Market Dynamics of the Space Sector

Econometric analysis of Size and Health data

EXECUTIVE SUMMARY

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Head Office: Somerset House, New Wing, Strand, London, WC2R 1LA, United Kingdom.

w: londoneconomics.co.uk/space
e: info@londoneconomics.co.uk
t: +44 (0)20 3701 7717
: @LE_Aerospace

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Authors

Rasmus Flytkjaer, Partner
Farooq Sabri, Associate Director
Su-Min Lee, Senior Economic Consultant
Tom Goulding, Economic Consultant
Katharina Knuth, Economic Analyst
Philip Hagelberg, Economic Analyst

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1 Purpose of the study

Every two years, the UK Space Agency surveys all the organisations in the UK who supply and/or make use of space or satellite services. This survey covers all aspects of the space sector from upstream manufacturing through to downstream satellite-enabled applications, and includes both commercial and non-commercial activities (e.g. fundamental research, space science). The 'Size and Health of the UK Space Industry' study (aka 'Size and Health' or 'S&H') aims to give a comprehensive, progressive, and accurate overview of the trends, size, performance, and characteristics of organisations engaged in space-related activity in the UK. Specifically, it seeks to do this by supplementing survey inputs with significant secondary research and adopting thought-leading frameworks and best practice techniques to measure the space economy.

The objective of this study is to leverage the Size and Health datasets generated since 2016[1] to enable trend identification and predictive forecasting on companies' growth and survival in the UK space sector. This study is the first attempt to consolidate data from different survey iterations and derive a meaningful data series for each company, assembled in a panel dataset suitable for econometric analysis. Applying advanced statistical and economic methods makes it possible to derive results that increase the understanding of the space sector and help develop future policies.

The length of the data series and the coverage, both in terms of sample size and in terms of the variables requested means there is a treasure trove of information waiting to be unlocked. The present study seeks to utilise the wealth of data collected for the Size and Health studies to draw inferences on the properties that characterise the companies that grow faster or exit the industry.

Understanding which observable characteristics make a company likely to grow faster and remain in the space sector are valuable inputs into policy decision-making. The UK space sector has been growing at consistently high rates over the last 20 years significantly outperforming UK GDP. The National Space Strategy[2], defined in 2021, aims to grow and level up the space economy and put the UK space industry at the forefront of the global space industry.

This document is short-form publication from a more detailed study, with select technical details included in the Annex.

[1] As of the 2016 wave, survey respondents were able to provide a direct estimate of space-related turnover rather than total organisation turnover and a share of turnover that is space-related ('space share'), provided in a range. This innovation introduced an identifiable break in the series at the individual company level, which has led the authors of the present report to focus on the data from 2016 onwards.

[2] HM Government (2021). *National Space Strategy*

2 Methodology

2.1 Approach

To identify the key determinants of the UK space sector's firm-level growth, survival, and performance we used a robust data-driven approach in this study. After reviewing the literature, we gathered, merged, and quality assured the data. We then used descriptive analysis to visualise the data and segmented the population of space companies using Latent Dirichlet Allocation (LDA) into clusters. The main econometric analysis aims to identify the impact of individual independent variables on three outcomes of interest:

1) Whether a company is high growth
2) Whether a company is able to deliver on high growth potential
3) Whether a company exits the UK space sector

The analysis on high-growth companies aligns with the OECD definition of high-growth firms being those that achieve an annualised growth rate greater than 20%. A firm can exit the UK space sector by becoming inactive or by no longer operating in the UK space sector while still actively trading.

2.2 Literature review

In the first instance, we undertook a literature review to identify the existing empirical evidence for the drivers of high firm growth and firm exit in the academic and non-academic literature. The results of this analysis inform the choice of variables included in the regression and exit analysis. The literature suggests a positive impact on firm growth from R&D Investments (BEIS, 2017), export intensity (Greenaway et al., 2002), and foreign ownership (Javorcik, 2004). On the other hand, firm age (Evans, 1987), and the geographic distance to the nearest UKSA Space Cluster[3] (NIESR, 2021) are suggested to have a negative impact on growth. The full literature review is provided in the Annex to this summary report.

2.3 Data

The consolidated database is made up of four editions of the Size & Health study. Three of these – 2014, 2016, and 2018 – were previously undertaken by London Economics. Data from the 2020 edition of the Size & Health study was not available to us, but we matched data from the 2021 edition to the earlier datasets using unique Companies House identifiers or via manual matching of company names. The survey asks for data on the two years preceding the survey as well as a forecast of the current year of the survey. For example, the 2018 survey wave therefore covers information on 2016 and 2017, as well as a forecast for 2018.[4] The studies cover key information on company performance and characteristics including space sector turnover and employment, Gross Value-Added (GVA), R&D investment, export intensity, education levels of employees, and other variables. To increase the scope of analysis, this database is further augmented with other firm-level variables obtained from third-party firm-level databases Companies House and FAME[5]. These databases

[3] UKSA Space Clusters are drawn from a list of space clusters provided by the UK Space Agency, and cover geographic areas with active policies to promote local growth in space companies.
[4] The convention chosen for this study is to represent financial years by the last calendar year covered by the financial year. A company with its financial year from April to March thus enters in the calendar year of March (FY2017-18 is covered in calendar year 2018).
[5] FAME is a data service provided by Bureau van Dijk. It aggregated financial data from Companies House and supplements with internal Bureau van Dijk analysis, including on ownership.

provided variables including firm size; industry classification; year of foundation (for firm age); whether a firm is under foreign ownership; and the degree of urbanisation of a firm's location.

The final dataset includes 1,603 companies and data in twelve distinct years from 2012-2021. We excluded all non-commercial entities from the analysis as a first step, because they do not trade in a commercial market and their reasons for success and failure are therefore not determined by the same factors that affect commercial firm performance.

We also carried out a robust data quality assurance process on the aggregated dataset to identify extreme outliers and inconsistencies. We either modified or strengthened inconsistent data by sourcing additional information. When this was not possible the firm was excluded from the analysis. The last step in the quality assurance process was the categorisation of data into different levels of credibility. Survey respondents were assigned the highest credibility (group 1). The data for those that have not responded to the survey is estimated through desk-based research from company accounts or other non-financial sources. The credibility attributed to these companies depends on how much of their activity is in the space sector. Where available, the data is validated through survey responses from previous waves. The result of this exercise is seven credibility groups. The group with the lowest credibility, group 7, contains companies previously excluded due to data issues and those in the tail of the distribution of space companies.[6] These firms have all been assessed as relevant for the Size and Health study.

The table below shows the number of companies in each of the credibility groups. For the statistical analysis, we focused on those companies deemed to be the most credible. This means that some of the analysis is limited to a subset of the overall database, with group 7 excluded from all econometric analysis of the growth outcome variables which are being a high-growth firm and delivering on high-growth potential. In particular in the last survey wave in 2021, the sample size decreases significantly.

Table 1 Number of firms in each group

Survey wave	Groups 1-2 (survey respondents)	Groups 3-6	Group 7
2016	160	131	455
2018	310	145	435
2021	64	209	1,113

Note: the large increase in firms in category 7 in the 2021 survey wave is a consequence of the ambition for the study to represent a 'light touch' update of the S&H study and reflects both the lower survey response rate and the larger population of firms compared with the 2018 wave.

2.3.1 Descriptive statistics

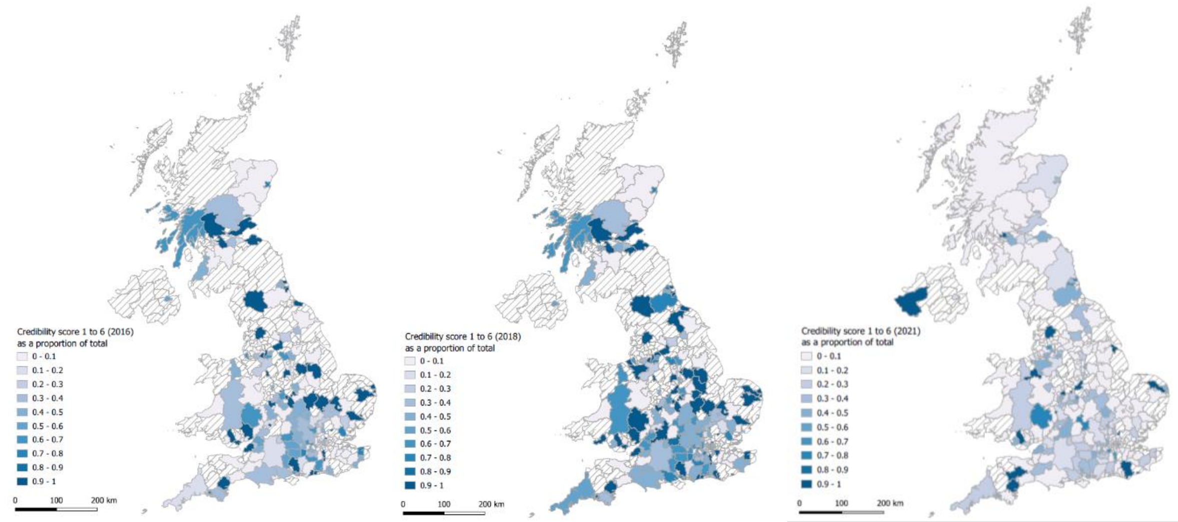
The first level of analysis is descriptive and aims to provide a brief overview of the data for different groups – e.g. in terms of aggregate space revenues, employees, R&D, firm size, export intensity, non-commercial share, growth rates, geographic distribution of employees, and proximity of firms to 'UKSA space clusters'. This analysis makes it possible to assess the extent to which different credibility groups are representative of the overall industry. The group with the highest credibility, i.e. survey respondents, are smaller on average in terms of turnover and space employment, but more R&D intensive than the industry overall. Companies which fill out the survey reveal that they consider themselves to be a member of the UK space industry. As such, the differences in characteristics exhibited between respondents and non-respondents may be due to sample self-

[6] These companies in the tail are covered by the small-firm reporting exemption from Companies House and financial information is therefore not available except through survey responses. Therefore, their turnover has been simulated or set to a common value.

selection. Overall, the groups are fairly similar across these categories. Further details are provided in the accompanying Annex.

Figure 1 shows the data that was categorised as credible and hence included in the growth analysis as proportions of the entire dataset in each local area. The darker-shaded regions show a higher share of credible data. The survey waves analysed are from 2016, 2018, and 2021. The years 2016 and 2018 clearly exhibit a good spatial coverage of credible observations. The year 2021 however, exhibits many areas with poor coverage of credible data, implying relatively few observations can be used in the subsequent statistical analysis.

Figure 1 Credible data as a proportion of total by region



Source: LE analysis

2.4 Analysis

The next level of analysis is focused on statistical and econometric analysis of the dataset to draw statistical inferences and identify the strength of relationships between different variables. We conducted three different types of analyses, using these methods:

- **Latent Dirichlet Allocation (LDA) cluster analysis:** to segment the sector into different groups based on the similarity of firm characteristics across predefined dimensions;
- **Growth analysis:** to model the relationship between independent variables and two dependent variables and revenue growth: being a high-growth company, and the ability to deliver on high growth potential
- **Exit analysis:** to assess the drivers of firm exit from the space sector by different categories of exits (all exits, inactive, active but exited UK space sector)[7].

Because of the break in the series between the 2014 and 2016 waves, the analysis data starts with the 2016 Size and Health study. Additionally, it has not been possible to create a panel dataset for analysis due to the relatively limited sample of companies in the 2021 wave with a credibility score of 1-6, and substantial difficulty matching firms between the 2018 and 2021 waves. For this reason, the econometric specification is a cross-section. Specifically, this means that the independent

[7] **Inactive companies** are those that appear as such on Companies House; **active, but exited the space industry** are companies that remain actively trading, but for which no space-related turnover is captured in Size and Health. **All exits** combine the two categories.

variable (firm growth or exit) is designated as the change between the early and later waves in the analysis. Two time periods are defined based on the earliest year in the early wave and the last credible year in the later wave. Specifically, the earliest year in the 2016 wave is 2014, and the latest year in the 2018 wave is 2017. For the second period, 2017 is also used as the starting point and the final observations are drawn from 2020. The LDA analysis was undertaken separately using data from the 2016 survey and data from the 2018 survey.

LDA cluster analysis was used to segment firms in the space sector into different groups, based on a wide range of characteristics. The method used, Latent Dirichlet Allocation (LDA), identified groups of firms based on combinations of shared characteristics. For example, firms that export may also tend to be firms that have high space employment and turnover. The identification of these combinations of shared characteristics by the LDA allows for an objective way of categorising the space industry across a wide range of characteristics without arbitrary choices about which characteristics are most important.

In both the 2016 and 2018 groupings, five sub-groups were identified with a few similar groups across the two survey waves. Both 2016 and 2018 included a group that contained core space companies that had high space employment/turnover and a broad range of customers (group 1 in both), a group of firms focusing on the UK domestic market (group 3 in 2018 and group 2 in 2016), and a group of firms with weak financials (group 4 in 2018 and group 3 in 2016). A fifth 'residual group' of firms not characterised by the other four groups and with fewer common characteristics between them was identified in both the 2016 and 2018 groupings. For each company, LDA clustering estimates the probability that it is in each of the clusters. It does not allocate a company to one specific cluster.

Figure 2 LDA cluster descriptions

The five clusters from the 2018 survey of companies can broadly be characterised as:

1. Core space companies	2. Space agency suppliers	3. Small domestic market suppliers	4. Small companies with weak financials	5. Residual group
• High space employment and turnover • Diverse customer types • Diverse space domains	• Medium space revenue • Customers more likely to be space agencies (UKSA, ESA)	• Pre-revenue companies or too small to report employment • More likely to serve the domestic UK market	• Small companies • Negative solvency and current ratios • Medium space employment	• Other aspects not as prevalent in the other groups

The five clusters from the 2016 survey of companies can broadly be characterised as:

1. Core space companies	2. Medium domestic market suppliers	3. Companies with weak financials	4. Stable companies outside clusters	5. Residual group
• High space employment and turnover • High R&D intensity • Diverse customer types	• Low or medium space revenue and employment • More likely to serve the domestic UK market	• High space revenue • Negative solvency and current ratios • International links through foreign ownership	• Medium solvency and current ratios • Medium R&D intensity • Location further from defined UKSA space clusters	• Other aspects not as prevalent in the other groups

In the **econometric analysis**, we tested the relationship between a list of independent variables and the outcome variables on growth using ordinary least squares (OLS) and Logit models.[8] The full methodology is explained in the Annex.

The **independent variables** identified in the literature review were each tested on their impact on the outcome variables. These include R&D investments, R&D intensity, number of space-related employees, firm size (number of total firm employees), firm age, export intensity, whether a company is within 5 km of a UKSA space cluster, whether a company is in an urban region, whether a company is foreign-owned, non-commercial income share, and which LDA cluster they are most likely in. The full list of variables of interest is included in the Annex.

To test the relationship between the independent variables and **company growth**, three outcome variables were created.

- The first outcome variable is the **3-year compound annual growth rate (CAGR) of space-related turnover.**
  - This relationship was tested using an OLS model. The results of this regression estimate the impact of the independent variables on a firm's growth rate.
- The second variable is a dummy that takes the value 1 if the 3-year CAGR is greater than or equal to 20%, i.e. the company is a **high-growth company**, and 0 otherwise.
  - This relationship was tested using a Logit model where the results indicate the probability that a company is high-growth.
- Lastly, if a company is a high growth company over both the first and the second period, a dummy for **delivering on high growth potential** takes the value 1, and 0 otherwise.
  - This relationship was also tested using a Logit model.

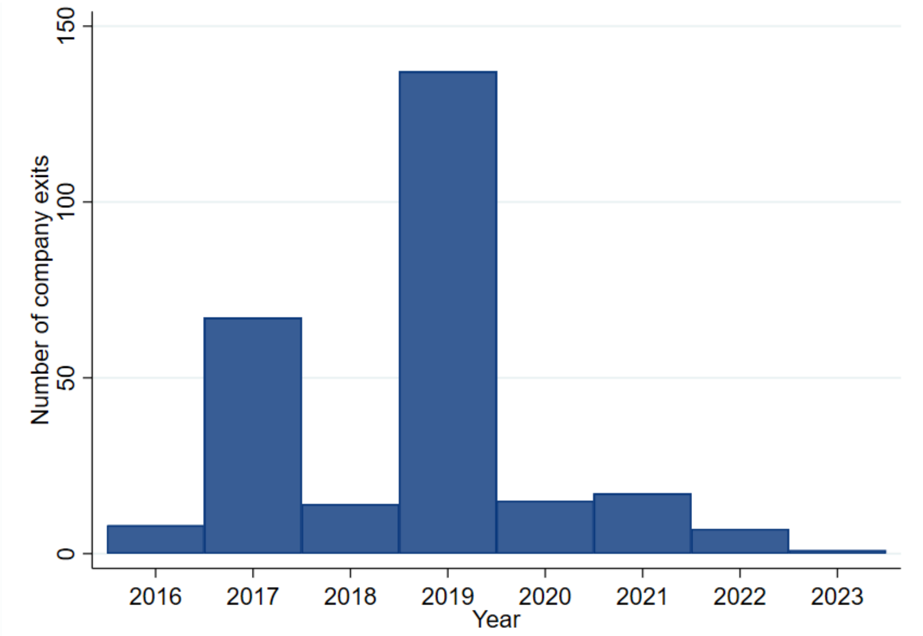
The sensitivity of the results was analysed in three parts:

1) Using different time periods: 2014-2017 and 2017-2020
2) Using different regression models: OLS and Logit
3) Using different subsamples including only survey respondents or the entire sample of credible data.

Along with the analysis of company growth, we also looked at factors determining the **survival of a company** in the UK space sector. A company can exit by becoming inactive, meaning they are dissolved or cease trading, or by remaining an active company that no longer operates in the UK space sector. This could mean that they either moved their activity to a different sector or have moved their space activity to a different country. The figure below shows the number of firms that have exited over time. The year of exit is the first year with zero space-related activity in the UK.

[8] Ordinary least squares (OLS) investigates the association between variables by minimising the sum of the squared differences between the observed dependent variable and the output of the (linear) function of the independent variable. A Logit model is a regression model where the dependent variable is a categorical variable taking on only discrete values. The output of a Logit model is a probability that an event occurs and is constrained between the values 0 and 1. Both OLS and Logit regressions were analysed in order to cross-validate results.

Figure 3 All company exits in the data over time



Note: For the 2018 survey, all companies of the previous survey wave were re-evaluated to assess whether they are still active in the UK space sector which resulted in a spike of company exits in 2017, i.e. after the 2016 survey wave. The second spike is a result of a large number of companies with positive space revenue in 2018 indicated to have zero space revenue from 2019 onwards. The spike may represent methodological or definitional changes as a result of a change in contractor as well as genuine company exits.

For this analysis, the outcome variable of interest is a dummy that takes the value 1 if the company had exited the UK space sector, no matter how. In the exit analysis, all credibility groups are considered.[9] Using a Logit model, it was tested which independent variables (which are the same as for the growth analysis) significantly change a company's probability to exit the UK space sector.

The results of this analysis are reported and summarised in the rest of this report.

[9] The presence of positive space turnover as assessed by the contractor delivering Size and Health is deemed sufficient to include a company in the sector and therefore be able to determine its exit when that turnover reduces to 0. The Size and Health database does include pre-revenue companies, and classifies these as members of the sector. However, it is deemed unlikely that companies get to a stage of post-revenue, but remain active in the sector.

3 Findings

3.1 Key findings

This report presents the results of a first attempt to derive statistical inferences from the unique Size & Health database on the drivers of firm-level growth and firm exit from the industry. These results need to be robust if they are to inform policy, investment, and other government interventions with any degree of confidence. The data-driven and statistically robust approach used in this study has attempted to do this in a way that can be replicated as future editions of the study are undertaken. This section summarises the key findings that emerge from these analyses.

The UK space industry can be **segmented into several key groups** that differ in terms of the level of space-related revenue and space-related employment, the range of customers that they serve, their solvency and asset/liability ratios, their size, their level of connectivity to international markets, the domains in which they are active, and their position in the value chain. While there are many other dimensions of difference between firms, these variables have been found to be the most prominent.

When it comes to the effect of different variables on **firm-level growth**, the results of both the OLS and the Logit regressions suggest that R&D intensity has a statistically significant impact on growth. This implies that firms that invest more in R&D tend to grow faster than those that do not. This result holds for the 2014-2017 period across all subsamples.

Additionally, two other variables were found to have a weakly significant impact on firm-level growth in the Logit regressions. The first of these is firm age, which has been found to have a negative and weakly statistically significant effect on growth, tentatively suggesting that younger firms experience faster growth. These results mainly hold for the 2017-2020 sample in the Logit regression. For firm age, there is some positive significance observed indicating a non-linear relationship.[10] The second variable is space employment, which has been found to have a negative and weakly statistically significant effect on growth, tentatively suggesting that firms with relatively fewer employees working in space experience faster growth. For the OLS model, the results only hold for the full sample in 2014-2017.

These (weakly) significant variables were collectively run as a single unified regression to test how the strength of the relationship between these variables. The results for both the OLS and the Logit regression show significant effects for R&D intensity (positive) and firm age (negative).In the unified regressions, the estimates for space-related employment were not significant.

The remaining variables tested, including firm size, have been found to have either a non-statistically significant or ambiguous relationship with firm-level growth. Ambiguous estimates imply different directions of impact across the subsamples, models, or time periods. These include variables such as proximity to a UKSA space cluster, export intensity, foreign ownership, commercial income share, and presence in an urban conglomeration. However, it is worth noting that these results are more likely to stem from the poor explanatory power of the data, given the weakness and small sample size of the data, rather than confirming that these variables have no effect on firm-level growth.

There was no statistically significant correlation between the LDA clusters and the growth of firms at the individual level. Similar to the other insignificant variables, this does not necessarily imply

[10] This is observed through including a quadradic variables of firm age in the analysis which obtained a positive, significant estimate.

that there is no relationship, but instead these results are a result of incomplete data. Therefore, it was not possible to determine whether companies with certain characteristics experience higher growth than others.

In the estimation of the properties influencing a firm's ability to **deliver on high growth potential** using a Logit model, only a few variables were found to be relevant. These include R&D intensity (positive) and space-related employment (negative). The small sample size has limited the conclusions that can be drawn from this analysis, and variables which are found to be highly significant in the previous analysis on firm-level growth, such as R&D intensity, lose some of their significance. In order to draw more comprehensive conclusions, a larger sample of companies is needed

Overall, this research sheds light on the complex nature of the UK space industry and highlights the importance of R&D investment for firm-level growth. While other variables may not have a statistically significant impact on growth, they may still play a role in shaping the dynamics of the sector. Further research with larger and more diverse datasets could help to deepen the understanding of these relationships.

The **exit analysis** of the UK space industry reveals several variables that have a weak but significant impact on firm-level exit. These variables include the level and intensity of R&D, firm size, export intensity, proximity to a UKSA space cluster, and foreign ownership. The relationship was tested for the periods 2014-2017 and 2017-2020 as well as in subsamples considering only firms that became inactive or firms that are still active but have left the UK space sector.

The estimates found that firms that have a higher level and intensity of R&D are less likely to exit the industry which suggests that investing in R&D helps space firms to remain competitive and sustain their operations. This result is weakly significant for the entire sample of exits in 2014-2017. Similarly, firms that have a higher level of export intensity are also less likely to exit the industry. The weakly significant result only holds when considering the subsample of firms that became inactive in the 2014-2017 sample.

Moreover, firm size has been found to have a negative impact on the probability of firm exit. Smaller firms are more likely to exit the industry than larger firms. Proximity to a UKSA space cluster also has a negative impact on firm exit. That is, firms that are located closer to a UKSA space cluster are less likely to exit the industry, suggesting that being part of a space cluster can provide firms with access to resources helping to sustain their position in the industry. The estimates for firm size and UKSA space cluster proximity only hold for some of the subsamples in both periods considered.

On the other hand, foreign ownership has a positive impact on firm exit when considering all company exits in the 2014-2017 sample. Firms that are foreign-owned are more likely to exit the UK space sector than those with domestic ownership.

While some of the above results are in line with findings from the literature or logic, such as the positive effect of R&D investment on firm growth and survival and the seeming 'flightiness' of foreign capital, many of the results cannot be interpreted as definitive and therefore should not become the sole basis of any clear policy recommendations. This is because the limitations to the data have reduced the number of firms that can be robustly subject to the regression and exit analysis, increasing the likelihood of statistical insignificance and 'null' results. These data limitations are described in the subsequent section.

4 Limitations

4.1 Caveats and limitations

While all reasonable steps have been taken to ensure the quality of the data is of the highest standard, several caveats must be observed when using the results of this study. Some of the caveats apply to Size and Health data more generally, and some apply specifically to the data aggregation process undertaken for the present study:

- **Reporting errors:** We have assumed that organisations that complete the Size and Health survey will provide better estimates of their space activity than any analyst could. However, historical experience suggests that some companies report turnover in incorrect units or misunderstand questions leading to false answers. While care and attention have been paid to resolve such issues, some may have slipped through and be present in the data.
- **Measurement error uncertainty of estimation:** The characteristics of the space sector make it inherently difficult to measure economic activity. For this analysis, we have employed estimation and approximation techniques based on survey data, supplemented by financial account data and desk-based research where estimation relies on careful judgement. It is therefore not possible to accurately assess the coverage of the analysis and the measurement error associated with survey data.
- **Self-selection into the sample**: Due to the reasons listed in the previous two points, companies that have responded to the survey are accredited with the highest credibility level. However, companies which fill out the survey reveal that they consider themselves to be a member of the UK space industry. As such, the differences in characteristics exhibited between respondents and non-respondents may be due to sample self-selection.
- **Unidentified omissions:** The objective of Size and Health is to capture the full UK space industry. Nevertheless, relevant companies may not have been identified and be missing from the database.
- **Exchange rate fluctuations:** The Size and Health study normalises all financial values to a common currency, GBP. For that reason, companies that trade in other currencies may experience a change in revenue or input costs purely as a result of exchange rate movements rather than any underlying trend. These fluctuations affect the competitiveness of UK companies in foreign markets so it is not possible to strip out the effect, but the results should be studied carefully to take account of this factor.
- **Financial years:** All companies estimate income and employment across financial years where the start and end vary between companies which reflect the specific financial years of companies. **References to years in this report are simplified such that a year represents the end year of the companies' accounts**. I.e., the year 2020 covers company financial years ending in any month of 2020. This introduces some degree of comparability issues in cases where significant macroeconomic events occur.
- **Company matching**: The Size and Health questionnaire does not explicitly request the reporting company's unique identifier found in Companies House. This means that some organisations may not be matched between survey waves (e.g., if they have changed names and moved location in the intervening period). Even where company numbers are clearly identifiable, they may not represent the same in different years. E.g., if there has been a merger this means that the acquiring company may display significant growth rates resulting from consolidated reports rather than underlying market developments.

For the reasons outlined above, this study should be viewed as a first attempt at identifying characteristics of growth companies

4.2 Variables that could not be collected

This report presents the results of a first attempt to derive statistical inferences from the Size & Health database. Future iterations of this study could benefit from studying additional variables, which have not been possible to collect for this iteration, including:

- **Deprivation indexes** could be used to capture socioeconomic conditions that may impact firm outcomes over time. Deprivation index data in the UK is released on the devolved administration level, and often the years of release differ. The process of analysing the data also differs between administrations as they use different definitions for what constitutes a 'deprived area'. This meant that this variable could not be standardised for inclusion.
- The Size and Health survey does not include data on **management quality**, and it was not possible to find a valid proxy from available data on FAME.
- **Altman's Z score** is an indicator used to predict whether a firm is heading towards bankruptcy.[11] Not all variables required for its construction were available in FAME, particularly for small companies but some variables were not present in the database at all. Alternative financial indicators like the "Springate score" also suffered from this problem.
- An accessible database of **alumni from accelerators or business incubators** could not be found, and therefore this dummy variable could not be considered in the analysis.
- There were also issues with collecting data on **venture capital funding** and this was therefore not included in the analysis.
- Data on **university spinouts** was collected but due to the small number of observations it was not possible to analyse the effects on growth.

According to the literature, being an alum of an accelerator or being a university spinout has a positive effect on growth. Venture capital funding should also have a positive impact on growth, although selection bias is present since firms which attract more venture capital funding are likely to have higher growth potential.

[11] A measure of financial distress based on ratios of sales, working capital, retained earnings, and EBIT over total assets, market value of equity over book value of debt.

5 Recommendations

The challenges to creating a panel dataset of UK space industry companies have limited the explanatory power of the econometric analysis and the sophistication of the methods employed. This analysis is strongly dependent on the quality of the input data from several Size and Health waves, and clear indications of inconsistencies between different survey years have been identified.

To improve the breadth of results and richness of the data, LE recommends building consistency checks into the Size and Health project to a much greater degree than has been the case. At the practical level, this would mean assigning all companies a unique identifier (Company Registration Number from Companies House is suggested), to ensure there is traceability of the company's data and a clearer path to querying the data.

Companies that respond to the survey engage in a form of a dialogue with the UKSA and historically, many have answered clarifying questions. We recommend that this activity should be encouraged and responses logged in a deliverable as part of the study to ensure there is traceability.

As this report has shown, however, a sizeable proportion of the findings in the Size and Health study draws on data that are not based on survey responses. These cannot obviously be queried and the results therefore depend on the judgement of the analyst that has investigated the company's activities and classified a space share from annual reports and websites. We believe, comparing results at the company level would result in a better output. Although this must be balanced against the primary objective of the Size and Health study: to provide an up-to-date picture of the industry's performance.

Index of Tables, Figures and Boxes

Tables

Figures

ANNEXES

Annex 1 Literature review

The literature review identified several relevant variables for studying the determinants of high growth for firms in the UK space sector. An understanding of these factors has the potential to inform policy and support economic growth.

In the context of the UK space industry, such an understanding can support progress towards one of the National Space Strategy's (2021) objectives of “growth and levelling up of the UK space economy”.

This section presents a summary of the key findings of the literature review. It starts with an overview of those variables identified as important for firm growth in the literature; summarises the evidence on sector-specific constraints that are likely to inhibit growth, and discusses the implications of these findings for the statistical analysis underlying this work.

A1.1 Characteristics of high-growth firms

A1.1.1 Firm-specific characteristics

Of particular importance for firm-growth determinants are characteristics that relate specifically to the firm.

Innovation and R&D

Innovation has been suggested as an important driving factor for business growth. This is clear from the prominent position of innovation in the 2021 Plan for Growth Report which sets out the importance of a more even distribution of R&D activity across the UK (HM Treasury, 2021; NIESR, 2021).

BEIS (2017) study the impact of receipt of support for business innovation through grants, loans, advice, and access to specialist services operated by Innovate UK and the National Measurement System (NMS) on the survival, employment, and turnover of firms. They find consistent evidence of positive, significant impacts on survival and employment for both treatments of receiving support from Innovate UK or the NMS, as well as generally positive but not significant effects on turnover.

NIESR (2021) find that private R&D investment, in the form of self-reported R&D expenditure from the UK Innovation Survey, has a strong, positive effect on productivity, particularly in high-tech manufacturing industries and knowledge-intensive service sectors. Smaller positive returns are also found for firms in less technologically intensive industries.

Firm size

The size of a firm and its implications on growth have been extensively discussed.

Robert Gibrat’s ‘Inègalitès Èconomique’ presented the first formal model of the dynamics of firm size and industry structure (Sutton, 1997). Gibrat proposed a rule stating that the proportional rate of growth of a firm is independent of its absolute size (Gibrat, 1931; Samuels, 1965).

Further studies have questioned the specifics of the relationship. Singh & Whittington (1975) documented a weak, positive relationship between size and growth. There is therefore an argument to include various dummies for industry types to try and study this relationship in greater depth.

This is further supported by Voulgaris et al. (2003) who found that the growth of Greek manufacturing SMEs varies by industry subgroups.

Hart & Oulton (1996) found that when their sample was broken down by size group, small firms grew quicker in their study period of 1989-1993.

Large firms exhibited no relationship between growth and size, implying that Gibrat's law holds only for firms of a larger size. Evans (1987) found that firm growth decreases with size, which is inconsistent with Gibrat's law and also found evidence to suggest that growth declines with firm age.

Management quality

Management quality has been suggested as a further driver of firm growth.

Bloom et al. (2016) found a positive impact of management on firm performance, and that as firms age, the average level of management increases and the dispersion of management practices decreases (due to the exit of poorly managed firms). Bloom et al. (2013) studied a management field experiment where free consulting on management practices was provided to a randomly chosen treatment of manufacturing plants. The adoption of these management practices led to a substantial increase in productivity in the first year through improved quality and efficiency, and reduced inventory. This evidence points to management quality as an important variable concerning the growth rate of firms.

Export intensity

There are indications that export intensity is relevant for firm growth.

Castellani (2002) found that entering the export market did not necessarily increase productivity per se, but increases in the export intensity (share of foreign sales on total sales) did have a significant and positive impact on productivity growth. It is suggested that significant involvement in international activities, specific investments, and knowledge accumulated through time and experience in foreign contexts are needed in order to capture the benefits of internationalisation (Castellani, 2002).

Greenaway et al. (2002) examined a panel of UK manufacturing firms and found that exporting firms tend to be more productive relative to non-exporters, and that they self-select, i.e., they are more productive before they enter the export market. They provided further evidence that exporting leads to increases in productivity. Crespi et al. (2008) found evidence consistent with the learning-by-exporting hypothesis for a panel of UK firms. This hypothesis proposes that firms learn in ways that enhance their performance via exporting.

Foreign ownership

Foreign ownership is another characteristic which has been discussed in the literature as potentially important for firm growth.

There is a general expectation that foreign direct investment (FDI) inflows will bring capital, new technologies, marketing techniques, and management skills, which could lead to increased growth (Javorcik, 2004). An analysis using firm-level data from Lithuania was undertaken by Javorcik (2004) and produced evidence consistent with positive productivity spillovers from FDI taking place through contacts between foreign affiliates and their local suppliers in upstream sectors. The data indicated that spillovers were associated with projects with shared domestic and foreign ownership but not with fully owned foreign investment. This can be explained by the former type of FDI investment involving more local sourcing. Keller & Yeaple (2003) estimated international technology spillovers to US manufacturing firms and found evidence that FDI leads to significant productivity gains for domestic firms. The estimated FDI spillovers were also found to be much larger in relatively high-technology industries than in relatively low-technology industries.

Other characteristics

Beauhurst suggests further characteristics of relevance for high firm growth. These include whether a firm is a university spinout, the proportion of turnover that comes from grant funding, whether venture capital investment is present within the firm, and whether the firm has graduated from a selected accelerator.

A1.1.2 Geography

Since 1990, a new genre of research emerged, described as ‘New Economic Geography’ (Krugman, 1998). It led to the greater consideration of spatial factors (such as agglomeration externalities) when undertaking economic analysis and served the important purpose of placing geographical analysis in the economic mainstream. It is therefore important to discuss these factors and, when appropriate, to take them into account.

Proximity to R&D activity

An important consideration regards spillover effects of R&D investment. Firms benefit from knowledge and ideas that spill over from geographically and technologically proximate firms, universities, or organisations undertaking R&D (NIESR, 2021).

Arzaghi & Henderson (2008) found that these networking and information spillover effects were significant for advertising agencies in New York, although they dissipated quickly with distance. Greenstone et al. (2008) found evidence that this also impacted the manufacturing industry, by showing that manufacturing plants located in US counties where a BMW ‘Million Dollar Plant’ chose to locate (‘winning county’) experienced a sharp and persistent increase in total factor productivity (TFP) relative to plants in ‘losing’ counties. Further, the spillovers between the ‘Million Dollar Plant’ and incumbent firms were larger when they shared labour pools and technology. Thus, it is relevant to consider the geographic proximity of space organisations to universities, to each other, or to research organisations in the space sector.

Geographic cluster/concentration

Geographical clustering offers a great variety of economies of scale and scope such as transaction benefits, contact opportunities, and search advantages (Verhoef & Nijkamp, 2003). The existence of these urban agglomeration externalities, highlighted in studies such as that of Arzaghi & Henderson (2008), means that it is also important to examine whether a firm is located in an urban or rural area. Pugh et al. (2019) observed a wide distribution of both standard, and high-growth companies, and found that high-growth companies are more likely to be found in ‘major conurbations’, which are the most densely populated areas in their study, rather than in more sparsely populated areas including cities, towns, and in the fringes of towns. Voulgaris et al. (2003) found in their study of Greek manufacturing firms that SMEs located in big cities behaved differently from firms located in the periphery. They found that factors such as the percentage of exports over sales, asset profitability, and long-term leverage were related to fast growth for firms located in the city and not for firms located in the periphery. Similarly, Rijkers et al. (2010) studied manufacturing enterprise performance in Ethiopia, and found that urban firms were larger, more capital intensive, have higher labour productivity, and grew relatively faster when compared to rural firms. The results were partly attributed to differences in the quality of infrastructure, access to credit, and transportation costs across rural and urban areas. These studies highlight the importance of taking location into account when analysing the characteristics of high-growth firms.

A1.1.3 Socio-economic factors

Socio-economic factors which have been recently targeted in the government's 'Levelling-Up' agenda. This aims to reduce the geographic inequality across the United Kingdom and focuses on policies aimed at improving infrastructure, education, healthcare provision, innovation, and reducing crime (DLUHC, 2022). Over half of the Space organisations in the UK are located outside the London and South-East region, which suggests that policies aimed at tackling geographic inequality, centred in coastal areas, the North, and Midlands, will have an impact on numerous space organisations (Bryce Tech, 2021). The tackling of the driving factors of disparity could lead to periods of high-growth following this intervention. Therefore, it may be important to consider variables such as healthcare budget, local crime statistics, and infrastructure investment in the vicinity of space organisations to control for the effect of this policy.

Quality of infrastructure

Infrastructure investment has been found by numerous studies to have positive impacts on inter regional trade. Donaldson (2018) investigated the impact of railroad building in India during the British colonial period, and concludes that railroad expansion reduced the cost of trading, reduced inter-regional price gaps, and increased trade volumes.

Rijkers et al. (2010) found that rural firms grow less quickly than urban firms, partly attributing this to differences in the quality of infrastructure. Their analysis suggests that, amongst other interventions, improving electricity supply would help catalyse the growth of small enterprises. Jensen (2007) studied the impact of the introduction of mobile phone service throughout the Indian state of Kerala between 1997 and 2001, focusing on the impacts on local fishers. Improvements in information dissemination through investment in infrastructure, such as phone tower construction, led to improvements in market performance and welfare. The adoption of mobile phones was shown to be associated with a dramatic reduction in price dispersion, the complete elimination of waste (a particular problem due to the perishability of fish), increased profits amongst fishermen, and the near-perfect adherence to the 'Law of One Price' (i.e., the price of a good should not differ between any two markets by more than the transport cost between them). Both consumer and producer welfare were shown to have increased. Infrastructure investment is shown to have important and substantial impacts on economic outcomes, and it is therefore important to take this into account.

A1.1.4 UK space sector growth constraints

The UK space sector has faced unique challenges since the exit of the UK from the European Union.

Loss of access to EU space programmes

Currently, the UK does not participate in the Galileo or EGNOS programmes, although it is able to continue using the open position, navigation, and timing services (Wilson & Galasso, 2019). The participation of the UK in the Copernicus project was worth £750 million per year, which the government paid to the annual EU budget, and which was then roughly returned to the UK space industry in the form of major contracts. This made Copernicus an important driver of growth in the UK space sector.

The UK has, since Brexit, been suspended from participating in the EU Space Programme. However, the project has moved forward and UK companies have lost the most valuable Copernicus and Galileo contracts to EU companies. Additionally, the 'third country' status of the UK would give it no voice in the evolution or management of the programme (Elefteriu, 2022). This could lead to a potential reduction in the competitiveness of UK space companies for contracts relating to Copernicus and Galileo if the EU decide to change procurement legislation. At the time of writing, it is not clear what the UK's long-term position will be.

Disruption to supply-chains, trade, and workforce

The effect of EU exit related challenges is reflected in the 2020 edition of the Size and Health report of the UK Space Agency, where a little under half of the survey reported negative impacts from Brexit on income and demand. About 1 in 3 respondents reported some negative impact in their workforce, suppliers, and investments which correspond to the barrier of the UK's exit with the EU (know.space, 2021). The 2021 Space Census further discusses the constraints Brexit poses. Foreign nationals in the space sector were 3 times more likely to be changing jobs due to immigration related issues, such as Brexit (Thiemann & Dudley, 2021). The Space Skills survey also stated that "Brexit has made it more difficult to recruit from Europe and has encouraged some European staff to return to their original countries" (BMG Research, 2021). Brexit could therefore have serious implications for the growth of firms in the UK space sector and it would be important to include this in the statistical analysis.

Other structural weaknesses

The upstream sector suffers from structural weaknesses, identified in Red Kite Management Consulting's report on the UK Space Supply Chain. Firstly, the sector is highly dependent on imports, with over 60% of inputs being imported from abroad. It does however export strongly, with imports and exports being in approximate balance. Secondly, although the UK has companies with capabilities to integrate all sizes of satellites and provide crucial systems, Airbus is the only UK supplier with the ability to manufacture and integrate satellites above 115kg and supply many of their key subsystems (Red Kite, 2022). The presence of a capable company such as Airbus has allowed the UK to be involved in large commercial ESA space projects, however, there is limited competition in the procurement of large national space systems. Thirdly, the sector is underrepresented in medium to very large companies with 100+ employees and instead has a large number of smaller SMEs. This raises the question of whether the lack of presence of medium to very large companies constrain the undertaking of large scale and costly research and development. Despite this there are several 'outposts' of large foreign-owned groups that have expressed interest in expanding their UK operations (e.g. Lockheed Martin, Thales Alenia Space) which implies this balance may shift in the near future.

A1.1.5 Variables that could not be collected

There were a number of variables that presented issues with regards to data collection. **Deprivation indexes** could be used to capture socioeconomic conditions that may impact firm outcomes over time. Deprivation index data in the UK is released on the devolved administration level, and often the years of release differ. The process of analysing the data also differs between administrations as they use different definitions for what constitutes as a 'deprived area'. This meant that this variable was not included in the analysis.

The Size and Health survey does not include data on **management quality**, and it was not possible to find a valid proxy from available data on FAME.

Altman's Z score[12] was also difficult to construct as data for some of the variables in the calculation were not reported by smaller firms in FAME, and some variables were not present in the database at all. Alternative financial indicators like the "Springate score" also suffered from this problem.

An accessible database on **alumni from accelerators** or **business incubators** could not be found, and therefore this dummy variable was not able to be considered in the analysis. There were also issues with collecting data on v**enture capital funding** and this was therefore not included in the analysis. Data on **university spinouts** was collected but due to the small number of observations, it was not possible to analyse the effects on growth. Being an alum from an accelerator or being a university spinout is hypothesised to have a positive effect on growth. Venture capital funding should also have a positive impact on growth, although selection bias is present since firms which attract more venture capital funding are likely to have a higher growth potential.

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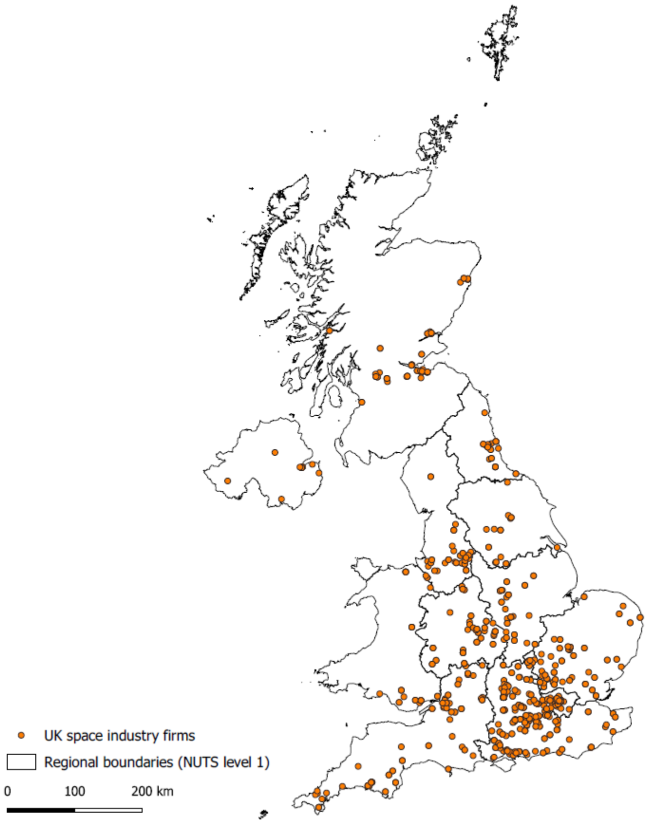
Annex 2 Descriptive analysis

The descriptive statistics in this section give a brief summary and overview of the data. First the geographic distribution, in particular related to the proximity to the nearest UKSA space cluster[13] is discussed. This is then followed by summary statistics on the variables of interest.

Figure 4 Location of UK space companies used in the analysis across all years

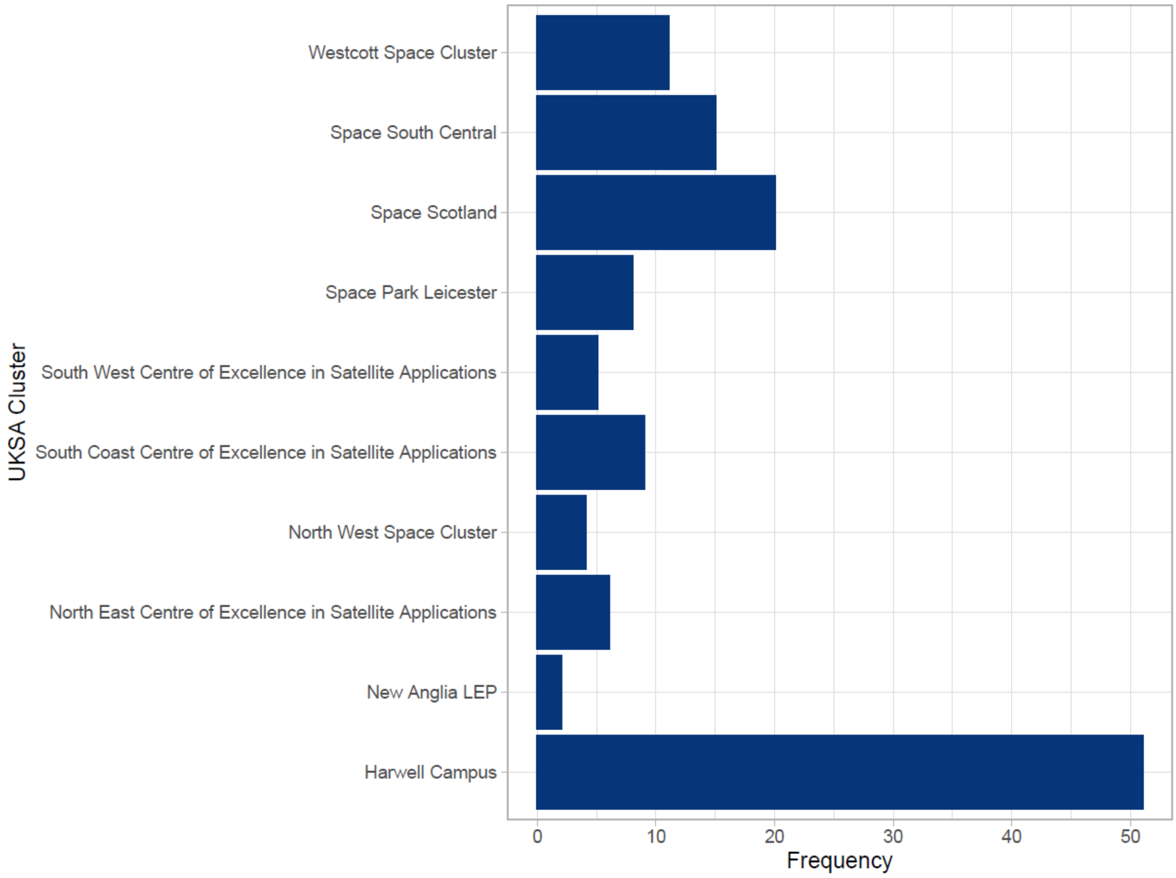


Source: LE analysis

Figure 4 gives a visual representation of where space companies are located in the UK and shows an uneven distribution of firms across space. It is clear that the majority are found in the Southeast of England, although a sizeable number can be found around Manchester, and in Scotland between Edinburgh and Glasgow.

[13] The UKSA hold a list of designated UK areas classified as space clusters. In this report these clusters are referred to as UKSA space clusters.

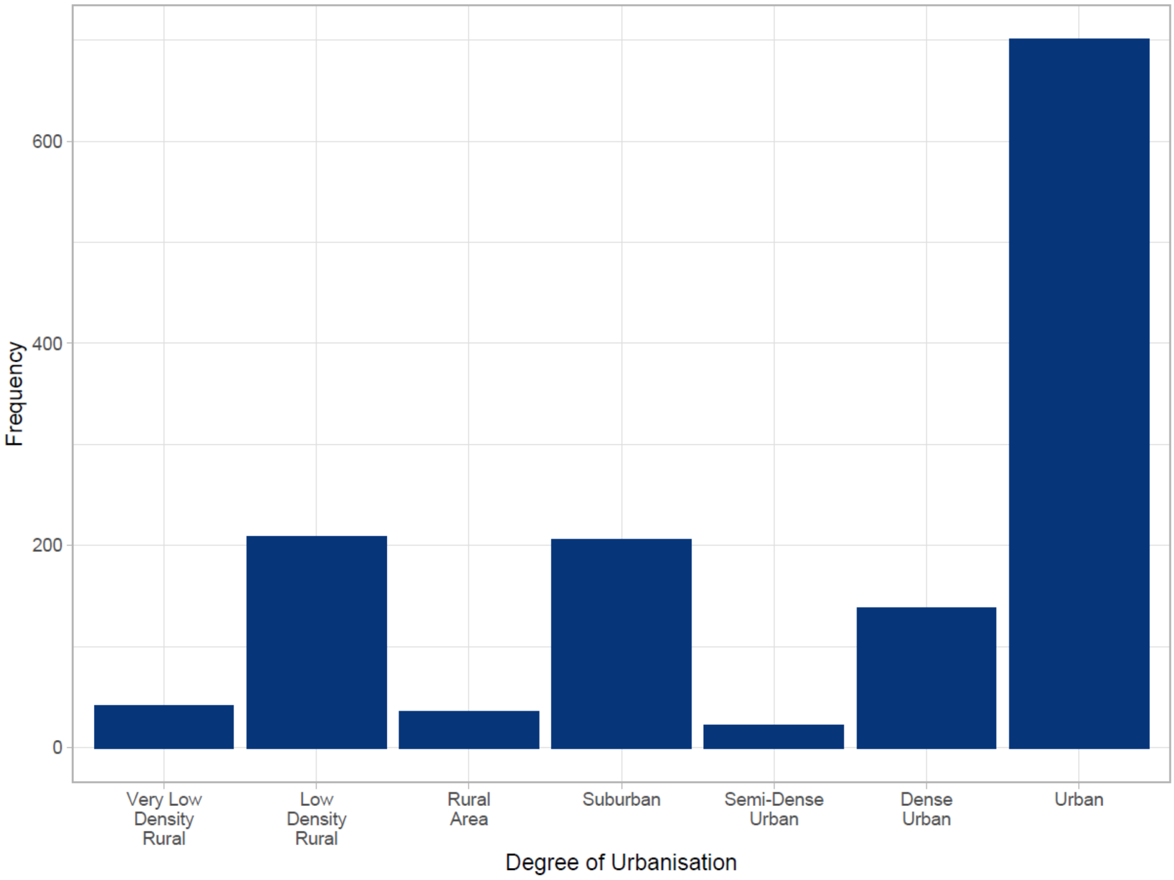
Figure 5 Frequency of space companies within 5km from a UKSA space cluster



Note: Space sector firms that were further than 5km from the nearest UKSA space cluster were excluded. All companies in the dataset except universities and government organisations are included.

Figure 5 sets out how many space sector companies are located within 5km from a UK Space Agency (UKSA) identified cluster. The UKSA space cluster is an intentionally created agglomeration of space companies attempting to derive the positive benefits of co-locating. Harwell campus contains the largest number of space industry companies. It is important to note that 'UKSA space clusters' have no connection with the 'LDA clusters' identified in this report using the LDA method.

Figure 6 Frequency of urban/rural classifications where firms locate



Note: All companies in the dataset except universities and government organisations are included.

Figure 6 shows the frequency that a space sector firm is located in a specific urban/rural classification. Most space sector firms are shown to be located in urban areas. Notably, suburban, and low density rural also have relatively high frequencies.

The outcome variable of interest for the growth analysis is each firm's compound annual growth rate (CAGR) of space-related revenue. Table 2 breaks the sample of firms into deciles in terms of 3-year-CAGR of revenue between the years of 2014 - 2017 and 2017 - 2020.

Table 2 Space revenue 3-year CAGR deciles

Revenue CAGR (2014 – 2017)								
10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
-21.50	-8.58	0.58	4.01	8.58	14.90	24.54	51.61	80.82
Revenue CAGR (2017 – 2020)								
-50.55	-33.10	-15.16	-7.86	-1.40	2.73	14.85	35.12	60.86

Note: All values are expressed in percentages. This includes all data underlying the growth analysis (credibility scores 1-6).

In 2014 – 2017 the vast majority of firms documented positive growth rates, which is in stark contrast to 2017 – 2020 where the majority of firms saw negative growth rates. These differences might reflect events in the latter period such as Brexit and the Covid-19 pandemic that have impacted firm-level and GDP growth. For reference, the UK's GDP grew around 2.2-2.4% in 2014-2017, while it decreased by 11% in 2020 due to the pandemic.[14]

Table 3, Table 4, and Table 5 show the summary statistics by credibility score to compare groups included in the econometric analysis (groups 1-6) to the entire sample. Survey respondents are assigned a credibility score of 1 and represent the most trustworthy data in the sample. Credibility score 2 considers companies that have responded to the survey in the previous wave, therefore the current data builds on these responses and supplemented by annual reports or other desk-based research. Scores 3 to 6 considers data that was collected from desk-based research only, with the credibility of the data reducing as the company's space share reduces. Credibility score 7 was assigned to data based on simulation or arbitrary values (the 'tail') which is highly questionable, and oftentimes incorrect.

When considering the sample, firms with the best available data (i.e., credibility = 1) are different from those assigned higher credibility scores, specifically being smaller in terms of turnover and space employment, but more R&D intensive. Companies which fill out the survey reveal that they consider themselves to be a member of the UK space industry. As such, the differences in characteristics exhibited between respondents and non-respondents may be due to sample self-selection.

Across the years, the sample size increases substantially when comparing only survey respondents (score = 1), and those with a score between 1 and 6. The largest differences in the samples can be seen in Table 5, mainly due to the vast majority of firms in the sample being assigned a credibility score of 7.

The econometric analysis in this report is presented for different cuts of the credibility scores. From covering only survey respondents to capturing all of the firms in credibility scores 1-6.

Table 6 provides statistics on the proportion of observations, and proportion of the total value that is represented by credibility scores.[15] This provides further evidence that companies assigned a credibility score of 1 are different than those who are not, and these companies make up a much larger proportion of the data when compared to their relative observations.

Table 3 Credibility score (2016) descriptive statistics

Credibility score	N		Mean		Standard deviation		Min		Max	
(2016)	≤ 6	≤ 7	≤ 6	≤ 7	≤ 6	≤ 7	≤ 6	≤ 7	≤ 6	≤ 7
Space revenue (£m)	279	588	16.950	9.417	84.470	59.090	0	0	833.8	833.8
Space-related employees (#)	279	587	45.40	26.85	197.8	140.1	0	0	2,718	2,718
Space R&D (£m)	262	570	0.785	0.439	4.968	3.430	0	0	71.9	71.9
R&D intensity (%)	226	525	0.262	0.145	0.940	0.630	0	0	11	11
Firm size (# employees)	147	210	2,017	2,520	9,403	13,064	2	1	95,455	132,300
Export intensity (%)	291	745	48.18	36.07	39.71	34.76	0	0	100	100
Non-commercial share (%)	156	157	23.07	23.56	36.93	37.32	0	0	100	100

[14] Source: Office for National Statistics (ONS): Gross Domestic Product: Year on Year growth.

[15] The 'value' is computed by summing all observations for which the credibility score equals a certain value, and then dividing by the total for credibility score 1 to 7. For 'observations', rather than summing all values, the number of observations is counted instead.

Table 4 Credibility score (2018) descriptive statistics

Credibility score (2018)	N		Mean		Standard deviation		Min		Max	
	≤ 6	≤ 7	≤ 6	≤ 7	≤ 6	≤ 7	≤ 6	≤ 7	≤ 6	≤ 7
Space revenue (£m)	455	888	13.470	8.139	85.950	63.310	0	0	1,009	1,009
Space-related employees (#)	206	207	35.61	36.83	209.4	209.7	0	0	2,369	2,369
Space R&D (£m)	206	211	0.986	1.074	4.776	4.841	0	0	60.3	60.3
R&D intensity (%)	174	179	0.924	0.904	5.531	5.454	0	0	68.97	68.97
Firm size (# employees)	316	552	819.9	795.9	4,389	5,741	1	1	50,000	79,900
Export intensity (%)	455	888	44.95	40.90	38.71	33.03	0	0	100	100
Non-commercial share (%)	232	233	29.45	29.33	39.85	39.81	0	0	100	100

Table 5 Credibility score (2021) descriptive statistics

Credibility score (2021)	N		Mean		Standard deviation		Min		Max	
	≤ 6	≤ 7	≤ 6	≤ 7	≤ 6	≤ 7	≤ 6	≤ 7	≤ 6	≤ 7
Space revenue (£m)	273	1,115	19.510	7.934	98.770	75.880	0	0	987.8	1,826
Space-related employees (#)	273	1,115	47.73	20.38	166.4	125.9	0	0	2,245	3,054
Firm size (# employees)	232	945	918.1	450.4	4,697	3,752	1	1	48,200	81,000

Table 6 Credibility score proportions

		Credibility (2016)		Credibility (2018)		Credibility (2021)	
		= 1	≤ 6	= 1	≤ 6	= 1	≤ 6
R&D intensity	**Value**	0.658	0.776	0.949	0.993	N/A	N/A
	Observations	0.183	0.430	0.721	0.972	N/A	N/A
Space revenue	**Value**	0.252	0.854	0.341	0.848	0.256	0.602
	Observations	0.253	0.474	0.261	0.512	0.057	0.245
Space employment	**Value**	0.351	0.804	0.962	0.962	0.284	0.573
	Observations	0.254	0.475	0.995	0.995	0.057	0.245

Source: LE analysis

Annex 3 Approach

A3.1 LDA Cluster analysis

Latent Dirichlet Allocation (LDA) has been used to identify clusters of UK space sector companies in the dataset. Cluster analysis such as the LDA can distil salient categories of companies that are similar to each other across a wide range of characteristics, which is especially advantageous given the large amount of information available for each company.

Subsequent outcomes that capture company growth are compared across LDA clusters to understand whether certain types of space sector companies are more likely to grow faster than others. This suggests which characteristics and combinations of characteristics are associated with faster growth.

Cluster analysis such as the LDA enhances the understanding of which companies are likely to grow faster beyond comparing summary statistics between low-growth and high-growth space sector companies. Comparing the mean sizes of low-growth and high-growth companies and finding similarities may not reveal important differences between the two groups. For example, high-growth companies may actually be made up of two LDA clusters (small start-ups and large established companies) which comparing mean sizes would not capture.

Further, machine-learning methods can recognise relationships between characteristics that would otherwise be impractical to identify through other methods.

The LDA has been used to analyse data in a variety of settings, such as grouping medical studies (Wu et al., 2012). LDA has also been used in economics to analyse the transcripts of the Federal Reserve's policy-making decisions (Hansen et al., 2018), CEO behaviour (Bandiera et al., 2020), characteristics of political candidates (Lee, 2021), and political ideologies among voters (Draca & Schwarz, 2021). While the LDA was originally developed for the analysis of text documents, recent research has adapted the methodology to other forms of data, such as datasets with numerical or categorical variables.

The LDA finds groups of characteristics that are often found together, which is defined as a cluster, and estimates the probability that individual companies are a member of each cluster. The implementation of the LDA was undertaken using the following steps:

- preprocessing of the data to create company profiles, which includes
  - conversion of data into word profiles for each company, and
  - categorisation of continuous variables into binned variables;
- specification of the number of clusters to be identified;
- identification of clusters by finding clusters across the k-dimensions of characteristics, where there are k characteristics included in the data (for example, there may be a cluster that is broadly a collection of companies that are large, foreign owned, and based near a UKSA space cluster);
- assign a probability to each company of being a member of each of the N clusters,
  - for example, Company A could be assigned a 10% probability of being part of cluster 1, 30% probability of being part of cluster 2, and 60% probability for cluster 3, and

- companies are assigned to groups either probabilistically (for example, Company A is mostly a Cluster 3 type but has some characteristics similar to those of Cluster 2) or deterministically (Company A is a Cluster 3 type as 60% probability is higher than for either Cluster 1 or Cluster 2); and
- interpretation of the identified clusters.

A3.1.1 Robustness checks and evaluation

The analysis is reproduced for different numbers of clusters. This provides an understanding of the value of additional clusters (such as their intuitive interpretation) and whether there is a risk of overfitting, where noise within the data is mistaken for systemic differences between clusters.

Quantitative methods of estimating the optimal number of clusters have also been explored. These include an 'elbow method' to measures such as a coherence score, which assesses how effective the model is in clustering characteristics together. As the number of groups increases, the coherence score of the LDA may increase as each group is more tightly defined by a set of characteristics. However, the marginal explanatory power of an additional cluster may decrease and increases the risk of overfitting (where noise in the data influences clusters), so the optimal number of groups may be chosen when the coherence score levels off (at the 'elbow').

The interpretability of the identified clusters has been assessed using information from the literature review. If the literature confirms that smaller firms that are foreign owned are more likely to be close to a cluster, then we are likely to have greater confidence in the relevance of the identified clusters. We will also investigate reasons for any significant differences between identified clusters and conclusions from the literature review.

A3.1.2 Advantages of the LDA

The LDA provides a deeper understanding of space sector companies than using other descriptive analysis as it considers interactions between many characteristics. This takes advantage of detailed information about companies by using the full range of characteristics in the dataset at the same time, rather than one or two characteristics at a time.

In addition, the LDA has several advantages over other machine-learning clustering analysis:

- it allows for non-linear relationships between characteristics, compared to other classifications such as Principal Component Analysis and Factor Analysis which do not,
- the LDA is a multi-member model which recognises that a company could be part of different clusters, in contrast with k-means clustering and Latent Class Analysis, so it can provide a more nuanced assessment of the clusters that a company is likely to be a part of, and
- as an unsupervised model (it does not explicitly form clusters in order to predict outcomes and solely focuses on clusters across characteristics), it has the potential to provide broader insights into segments of the space sector that may not be found in a supervised model that focuses on predicting a certain outcome.

A3.1.3 Limitations of the LDA

There are some limitations of the LDA that should be considered when interpreting the results:

- the probabilistic model (where each company is assigned probabilities that they are a member of each group) may difficult to interpret,
- there is no guarantee that there will be any immediately obvious meaning attached to each group's associated characteristics. The model groups characteristics that often occur together which may be otherwise unrelated, which may make it more difficult to interpret the groups,
- the LDA may struggle when relatively few characteristics are available as it assumes that each company displays characteristics associated with a mix of different clusters. The LDA takes a prior assumption (before analysing the data) that each company is equally likely to be part of each cluster. If relatively little information is available, the estimated probabilities may not change much from the prior assumption, and
- the results may be sensitive to how the data has been prepared. For example, continuous variables are transformed into categories (such as none, low, medium, and high). How these categories are defined may impact the results and their interpretation.

A3.1.4 Interpretation of clusters

The clusters are formed agnostically – they are not formed to explicitly predict a particular outcome – so it is important to interpret the identified clusters before undertaking further analysis. This is done using a range of methods:

- lists of common characteristics with the prevalence of characteristics within those cluster (e.g., what proportion of a cluster are large firms or foreign-owned?), which can reflect
  - the absolute proportion of firms within the cluster that have a certain characteristic, and
  - the relative proportion, which can be interpreted as how more or less likely it is a firm from a cluster has a certain characteristic compared to the sample average, and highlights characteristics that are found disproprtionately often in a cluster;
- word clouds are used to intuitively represent each group, with the size of the word proportional to the (relative) prevalence of the characteristic within the group;
- stacked bar charts illustrate the prevalence of groups across different characteristics, such as the proportion of large companies that are members of each cluster.

Some identified clusters may not have an immediately obvious interpretation. This is mitigated by observing the results of different numbers of clusters.

For example, if two clusters are specified, but Cluster 1 has little intuitive interpretation, then the results are compared to those when three or more clusters are specified. It may be the case that there are too few clusters specified and Cluster 1 is made up of multiple clusters within it that have a more intuitive interpretation. Increasing the specified number of clusters may allow for these better-defined sub clusters within Cluster 1 to be identified. Coherence score is also used as a quantitative method of assessing how well-defined the clusters are.

A3.2 General econometric specification

A3.2.1 Dependent variables and controls

The dependant variables or the regressions will be firm specific "space turnover". These will be expressed in percentage change terms (between 2017-2020 or 2014-2017). Independent variables have time subscript *T** in the specifications. This will refer to either 2017 or 2014 (respectively) depending on the dependant variable year.

General controls to be added to all regressions:

- Region dummies/GVA
- Optional: characteristics of firms (nationality, education, industry type)

A3.2.2 Regression specifications

LDA Cluster ID

Hypothesis: *The LDA clustering has identified properties of growth companies*

- This regression seeks to understand which clusters, identified using LDA, grew fastest in terms of space employment and turnover. If so, the properties that determine the LDA clusters are the same properties that determine growth.

The following regression specification will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 LDAClusterID_i + \beta_2 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = \frac{1}{1 + e^{-(\beta_1 LDAClusterID_i + \beta_2 \boldsymbol{X}_{i,T*} + u_{i,T*})}}$$

Subsequent specifications will be written using a short-hand notation as follows:

$$P(HighGrowth_i = 1) = logit(\beta_1 LDAClusterID_i + \beta_2 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

R&D Investment

Hypothesis: *R&D investment is positively associated with firm growth*

- Increased investment in R&D and innovation should lead to higher productivity.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 R\&DInvestment_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 SurveyResponse_{i,T*} + \beta_4 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 R\&DInvestment_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 SurveyResponse_{i,T*} + \beta_4 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

Where β_1 is the coefficient of interest and $\boldsymbol{X}_{i,T*}$ is a matrix of controls. The relationship may vary between firms in different industries. Therefore, the variable "***IndustryType***" will be included which is a matrix of dummy variables that are equal to one if a firm conforms to a particular definition for the industry, it operates in. The relationship between firm growth and the log transformation of R&D investment will also be investigated. The dummy "*SurveyResponse*" is added because the R&D figures reported by survey respondents are not the same as those reported in annual reports. Survey respondents include both intramural and extramural R&D, whereas annual reports only report intramural R&D.[16] When the effect of R&D on firm growth is estimated, the result will be biased if this is not taken into account.

R&D Intensity

Hypothesis: *R&D intensity is positively associated with firm growth*

- Increased investment in R&D and innovation should lead to higher productivity.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 R\&DInvestment_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 SurveyResponse_{i,T*} + \beta_4 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 R\&DInvestment_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 SurveyResponse_{i,T*} + \beta_4 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

Where β_1 is the coefficient of interest and $\boldsymbol{X}_{i,T*}$ is a matrix of controls. The relationship may vary between firms in different industries. Therefore, the variable "***IndustryType***" will be included which is a matrix of dummy variables that are equal to one if a firm conforms to a particular definition for the industry, it operates in. The dummy "*SurveyResponse*" is added because the R&D figures reported by survey respondents are not the same as those reported in annual reports. Survey respondents include both intramural and extramural R&D, whereas annual reports only report intramural R&D. When the effect of R&D on firm growth is estimated, the result will be biased if this is not taken into account.

Firm size

Hypothesis: *Firm size is independent of firm growth*

- The relationship conforms to Gibrat's law.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 FirmSize_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 FirmSize_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

The variable "***IndustryType***" is included as it has been documented that Gibrat's law may not hold when industry type is controlled for. The variable "***IndustryType***" is a matrix of dummies for the different industry classifications that are included. The relationship between firm growth and the log transformation of firm size will also be investigated.

Space Employment

Hypothesis: *Space employment is independent of firm growth*

[16] There is no standardised way of reporting R&D in annual reports, so while a survey of approximately fifty global leaders in the space industry suggests that companies that report R&D only report intramural figures, it is not possible to conclude anything categorical. Nevertheless, evidence suggests that survey respondents are likely to include a large volume of R&D in their responses than they would put in their annual reports.

- Like for overall firm size, the relationship conforms to Gibrat's law.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 SpaceEmployment_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 SpaceEmployment_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

The variable "***IndustryType***" is included as it has been documented that Gibrat's law may not hold when industry type is controlled for. The variable "***IndustryType***" is a matrix of dummies for the different industry classifications that are included. The relationship between firm growth and the log transformation of space employment will also be investigated.

Firm age

Hypothesis: *Firm age is negatively related to firm growth*

- Older firms may have trouble adapting to newer market conditions.
- This may be related to management quality which can vary depending on the age of a firm, potentially biasing the result if not controlled for.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 FirmAge_{i,T*} + \beta_2 FirmAge^2{}_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 FirmAge_{i,T*} + \beta_2 FirmAge^2{}_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

A quadratic term, "*FirmAge*^{2}", will be included in the regression to test the non-linearity of the relationship.

Export intensity

Hypothesis: *Export intensity is positively associated with firm growth*

- Learning-by-exporting leads to increased firm productivity.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 ExportIntensity_{i,T*} + \beta_2 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 ExportIntensity_{i,T*} + \beta_2 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

UKSA space cluster proximity

Hypothesis : *Closer proximity to UKSA space clusters is positively associated with firm growth*

- Spillover effects from the sharing of knowledge and ideas from geographically proximate firms increases firm productivity.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 UKSAClusterDummy_i + \beta_2 GeoUrban_i + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 UKSAClusterDummy_i + \beta_2 GeoUrban_i + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

Since agglomeration externalities exist in urban areas, the dummy variable for the level or urbanisation of an area, "*GeoUrban*", will isolate the effect of knowledge/innovation spillovers.

Urban areas

Hypothesis: *Firms located in urban areas are positively associated with firm growth*

- Agglomeration externalities are expected to have positive impacts on firms, where urban density brings certain distinct advantages such as transaction benefits, improved contact opportunities, and search advantages.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 GeoUrban_i + \beta_2 UKSAClusterDummy_i + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 GeoUrban_i + \beta_2 UKSAClusterDummy_i + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

The coefficient of interest is β_1. The variable "*GeoUrban*" is a dummy variable which is equal to 1 if firm i is located in an area that conforms to the definition of being urban. It is important to control for the distance to UKSA space clusters in order to isolate the pure effect of urban agglomeration externalities, therefore, the variable "*UKSAClusterDummy*" is included.

Foreign ownership

Hypothesis: *Foreign ownership is positively related to firm growth*

- Foreign direct investment brings inflows of capital, innovative technologies, marketing techniques, and management skills which could lead to increased growth.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 ForeignOwnership_i + \beta_2 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 ForeignOwnership_i + \beta_2 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

Where "*ForeignOwnership*" is a dummy variable equalling 1 when the global ultimate owner is registered as being from outside the UK.

University Spinout

[Insufficient number of spinouts to assess correlational relationship with growth]

Hypothesis: *University spinout status is positively related to firm growth*

- Firm size may be a relevant variable for this hypothesis and should be controlled for.

The following regression specifications will be estimated to test this relationship:

$$\Delta SpaceTurnover_i = \beta_1 University\ Spinout_i + \beta_2 FirmSize_{i,T*} + \beta_3 \boldsymbol{IndustryType}_{i,T*} + \beta_4 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 University\ Spinout_i + \beta_2 FirmSize_{i,T*} + \beta_3 \boldsymbol{IndustryType}_{i,T*} + \beta_4 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

It is likely that within the sample of university spinouts, the effect varies with firm size and should therefore be controlled for. Further, effects are likely to vary with industry types and the variable "***IndustryType***", a matrix of industry dummies, is included to control for this effect.

Grant funding (non-commercial income)

Hypothesis: *Higher grant funding is positively related to firm growth*

- Grants can lead to productivity increases if used for investment in innovation and R&D.

The following regression specification will be estimated to test this relationship (only for 2018 survey wave onward):

$$\Delta SpaceTurnover_i = \beta_1 NonCommercialIncome_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 NonCommercialIncome_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

Industry dummies will be included in the regression to investigate whether the effect varies between industry classifications.

Unified regression

The independent variables that have previously been found to be significant in the growth analysis are combined in a single unified regression. The following specification aims to test the strength of the relationship between these variables:

$$\Delta SpaceTurnover_i = \beta_1 R\&DIntensity_{i,T*} + \beta_2 ln\ (SpaceEmployment)_{i,T*} + \beta_3 NonCommercialShare_{i,T*} + \beta_4 FirmAge_{i,T*} + \beta_5 {FirmAge^2}_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 SurveyResponse_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*}$$

$$P(HighGrowth_i = 1) = logit(\beta_1 R\&DIntensity_{i,T*} + \beta_2 ln(SpaceEmployment)_{i,T*} + \beta_3 NonCommercialShare_{i,T*} + \beta_4 FirmAge_{i,T*} + \beta_5 {FirmAge^2}_{i,T*} + \beta_2 \boldsymbol{IndustryType}_{i,T*} + \beta_3 SurveyResponse_{i,T*} + \beta_3 \boldsymbol{X}_{i,T*} + u_{i,T*})$$

Industry dummies will be included in the regression to investigate whether the effect varies between industry classifications. The dummy "*SurveyResponse*" is added because the R&D figures reported by survey respondents are not the same as those reported in annual reports. Survey respondents include both intramural and extramural R&D, whereas annual reports only report intramural R&D. When the effect of R&D on firm growth is estimated, the result will be biased if this is not taken into account.

A3.3 Exit analysis

To understand the characteristics that companies that exit have, the following regression specifications are estimated to test this relationship:

$$P(Exit_i = 1) = \frac{1}{1 + e^{-(\beta_1 Var_{i,T*} + \beta_2 \boldsymbol{X}_{i,T*} + u_{i,T*})}}$$

The dependent variable of the regressions is a dummy that takes the value 1 if the company exited the space sector. This is the case if the company has been part of the first survey wave (the surveys conducted in 2016 and 2018), but not part of the second survey wave (the surveys in 2018 and 2021 respectively). The independent variable $Var_{i,T*}$ has the time subscript $T*$ in the specifications which refers to either 2017 or 2014 (respectively) depending on the dependent variable year. In the specification β_1 is the coefficient of interest and $\boldsymbol{X}_{i,T*}$ is a matrix of controls (regional GVA, industry type).

Independent variables $Var_{i,T*}$ that were tested:

- Log of R&D Investments
- R&D intensity
- Log of space-related employees
- Log of firm size (number of employees)
- Export intensity
- UKSA space cluster proximity dummy
- Urban dummy
- Foreign ownership dummy
- Firm age
- Grant funding

When considering all types of exits, the estimates suggest that being foreign-owned increases the probability of a company exit while a higher R&D intensity or being further located from the nearest UKSA space cluster has a negative impact.

When distinguishing between the types of exits, the estimates in the 2017-2020 analysis suggest that a higher space R&D, more space-related employees and a larger firm size all decrease the probability of exiting. Analysing the companies that are still active but no longer operate in the space sector gives negative estimates of firm size, export intensity, and UKSA space cluster proximity. Excluding some of the data from the 2021 survey yields comparable results.

A3.4 Variables of interest

Table 7 summarises the variables of interest, along with their relevant sources and methodologies. The table is the summary output of the literature review to determine firm characteristics to explain growth.

Table 7 Variables of interest for the analysis

Variable	Description	Source
R&D investments	Percentage of total income invested in R&D	Size and Health data
R&D intensity	R&D investments as a share of the GVA of the company	LE Analysis using Size and Health data
Space-related employees	Number of space-related employees in each firm	Size and Health data
Firm size	Total of number of employees	FAME – Bureau van Dijk
Firm age	Firm age in the year of analysis using the year of foundation	FAME – Bureau van Dijk
Export intensity	Share of exports not to the UK	LE Analysis using Size and Health data
UKSA space cluster dummy	Assigns a value of 1 if a company is within 5km of a UKSA space cluster	LE analysis using UKSA space clusters
Urban dummy	Equal to one if a firm is located in a dense urban centre, semi-dense urban, suburban area. Equal to zero if a firm is located in a rural area, low density rural, or very low-density rural location.	Global Human Settlement Layer (GHSL)
Foreign ownership dummy	Dummy where 1 indicates the GUO ISO code does not contain “GB”	FAME – Bureau van Dijk
Non-commercial income share	Share of income from grant funding	Size and Health data

Somerset House, New Wing, Strand,
London, WC2R 1LA, United Kingdom
info@londoneconomics.co.uk
londoneconomics.co.uk
@LondonEconomics
+44 (0)20 3701 7700