ijt}$ are unobservable fixed and time effects and the error term respectively. In estimating our equation (1), we use a probit regression model where *R&D intensity* is regressed on *PRIV* and *controls* and the reported estimates are based on robust standard error. For robustness checks, we also use logit regression specification and an alternative dependent variable measure where R&D intensity is measured as the ratio of total assets. In addition to this, we also employ simultaneous equations model to deal with possible endogeneity concern.

4. Results and discussion

4.1. Summary statistics and bivariate correlations

Table II presents summary statistics for our variables of interest used in this empirical study. It is important to highlight some of the key findings. In Table II, we report the firm characteristics and R&D intensity of private and public firms in the full sample (Panel A) and the matched sample (Panel B). In the full sample, private firms on average keep high cash flow, *CF*, and leverage, *LEV*, and are more profitable, *PR* (0.062, 0.260, and 0.046), compared with public firms (0.027, 0.144 and 0.042) respectively. Public firms on average are bigger in size, *SZ*, and older, *FY*, compared with private firms. The age of the firm is the difference between the current year (2015) and the founding year of a firm. Again, public firms use longer maturity, *DM*, hold more cash holdings, *CH*, and higher sales growth, *SGR*. In terms of information quality, *IQ*, public firms' operational environment produces more information than that of private firms. This is unsurprising, given that private entities provide little information to the market for fear of losing investment opportunities to their rivals.

As for R&D intensity activities, Panel A of Table II shows that public firms spend more on R&D than private firms. Thus, in terms of R&D activity, private entities on average have significantly less innovation (R&D) intensity compared with public firms (0.001 versus 0.017). This partly confirms the proposition that, unlike public firms, privately owned entities only invest in R&D for profit opportunities and not for welfare motives (Clausen, 2009). Overall, similar differences between private and public firms are also observed in the matched sample (Panel B of Table II).

In Table III, we also report the Pearson correlations among the sample variables used in this study. Specifically, we observe positive correlations between investment (*R&D*) and cash holdings, *CH*, and profitability, *PR*, while cash flow, *CF*, leverage and debt maturity, *DM*, show a negative relation. Overall, the correlation matrix indicates that correlations between the covariates are low and exhibit no serious multicollinearity issues.

[Tables II & III about here]

4.2. Firm listing status (private vs public) and R&D intensity investment

In Table IV, we present the regression results of our baseline models to suggest the level of R&D intensity between private and public firms. We adopt two main estimation methods in testing our model: probability model (probit) and logit model. Our dependent variable (*R&D_ Intensity*) takes the value of one (1) if the ratio of the firm's R&D spending is positive, and zero (0) otherwise (Gonzalez and Pazo, 2008; Acharya and Subramanian, 2009). The independent variable (*PRIV = 1 or 0*) is also represented by a dummy of one (1) if the firm is a private entity and zero (0) in the other case (Acharya and Xu, 2017). Our main results are based on probit models (1 & 2), while models 3 & 4 and 5 & 6 show an alternative specification logit model and an alternative dependent variable measure respectively, which are used for robustness purposes. Specifically, models 1 & 2 show a negative and significant effect of *PRIV* on *R&D_Intensity* even after including conventional control variables in the fully specified probit model (2). Thus, employing a probability model to our matched sample, the variable of interest, *PRIV*, shows that, compared to public firms, private firms (*PRIV*) are less likely to aggressively commit R&D intensity. The finding partly supports the assertion that the limited financing options available to private firms inhibit their innovative activities (Rajan, 2012; Archarya and Xu, 2017). Another possible explanation is that, because innovation (R&D) activities require substantial capital and outcomes are highly uncertain (Holmstrom, 1989), private firms, for fear of project failure, may be discouraged from committing to such projects. Thus, unlike public firms, privately owned firms do not invest for welfare reasons and are likely to disinvest when opportunities for making profits are unavailable (Clausen, 2009; Ishibashi and Matsumura, 2006). Our results remain qualitatively similar across the logit models (3 & 4) where *PRIV* still remains negative and statistically significant to *R&D_Intensity*, providing collaborative evidence to the earlier results reported in models 1 & 2. Again, in models 5 & 6, we employ ordinary least square (OLS) to an alternative dependent variable (R&D ratio) and find that *PRIV* is still negative and significant. Moreover, having recorded similar results employing different econometric estimators, endogeneity problem is likely to affect the validity of our results. For instance, it has been argued that a firm decision to go private or public may be influenced by the firm's financing and investment policies (Acharya and Xu, 2017; Asker, Farre-Mensa, and Ljungqvist, 2012; Brav, 2009). Supporting this view, Asker *et al*. (2012) show that private firms tend to respond more quickly to growth opportunities than their public counterparts while Badertscher *et al*. (2013) contend that the responsiveness of private firms to investment growth opportunities is linked to these firms' proactive reaction to the market information. Thus, given the fact that, a firm listing status (private or public) is not exogenous factor, it is possible that our reported findings might have been caused by some unobserved external factors. To further ensure that our result is not plagued by endogeneity, we adopt simultaneous equations model approach, and it is stated as follows:

$$PRIV_{i,t} = \alpha + \beta R\&D_{i,t} + \beta IV_{i,t} + \beta Controls_{i,t} + \varepsilon_{i,t} \qquad (2i)$$

$$R\&D_{i,t} = \alpha + \alpha PRIV_t + \beta Controls_{i,t} + \varepsilon_{i,t} \qquad (2ii)$$

In the first stage equation – *PRIV* - 2i), we include R&D investment and instrumental variable – *IV: ID-SGR*$_{it}$ - *industry-median growth*) together with other controls defined in Table 1. Both theoretically and empirically, instrumental variable (*ID-SGR*$_{it}$ - industry-median growth*)* needs to be strongly correlated with the endogenous variable - *PRIV* to satisfy the relevance criterion. Thus, we argue that private or public firms' reaction to the industry growth opportunities will indirectly affect how much they allocate to R&D activity. In our case, industry-median growth opportunity should be correlated with the private or public firm's responsiveness to investment activities. This is confirmed by our strong positive coefficient reported on ID-*SGR*$_{it}$ in the first stage - *PRIV* regression. That is , we regress *PRIV* on the determinants (i.e., including endogenous variable - R&D) to obtain the predicted values, which are then included in the *R&D intensity* (measured as R&D dummy and R&D ratio) equation (2ii). Still our reported results in Table V shows a negative coefficient on *PRIV,* similar to the main results in Table IV. Overall, our results are robust to all these alternative techniques.

4.3. Further tests

4.3.1. Firm listing status (private vs public) and R&D intensity – Sector-level evidence

In this section, we provide further evidence of private firms' R&D behaviour at the industry level. Specifically, we test if firms' (private vs public) R&D spending intensity varies across different sectors. Our primary argument is that firms operating in the technological industry often allocate huge resources to R&D activity (Acharya and Xu, 2017; Clausen, 2009; Klette *et al*., 2000; Trajtenberg, 1990). Due to do this, we perform this analysis by first disaggregating our data into two main sectors: technology sector (TEC) and non-technology sector (NTEC) using dummies, and then interact the dummies with private firms' status (PRIV = 1 or 0 otherwise) to obtain the interaction terms. We re-run our probit model 2 (fully specified) by including the respective interaction terms (PRIV_TEC) and PRIV_NTEC) in the respective models, 1 & 2 in Table VI. The results of this analysis are presented in Table V. From the results, we find that the R&D investment behaviour of both private and public firms differs across our two sectoral groups. In particular, we observe that, in the technology sector, private firms show a strong positive coefficient sign, 4.864 (t-stats 52.77) while those non-technology ones suggest a negative coefficient, -0.609 (t-stats 2.63), on R&D intensity. These findings suggest that private firms in the technology sector are more likely to commit R&D intensity compared with public ones, whereas those in non-technology show lower commitment to R&D intensity. Compared to public firms, privately held R&D firms are more probable to intensify their innovation spending but such investment intensity is lowered for non-technology private ones. Thus, noting the magnitude of coefficient estimates, 4.864 and -0.609 for technology sector and non-technology sector respectively, private firms in the technology industry intensely support more R&D investment, which is consistent with Clausen's (2009) assertion. However, non-technology private firms are likely to experience lower R&D intensity compared to their public counterparts. Implicitly, our results show that while private (public) firms in technology are more (less) likely to commit to R&D intensity those in non-technology decrease (increase) such intensity.

[Tables V about here]

4.3.2. Firm listing status (private vs public) and R&D intensity: The of cash flow

As observed, our main result (models 1 & 2 of Table IV) shows a lower R&D intensity for private firms compared to public ones. One reason that could possibly explain lower R&D behaviour of privately held firms is that these firms often face financing constraints problem (Saunders and Steffen, 2009; Gao *et al*., 2013; Acharya and Xu, 2017). Compared to public ones, private firms are known to offer minimal information about their intangible activities (Santos and Winton, 2008). Such low information makes it difficult and even more costly for them to raise external funds to sponsor innovation activities (Saunders and Steffen, 2009; Rajan, 2012; Badertscher *et al*., 2013). As a result of this, private firms are more likely to sponsor innovation (R&D) activity from their internally generated funds. Further, noting the financing benefits enjoyed by publicly listed firms and the private incentives of managers to engage in earnings management (Stein, 1989; Ferreira *et al*., 2014; Acharya and Lambrecht, 2015), it is less probable that managers of listed firms will use internally generated funds to finance R&D activity. In line with this, we reason that, relative to public firms, private ones are more likely to finance R&D intensity from their internally generated cash flow due to their financial inflexibility problem.

To test this empirically, we augment our baseline probit model (2) by including the interaction term (*PRIV_CF*). In Table VI, model 3 shows the coefficient estimates for the covariate term *PRIV_ CF* to be positive and both statistically and economically significant at 1% confidence level. Thus, the probit model estimate is 1.035 (t-stats 3.45), which suggests that, compared to public firms, private ones have a high likelihood to commit R&D intensity when they have more internal cash flow, which is consistent with argument in the extant literature (see e.g., Acharya and Xu, 2017; He and Wintoki, 2016; Brown and Petersen, 2011). Thus, relative to public firms, privately owned firms are more likely to increase innovation (R&D) intensity when they hold more internal cash.

4.5. Firm listing status (private vs public) and R&D intensity: the role of leverage

Rajan (2012) posits that the ability to secure external capital alters the innovative nature of firms. Relative to private firms, public entities enjoy the benefits of cheaply raising capital from the equity markets to innovate, transform and create value for shareholders (Acharya and Xu, 2017; Brown *et al*., 2012). This makes equity capital more preferable to debt in financing innovation activity (Hall and Lerner, 2010). Further, given the possibility of losing critical collateral assets to creditors in the event of innovation project failure (Rajan, 2012), listed firms find it more convenient to issue equity to finance such projects (Hall and Lerner, 2010; Acharya and Xu, 2017). In contrast, privately held firms have limited external financing options (i.e., debt only) and this limitation causes these firms to use more debt financing, especially when internal funds are inadequate (Brav, 2009; Asker *et al*., 2012; Gao *et al*., 2013). For instance, Gao *et al*. (2013) suggest that private firms drastically keep higher leverage than their public counterparts. Given this contrasting argument, it is more probable that the private firms' R&D intensity will be more sensitive to leverage than the public ones.

To empirically test this assumption, we interact our independent dummy variable (*PRIV = 1 or 0*) with leverage (LEV) and then include the interaction term in the fully specified probit model (1). Table VI presents the results. Specifically, our finding shows that the coefficient for *PRIV_LEV* is both positive and significant, indicating that privately held firms are more likely to use debt financing to support innovation (R&D) intensity than their public counterparts. The overall results suggest that the limited external financing options of private firms force them to apply more debt to financing R&D intensity compared to public ones (Acharya and Xu, 2017; Gao *et al*., 2013; Brav, 2009). This is inconsistent with the claim that private entrepreneurs' fear of losing collateral security may prevent them from financing innovative activities with debt (Rajan, 2012). Thus, the limited financing options available to these private R&D firms make them more likely to use debt financing, unlike their public counterparts.

4.6. Firm listing status (private vs public) and R&D intensity: the role of information quality

Next, we examine how the information environment affects private – public firms' R&D intensity behaviour. For instance, public firms disclose more information and are seen to operate in a more transparent environment (Aggarwal and Hsu, 2014). Asker *et al*. (2012) posit that private firms respond more quickly to growth opportunities than their public counterparts while Badertscher *et al*. (2013) contend that the responsiveness of private firms to investment growth opportunities is linked to their proactive reaction to the industry information. Based on their model, Badertscher *et al*. (2013) suggest that as the industry releases more public information, private firms become aware of the opportunities in that particular industry and may respond appropriately to these investment opportunities. That is, the resulting information quality in the industry provides an opportunity to these privately held firms to respond more rapidly to the anticipated investment opportunities in that industry.

Extending this argument, we posit that private firms operating in an information quality environment are more likely to rapidly respond to innovation activity. Thus, greater transparency or information flow in an industry can facilitate private firms engaging in innovation (R&D) intensity.

To empirically examine this, we measure industry information quality (*IQ*) as the ratio of public firms' sales to total industry sales, consistent with Badertscher *et al.* (2013). We interact our private (*PRIV = 1 or 0*) firm indicator variable with the information quality- (*IQ*) and then include the interaction term (*PRIV_ IQ*) in our probit specification. The modified equation is estimated, and the results are presented in Table VI. Specifically, we observe in model 5 that the interaction term coefficient (*PRIV_ IQ*) is positive and statistically significant at 1% confidence level. The probit estimates on the covariate *PRIV_IQ* variable is 4.418, largely confirming the assertion that private firms operating in an industry with better information flow are more likely to intensify their R&D spending. Thus, the industry information quality induces private firms to commit innovation (R&D) intensity.

5. Conclusion

In this study, we examine the R&D intensity of both private and public UK firms for the period 2006 - 2016. Although there are a number of empirical studies that explain the effect of R&D intensity on various corporate decisions (see e.g., Leung and Sharma, 2021; Adomako *et al*., 2019; Padgett and Galan, 2010; Lin *et al*., 2006) our study is among the first to examine how R&D investment varies across private and public firms in the UK. Thus, we gain insights into theories of private firm R&D investment by comparing private with public firms. We observe that, in general, private firms are less likely to commit R&D intensity compared to their public counterparts. However, compared to public ones, private firms are more likely to commit R&D intensity in the technology sector, but such intensity is lessened among private firms in non-technology counterparts compared to public ones. Similarly, private firms are more likely to use internally generated cash flow to sponsor R&D investment intensity than their public peers. We further find that, unlike public firms, private ones have a high probability of using debt to increase R&D intensity. Finally, we contribute to the literature by demonstrating the role of information quality in driving R&D investment among private firms. In all, our results remain robust to various econometric models. Indeed, our study highlights the variation of R&D intensity among private and public firms, thereby offering a useful contribution to the existing literature on corporate innovation. From the theoretical perspective, our evidence offers support for the financing frictions associated with innovative activity (Brown, Martinsson and Petersen, 2012). Thus, different from prior research (e.g., Brown, Martinsson and Petersen, 2012; Gonzalez and Pazo, 2008), we state that compared to public firms, privately-held R&D firms are more susceptible to financing constraints and that they rely more on internal cash and debt to finance their innovative (R&D) activity. The implication of this results is further confirmed in the works of Brown et al. (2012) and Uppenberg (2009) who suggest that UK public firms issue more equity financing to support their R&D activities. Beyond the financing difficulties, our results show that private R&D firms operating in informationally flow environment (proxied by information quality) are likely to intensify their R&D spending. This evidence adds a new dimension to the observed R&D intensity in private firms. Despite these important findings, we would like to point out that our use of a single country's data limits the generalisability of our findings. Thus, future studies may also consider extending this study across multiple countries. Also, future studies can investigate whether both public and private firms benefit from R&D investment and any potential mimicking effects on corporate innovation between public and private firms.

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Table I: Description of variables

Dependent Variable	**Description**	**Literature**
R&D ratio	R&D expenditure scaled by Total Assets	Hall and Lerner (2010), Brown *et al*. (2012), Gao *et al*. (2018)
R&D intensity	Dummy variable of one (1) if the R&D ratio is positive and zero (0) otherwise	Gonzalez and Pazo (2008), Arrighetti *et al*. (2014)
Key Independent variables		
Firm status – Private (PRIV) firm	An indicator variable that takes the value of one (1) if a firm is privately owned, and zero (0) otherwise	Acharya & Xu (2017) Gao *et al*. (2018)
Control variables		
Cash flow (*CF*)	EBITDA scaled by Total Assets	Brown *et al*. (2012), Acharya & Xu (2017)
Sales growth (*SGR*)	Log of Sales $_{t-1}$ minus Sales_t. i.e., change in log of sales_t-1 to year _t.	Badertscher *et al*. (2013), Asker *et al.* (2012)
Firm size (*SZ*)	Natural logarithm of Total Assets	Acharya and Xu (2017), Danso *et al*. (2020), Arrighetti *et al*. (2014)
Cash holdings (*CH*)	Cash holdings scaled by Total Assets	Acharya and Xu (2017), Brown *et al*. (2012)
Leverage (*LEV*)	Total Debt scaled by Total Assets	Gao *et al*. (2018), Acharya and Xu (2017).
Profitability (*PR*)	Profit for the period scaled by Total Assets	Acharya and Xu (2017)
Firm years (*FY*)	Firm number of years of operation	Acharya and Xu (2017), Gao *et al*. (2018).
Debt maturity (D*M*)	Long-term debt that matures after one year divided by total debt	Dang (2011)
Information quality-IQ (Public firms' presence)	The sum of all public firm sales in each industry, divided by total firms sales in the same industry.	Badertscher *et al*. (2013)

Table II: Summary statistics

	Panel A: Full sample						Panel B: Matched sample				Diff. in means
	Public			Private			Public		Private		
	Mean	50%	St. Dev.	Mean	50%	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	T-test
R&D	0.017	0.000	0.076	0.001	0.000	0.022	0.016	0.078	0.002	0.024	0.014***
CF	0.027	0.030	0.169	0.062	0.015	0.134	0.033	0.169	0.068	0.134	-.035***
SGR	1.008	1.003	0.097	1.005	1.003	0.079	1.009	0.098	1.005	0.075	0.004***
SZ	7.765	7.752	1.117	7.217	7.223	1.080	7.910	1.235	7.259	0.192	0.652***
CH	0.167	0.083	0.207	0.112	0.030	0.180	0.158	0.205	0.108	0.168	0.050***
LEV	0.144	0.068	0.180	0.260	0.171	0.259	0.160	0.187	0.259	0.255	-.099***
PR	0.042	0.018	0.055	0.046	0.015	0.061	0.044	0.055	0.046	0.060	-.002***
FY	23.86	12.00	28.63	20.12	13.00	20.51	25.41	29.53	21.45	20.89	3.955***
DM	0.560	0.703	0.402	0.339	0.049	0.400	0.590	0.402	0.351	0.398	0.240***
IQ	0.055	0.027	0.071	0.030	0.021	0.033	0.055	0.071	0.029	0.030	0.026***
N	12358			604369			**9479**		**222550**		

Table III: Correlation matrix

	R&D	CF	SGR	SZ	CH	LEV	FY	PR	DM	IQ
R&D	1.00									
CF	-0.02*	1.00								
SGR	-0.00	0.06*	1.00							
SZ	-0.00	-0.02*	0.07*	1.00						
CH	0.03*	0.11*	0.00	-0.24*	1.00					
LEV	-0.01*	-0.11*	0.01*	0.24*	-0.23*	1.00				
FY	0.00	0.02*	-0.02*	0.13*	-0.04*	-0.11*	1.00			
PR	0.02*	0.29*	-0.00	-0.07*	0.16*	-0.13*	0.03*	1.00		
DM	-0.01*	-0.01*	0.01*	0.11*	-0.10*	0.23*	-0.11*	-0.12*	1.00	
IQ	0.00	0.01*	0.09*	0.14*	0.01*	-0.01*	-0.02*	0.01*	-0.01*	1.00

This table presents the correlation matrix for the sample data. The sample and variable definitions are as described in Table I.
* indicates significance at 1% level.

Table IV: Firm Listing Status (Private vs Public) and Research & Development (R&D) Intensity

	(Model 1) R&D_Intensity	(Model 2) R&D_Intensity	(Model 3) R&D_Intensity	(Model 4) R&D_Intensity	(Model 5) R&D Ratio	(Model 6) R&D Ratio
PRIV	-1.338***	-1.229***	-2.656***	-2.304***	-0.017***	-0.013***
	(-42.18)	(-26.79)	(-41.50)	(-25.56)	(-12.72)	(-7.95)
CF		0.144**		0.348**		-0.007***
		(2.20)		(2.47)		(-5.52)
SGR		0.244**		0.494**		0.002***
		(2.08)		(2.05)		(2.83)
SZ		0.201***		0.486***		0.001
		(6.38)		(7.35)		(1.04)
CH		0.172***		0.331***		0.004***
		(3.78)		(3.49)		(5.95)
LEV		-0.290***		-0.585***		-0.001
		(-8.07)		(-7.62)		(-1.01)
PR		1.255***		2.611***		0.010***
		(9.61)		(9.62)		(5.11)
FY		0.001		0.001		-0.000***
		(1.19)		(1.30)		(-3.25)
DM		0.053***		0.133***		-0.001**
		(2.67)		(3.16)		(-2.14)
IQ		-6.957***		-15.33***		-0.016***
		(-7.03)		(-6.96)		(-5.07)
_Cons	-1.371***	-6.866***	-2.758***	-20.67***	0.016***	0.006**
	(-32.90)	(-25.16)	(-31.05)	(-32.99)	(12.14)	(2.02)
Year	YES	YES	YES	YES	YES	YES
Industry	YES	YES	YES	YES	YES	YES
N	**225427**	**118988**	**225427**	**118988**	**225427**	**118988**
PseudR	**0.20**	**0.20**	**0.20**	**0.20**	**0.01**	**0.02**
Chi2	**10347.31**	**11528.27**	**11074.96**	**11079.42**		
Prob>Chi2	**0.0000**	**0.0000**	**0.0000**	**0.0000**		

The table reports the probit and logit estimation results of firm status (private versus public) and their R&D intensity behaviour. Our dependent variable (R&D intensity) is an indicator variable of one (1) if the R&D ratio value is above the median and zero (0) otherwise. Also, our independent variable – private firm (PRIV) – is a dummy variable of one (1) and zero (0). Probit regression is our main regression results whilst the logit and alternative measure of dependent variable is for robustness purposes. In Models 5 & 6 , we apply OLS technique to the alternative measure of dependent variable (R&D ratio measured as R&D expenses normalised by Total Assets). All variable definitions are described in Table 1. *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels, respectively.

Table V: Firm listing status (private vs public) and R&D Intensity

	Simultaneous equations model (SEM) using 3SLS			
	(2nd Stage) R&D_dummy	1st Stage PRIV	(2nd Stage) R&D ratio	(1st Stage) PRIV
PRIV	-0.397**		-0.043*	
	(-2.26)		(-1.79)	
CF	0.0285***	0.058***	-0.005***	0.038***
	(2.78)	(26.22)	(-3.63)	(12.43)
SGR	0.007	-0.043***	0.001	-0.042***
	(0.82)	(-8.76)	(0.67)	(-8.54)
SZ	-0.006	0.021	0.003	0.030
	(-0.02)	(0.09)	(0.07)	(0.14)
CH	0.004	0.008***	0.005***	0.018***
	(1.31)	(4.58)	(11.01)	(8.18)
LEV	0.004	0.062***	0.002	0.066***
	(0.31)	(42.17)	(1.07)	(48.77)
PR	0.087***	0.033***	0.009***	0.028***
	(11.56)	(5.84)	(8.26)	(5.12)
FY	0.0003***	-0.0001***	-0.000***	-0.0003***
	(5.19)	(-9.68)	(-2.77)	(-21.17)
DM	-0.003	-0.045***	-0.002**	-0.051***
	(-0.43)	(-51.68)	(-2.06)	(-67.24)
IQ	-0.330***	-0.519***	-0.025*	-0.497***
	(-3.50)	(-23.34)	(-1.94)	(-22.52)
R&D_dummy		-0.278***		
		(-9.47)		
ID_SGR		1.018***		1.019***
		(7.06)		(7.03)
R&D				-2.316***
				(-8.03)
_Cons	0.363	0.004	0.039	-0.012*
	(1.30)	(0.45)	(1.03)	(-1.68)
Year	YES	YES	YES	YES
Industry	YES	YES	YES	YES
N	**224818**	**224818**	**224818**	**224818**

This table shows three-stage least square (3SLS) regression results of the effect of firm listing status on R&D intensity. The first stage regression is where the endogenous variable: PRIV is regressed on *R&D activity,* controls and instrumental variable (industry median growth ID_SGR). Our reported results used two measures of R&D intensity (R&D dummy and R&D ratio). The coefficients on the variable of interest: *PRIV* is shown in the *R&D* models. The models included fixed effects in all estimations. The reported t-statistics based on robust standard errors are within parentheses. Variable definitions are described in Table I. *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

Table VI: Firm Listing Status (Private vs Public) and R&D Intensity: the role of Industry, Cash flow, Leverage and Information Quality

	(Model 1) R&D_Intensity	(Model 2) R&D_Intensity	(Model 3) R&D_Intensity	(Model 4) R&D_Intensity	(Model 5) R&D_Intensity
PRIV	-1.223*** (-28.18)	-0.622*** (-2.74)	-1.265*** (-26.95)	-1.313*** (-19.34)	-1.409*** (-24.16)
CF	0.346*** (5.85)	0.353*** (5.90)	-0.841*** (-2.87)	0.147** (2.25)	0.135** (2.06)
SGR	-0.0247 (-0.26)	-0.0440 (-0.43)	0.249** (2.12)	0.247** (2.11)	0.252** (2.17)
SZ	0.0977*** (3.48)	0.102*** (3.62)	0.205*** (6.50)	0.200*** (6.35)	0.200*** (6.34)
CH	-0.065 (-1.59)	-0.0420 (-1.02)	0.160*** (3.52)	0.170*** (3.74)	0.170*** (3.75)
LEV	-0.391*** (-12.07)	-0.392*** (-12.07)	-0.285*** (-7.92)	-0.825*** (-2.61)	-0.294*** (-8.17)
PR	1.696*** (14.23)	1.710*** (14.27)	1.241*** (9.49)	1.258*** (9.63)	1.252*** (9.58)
FY	0.004*** (12.32)	0.004*** (12.14)	0.001 (1.36)	0.001 (1.28)	0.001 (1.06)
DM	0.034* (1.86)	0.036* (1.94)	0.0530*** (2.66)	0.053*** (2.68)	0.0542*** (2.72)
IQ	0.261 (1.39)	0.827*** (4.78)	-6.977*** (-7.06)	-6.994*** (-7.05)	-11.14*** (-8.40)
TEC	-5.382*** (-65.25)				
PRIV_TEC	4.864*** (52.77)				
NTEC		1.042*** (4.53)			
PRIV_NTEC		-0.609*** (-2.63)			
PRIV_CF			1.035*** (3.45)		
PRIV_LEV				0.543* (1.71)	
PRIV_IQ					4.418*** (4.69)
_Cons	-5.350*** (-22.53)	-6.378*** (-19.83)	-7.235*** (-20.38)	-6.775*** (-24.34)	-6.695*** (-24.59)
Year	YES	YES	YES	YES	YES
Industry			YES	YES	YES
N	**118988**	**118988**	**118988**	**118988**	**118988**
Pseudo R^2	**0.09**	**0.09**	**0.20**	**0.20**	**0.20**
Wald Chi2	**9963.08**	**9924.33**	**11578.36**	**13924.02**	**13714.61**

Models 1 &2 show the interaction effects of private (PRIV) dummy & technology sector (PRIV_TEC), private dummy & non-technology (PRIV_NTEC), while models 3, 4 & 5 – private dummy & cash flow (PRIV_CF), private dummy & leverage (PRIV_LEV) and private dummy & information quality (PRIV_IQ) – show the interaction term results. Our key interests are the interaction covariates: *PRIV_TEC, PRIV_NTEC, PRIV_CF, PRIV_LEV & PRIV_IQ* and are shown in the probit regression models: 1, 2, 3, 4 & 5. The *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels, respectively.