

INNOVATION & RESEARCH CAUCUS

BEHIND THE COLLABORATION PREMIUM:

International R&D collaboration and UK firm productivity

IRC Report No. 097

REPORT PREPARED BY

Tasneem Bani-Khaled
Aston Business School

Jun Du
University of Manchester

Dalila Ribaudo
Aston Business School

Lin Zhang
University of Manchester

UKRI Delivered with ESRC and Innovate UK

Authors

The core members of the research team for this project were as follows:

Authors are listed alphabetically.

- Ms Tasneem Bani-Khaled - Aston Business School
- Prof Jun Du - The University of Manchester
- Dr Dalila Ribaudo - Aston Business School
- Dr Lin Zhang - The University of Manchester

This document relates to IRC Project FFOpen06: UK Firms' R&D Internationalisation: A Comprehensive and Statistical Review

Acknowledgements

This work was supported by Economic and Social Research Council (ESRC) grant ES/X010759/1 to the Innovation and Research Caucus (IRC) and was commissioned by Innovate UK. We are very grateful to the project sponsors at UK Research and Innovation (UKRI) for their input into this research. The interpretations and opinions within this report are those of the authors and may not reflect the policy positions of Innovate UK.

We would also like to acknowledge and appreciate the efforts of the IRC Project Administration Team for their support in preparing this report.

About the Innovation and Research Caucus

The Innovation and Research Caucus supports the use of robust evidence and insights in UKRI's strategies and investments, as well as undertaking a co-produced programme of research. Our members are leading academics from across the social sciences, other disciplines and sectors, who are engaged in different aspects of innovation and research systems. We connect academic experts, UKRI, IUK and the ESRC, by providing research insights to inform policy and practice. Professor Tim Vorley and Professor Stephen Roper are Co-Directors. The IRC is funded by UKRI via the ESRC and Innovate UK, grant number ES/X010759/1. The support of the funders is acknowledged. The views expressed in this piece are those of the authors and do not necessarily represent those of the funders.

Contact

You are also welcome to email us if you have any questions about this report or the work of the IRC generally: info@ircaucus.ac.uk

Cite as: Bani-Khaled, T. et al. 2026. *Behind the Collaboration Premium: International R&D Collaboration and UU Firm Productivity.* Oxford, UK: Innovation and Research Caucus.

CONTENTS

EXECUTIVE SUMMARY 4
1. Introduction 5
2. Collaboration, capability and productivity: the evidence so far 7
2.1 Why collaboration might raise productivity 7
2.2 Evidence on collaboration and firm performance 8
2.3 Who benefits: absorptive capacity and the frontier 8
2.4 Selection or effect? Lessons from the exporting literature 9
2.5 What we already know about UK firms 10
2.6 What this report adds 10
3. Data and methods 10
3.1 Sample and data sources 10
3.2 Outcomes and treatment 11
3.3 Two identification strategies 12
4. Does R&D collaboration raise firm productivity? 13
4.1 The domestic and international channels 14
4.2 Is there such a thing as too much collaboration? 15
4.3 Who benefits from (international) collaboration: frontier firms and the IS-8 sectors 17
4.4 Does geography matter? 19
5. What happens after firms start collaborating? 20
5.1 Estimator and specification 20
5.2 Results 22
5.2.1 Staggered difference-in-differences 22
5.2.2 Propensity-score-matched difference-in-differences 25
6. Implications for UK innovation policy 27
6.1 Collaboration and absorptive capacity 27
6.2 Domestic and international collaboration as different instruments 28
6.3 IS-8 sectors and regions 29
6.4 Limitations of the evidence 29
6.5 Recommendations 30
6.6 Limitations of the evidence 30
7. Conclusion 31
REFERENCES 32
APPENDIX A 35
How many firms sit at high shares 40

EXECUTIVE SUMMARY

This report asks whether collaborating on R&D with international partners pays off for UK firms. It builds on our earlier report on which firms collaborate (Du & Ribaudo, 2026). It uses data on 4,481 UK firms that filed patents between 2008 and 2023, linking their patents to their accounts and ownership records. We look at the evidence in two ways: by comparing collaborating firms with similar firms that do not collaborate, and by following firms over time to see how their performance changes before and after they first collaborate.

- Firms that collaborate on R&D with international partners are around 25% more productive than similar firms in the same industry. The gap rises to around 44% once we allow for the fact that different kinds of firms choose to collaborate.
- Firms that collaborate with UK partners – i.e. domestic collaboration - grow their sales faster than similar firms, by around 3.5 percentage points a year, though this is not confirmed when we follow firms over time. They are no more productive.
- The productivity advantage of international collaborators is concentrated among the most productive firms in each industry (around 31% for the top third) and in the eight priority sectors of the government's Industrial Strategy (around 32%). The least productive firms, and firms outside the priority sectors, on average show no significant advantage from international collaboration.
- The advantages also vary by geography. It is positive and significant in the East of England the North East, South East, Wales and Scotland.
- Support for collaboration is most likely to raise productivity when it goes hand in hand with building firms' own capabilities in R&D, management and technology adoption. Schemes that simply increase the number of international collaborations are likely to benefit firms that are already ahead.
- Findings might be read as an argument against funding international collaboration. They are not. International partnerships serve goals beyond productivity, including access to science and economic security, and they are associated with large productivity advantages among capable firms. The case is for pairing collaboration support with capability building, and for judging each scheme against its own objectives.
- Design domestic and international instruments separately. The two channels are associated with different outcomes, revenue growth and productivity respectively, and should be supported and evaluated on those terms, while still allowing firms to pursue both.

1. Introduction

For almost two decades, the United Kingdom has been trying to solve what has become known as its 'productivity puzzle', that is the persistent slowdown in output per worker and per hour that followed the 2008 financial crisis, and from which it has not fully recovered. Before 2008, UK labour productivity grew at close to 2% a year (Financial Times, September 18th 2026[1]). The latest ONS estimates put output per hour 0.7% higher in the year to mid-2026 and 2.3% above its 2019 average, growth the ONS describes as subdued compared with the trend before the financial crisis (ONS, 2026[2]).

The slowdown is not unique to the UK - recent comparative work shows the United States and northern Europe experienced a broadly similar collapse in total factor productivity growth after 2007 (Fernald & Inklaar, 2025) - but the UK's has proved unusually persistent, and closing even part of the gap to the pre-2008 trend is now treated as a central and urgent test of economic policy (HM Government, 2025). Recent assessments point policy attention toward how firms generate and absorb new knowledge, rather than only toward how much capital they deploy (The Productivity Institute, 2025).

Productivity growth is also not evenly distributed across the economy, and the dispersion is widening rather than narrowing. Workers at firms in the 90th percentile of the firm-level productivity distribution now produce 3.5 times more per hour than workers at the median firm, up from 2.9 times before the financial crisis (ONS, 2025b). A puzzle framed only in aggregate terms can miss this: the question is not only why the whole economy has slowed, but why a growing minority of frontier firms continue to pull away from everyone else, and what - if anything - would help more firms close that gap.

One candidate lever is research and development, and specifically the way firms conduct it. Our previous report *Global Reach, Local Roots: Understanding the internationalisation of R&D among UK firms*[3], documented that international R&D collaboration has long been a distinctive strength of the UK innovation system, but one that has narrowed since 2014- particularly with

[1] https://www.ft.com/content/560fc2ad-5c7e-4878-ae9b-a3183004c394?syn-25a6b1a6=1
[2] https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/methodologies/componentapproachtomeasuringlabourproductivityuk1997to2024
[3] https://ircaucus.ac.uk/publications/global-reach-local-roots-2/

EU partners - and that is disproportionately undertaken by large, foreign-owned and older firms, while domestic SMEs remain comparatively disconnected from global knowledge networks.

This report examines whether R&D collaboration is associated with stronger firm performance and whether the relationship differs between domestic and international collaboration. It applies two complementary empirical approaches to a linked panel of UK patenting firms' accounts, patent records and ownership information covering 2008 to 2023. The first estimates productivity and growth differences between collaborating and otherwise comparable firms while addressing selection into collaboration. The second follows firms around the time of their first collaboration to examine whether performance changes subsequently and whether collaborating and non-collaborating firms were already following different trajectories before collaboration began.

The report addresses two research objectives:

- **RO1:** To estimate whether, and through which channel, domestic or international, R&D collaboration contributes to UK firms' productivity and growth, and whether the relationship is linear.
- **RO2:** To examine how the relationship between R&D collaboration and firm performance varies across firms, sectors and regions, and how productivity and growth evolve before and after collaboration begins.

The two approaches answer different questions. Section 4 identifies a substantial productivity premium associated with international collaboration, concentrated among frontier firms and firms operating in the IS-8 priority sectors. Section 5 provides a more qualified picture on the timing of this effect. Firms entering international collaboration appear to have been on different trajectories before collaboration began, and the analysis does not identify a statistically significant average productivity increase immediately following the first international collaboration. The findings distinguish between the productivity characteristics of firms that collaborate and the more difficult question of what changes because collaboration begins.

The Industrial Strategy treats R&D collaboration as a lever for growth and economic security (HM Government, 2025). Our findings qualify that expectation. International collaboration pays off mainly for firms that already have the capability to use it, so schemes that simply broker more partnerships are unlikely on their own to lift the firms that most need to improve.

The remainder of the report proceeds as follows. Section 2 reviews the evidence on R&D collaboration and firm performance. Section 3 describes the data and empirical approaches.

Sections 4 and 5 present the findings. Section 6 discusses the policy implications, and Section 7 concludes.

2. Collaboration, capability and productivity: the evidence so far

2.1 Why collaboration might raise productivity

Firms collaborate on R&D to gain access to knowledge and complementary capabilities they lack, to share the costs and risks of research, and to reach new markets and technologies (Kafouros & Forsans, 2012; Castellani & Du, 2023). How much they gain depends partly on experience: earlier alliances raise the returns to later ones, although only recent experience appears to count (Sampson, 2005). Collaboration across borders also carries costs. Coordination is harder over distance, and firms risk losing valuable knowledge to partners abroad, which helps explain why most firms keep the bulk of their R&D at home (Belderbos, Leten & Suzuki, 2013; Castellani & Du, 2023).

Collaborating with a foreign partner exposes a firm to new knowledge, standards and capabilities, and the diffusion of technology from frontier to non-frontier firms has long been identified as a determinant of aggregate productivity growth (Andrews, Criscuolo & Gal, 2015; Bloom, Schankerman & Van Reenen, 2013). Two bodies of prior evidence motivate treating the domestic and international channels separately and allowing the relationship to be non-linear.

First, international R&D and cross-border alliances have been linked to firm growth through channels distinct from local collaboration - access to complementary capabilities, larger and more diverse knowledge pools, and exposure to frontier technology (Rodríguez & Nieto, 2016; Nieto & Rodríguez, 2022; Kafouros & Forsans, 2012). Second, more collaboration is not necessarily better. A recurring finding across the open-innovation literature is an inverted-U relationship between external search or collaboration intensity and performance: firms that search too widely or rely too heavily on external partners incur coordination costs, appropriability risk, and management attention constraints that can offset the knowledge gained (Laursen & Salter, 2006; Grimpe & Kaiser, 2010; Berchicci, 2013; Hottenrott & Lopes-Bento, 2016). Both considerations - channel and intensity - are tested directly in Section 4. Our earlier rapid reviews for the IRC summarise the evidence on firms' international R&D

collaboration (Castellani & Du, 2023) and on R&I policy and productivity in manufacturing (Ribaudo, Marin-Cadavid & MacBryde, 2024).

2.2 Evidence on collaboration and firm performance

Firm-level studies generally find that R&D collaboration is associated with better performance, but the gains depend on the partner and on the outcome. Using Dutch innovation survey data, Belderbos, Carree & Lokshin (2004) find that cooperation with competitors and suppliers improves labour productivity growth, while cooperation with universities and competitors raises sales of products that are new to the market. In German data, cooperating firms earn a larger share of turnover from new-to-the-market products and achieve greater cost reductions from process innovation, with research institutes and competitors contributing in different ways (Aschhoff & Schmidt, 2008). External R&D raises productivity mainly when firms combine it with sufficient internal R&D (Lokshin, Belderbos & Carree, 2008). For the UK, evidence from the Community Innovation Survey suggests that the benefits of cooperation for innovation performance are less clear-cut than those of firms' own R&D and of multinationals' internal networks (Frenz & Ietto-Gillies, 2009).

Two features of this literature shape our analysis. First, different forms of collaboration are associated with different outcomes, which is why we examine productivity and sales growth separately and distinguish domestic from international partners. Second, most studies compare collaborating and non-collaborating firms at a point in time or over short panels, so they cannot easily separate the effect of collaboration from the characteristics of the firms that choose to collaborate.

Our measure of collaboration is the joint ownership of patents. Joint patenting is a specific and comparatively uncommon form of collaboration, which firms enter despite the complications of shared ownership (Hagedoorn, 2003). Co-owned patents can also be harder to exploit: patents co-owned with other firms are less likely to be built on by the owning firm, whereas co-patenting with universities is associated with higher market value (Belderbos et al., 2014).

2.3 Who benefits: absorptive capacity and the frontier

The returns to external knowledge depend on a firm's capacity to absorb it. Cohen & Levinthal (1990) argue that firms need prior related knowledge to recognise, assimilate and apply new external knowledge. Our earlier review for the IRC identified absorptive capacity,

complementarity between partners and effective integration of the knowledge gained as the main conditions under which firms benefit from international R&D collaboration, alongside the protection of intellectual property and the management of distance between partners (Castellani & Du, 2023). Griffith, Redding & Van Reenen (2004) show that R&D raises productivity both directly, by generating innovation, and by helping industries catch up with the technological frontier. At the firm level, Andrews, Criscuolo and Gal (2016) document a widening productivity gap between frontier firms and the rest, which they link to a slowdown in the diffusion of technology from the frontier. Industry context matters too. In Dutch firm data, R&D that firms conduct abroad raises productivity, and complements their domestic R&D, mainly in industries where the home country lags the technological frontier; in frontier industries, domestic R&D is the main source of productivity growth (Belderbos, Lokshin & Sadowski, 2015). That study concerns firms' own R&D abroad rather than collaboration, and the gap it measures is the home industry's distance from the global frontier, not a firm's position within its industry. This work implies that collaboration is likely to benefit most the firms that are already able to use it. Section 4 therefore examines whether the productivity premium differs with a firm's position in its industry's productivity distribution.

2.4 Selection or effect? Lessons from the exporting literature

Research on exporting has faced the same question this report asks of collaboration. Exporters are more productive than non-exporters, but Bernard and Jensen (1999) show that this largely reflects the fact that good firms become exporters: their advantages are visible before they start exporting, and their subsequent growth is not superior, particularly over longer horizons. Melitz (2003) formalises this selection, showing that only the more productive firms find it worthwhile to enter export markets. A review of studies covering 33 countries concludes that more productive firms self-select into exporting, while exporting itself does not necessarily improve productivity (Wagner, 2007; Jibril & Roper, 2022).

International R&D collaboration also involves fixed costs: finding partners abroad, agreeing ownership of results and coordinating across distance. The same logic suggests that more productive firms will select into it, in which case the productivity premium of collaborators reflects, at least in part, who collaborates. Section 5 tests this directly by following firms before and after their first collaboration.

2.5 What we already know about UK firms

International collaboration has declined since 2014, particularly with EU partners, even as UK-China research links grew to account for over 10% of UK joint patent output (Du & Ribaudo, 2026). International R&D remains concentrated among multinationals and foreign-owned firms, while domestic UK-owned companies collaborate predominantly at home. A firm's existing domestic subsidiary network creates 'home-anchoring' effects that make later internationalisation harder, and past innovation capacity predicts international collaboration better than R&D spending itself. The most innovative firms pursue mixed domestic-and-international strategies rather than treating the two as substitutes (Du & Ribaudo, 2026).

Our earlier report also identified a dual structure in UK innovation: a globally connected, patent-intensive tier led by large and often foreign-owned firms, and a domestically oriented tier of smaller firms that collaborate mainly within the UK, including partners such as universities (Du & Ribaudo, 2026). It noted that the most R&D-active firms also show higher productivity growth. This report tests that link directly.

2.6 What this report adds

Our earlier review for the IRC identified the direct impact of international R&D collaboration, including how its short- and long-term benefits differ, as a key evidence gap (Castellani & Du, 2023). This report addresses that gap in three ways. It uses a panel of UK patenting firms linked to their accounts over 2008-2023, rather than a single survey wave. It separates domestic from international collaboration and treats productivity and sales growth as distinct outcomes. And it follows firms before and after (until t+10) their first collaboration, so it can ask whether collaborators become more productive once they start, as well as whether they are more productive. If they do, widening access to collaboration is a direct lever for productivity. If they do not, the policy case rests on building the capabilities that make collaboration pay.

3. Data and methods

3.1 Sample and data sources

Three sources are linked at the firm-year level. Patent activity comes from Orbis Intellectual Property at DOCDB patent-family level, with each family assigned to a firm through its applicant identifier and to a year through its priority date. Accounts data - turnover, employment, assets, incorporation date, industry (NACE) and region (NUTS1) - come from FAME (Firms Financial

Made Easy - the UK section of Bureau van Dijk). Ownership data, including the country of a firm's largest shareholder and its global ultimate owner, come from Orbis. A patent family is classified as collaborative if it has more than one distinct applicant; it is domestic if every co-applicant is registered in the UK, and international if at least one of the co-applicants is a foreign one.

After keeping firms for which we have financial information (see Du & Ribaudo, 2026 for details on the cleaning steps), the estimation sample comprises 46,499 firm-years across 4,481 firms, observed for an average of 10.4 years each, between 2008 and 2023.

Table 1. The sample

	Count
Firms	4,481
Firm-years	46,499
Mean years observed per firm	10.4
Firms switching collaboration status (any channel)	1,409 (31.4% of firms)
Firms switching on domestic collaboration	1,018 (22.7% of firms)
Firms switching on international collaboration	698 (15.6% of firms)

A 'switcher' is a firm observed both collaborating and not collaborating within the sample window; only switchers identify a firm fixed-effects estimate. Source: authors' calculations from the linked Orbis IP-Fame-Orbis ownership panel.

3.2 Outcomes and treatment

Three outcomes are used throughout[4]: the log of labour productivity (turnover per employee, a level); revenue growth (the first difference of log turnover); and productivity growth (the first difference of log labour productivity). We separate the level from the growth rate because a one-off improvement in how a firm operates shows up in the level but not in the growth rate, whereas a change in trajectory shows up in both. Section 4 shows that the two behave very differently.

Collaboration is captured by three indicators: any collaboration, domestic collaboration, and international collaboration defined at the firm-year level from that year's patent filings (these are not mutually exclusive - 539 firm-years in the estimation sample involve both a domestic

[4] Each outcome is winsorised at the 1st and 99th percentile within year

and an international collaborative filing in the same year). All specifications control for the number of employees, firm's age, the firm's cumulative patent stock at the start of each year, whether the firm is an exporter, a foreign-ownership indicator, firms' capital intensity, and the region of the firm's largest shareholder (EU27, North America, ASEAN, Commonwealth).

3.3 Two identification strategies

The report combines two designs that answer related but distinct questions.

The first, presented in Section 4, estimates the productivity and growth premium associated with collaboration while correcting for selection. The main concern is reverse causality: firms that are already more productive may be more likely to collaborate. We aim to correct this by applying a conditional mixed process (CMP) model (Roodman, 2011), which jointly estimates the probability of collaborating and the outcome equation, instrumented by a leave-one-out peer-collaboration rate defined over each firm's technology class. The logic of the instrument is that collaborative choices are a property of a technology field - some fields are collaborative almost by default - rather than of any one firm, so a firm's exposure to a highly collaborative field shifts its own probability of collaborating for reasons unrelated to its own productivity.

The second, presented in Section 5, is a staggered difference-in-differences design using the Callaway & Sant'Anna (2021) estimator. It examines whether, and when, any productivity gain appears after a firm's first collaboration. The design is needed because firms adopt domestic and international collaboration in different years - a staggered-adoption setting in which conventional two-way fixed-effects regressions are known to be biased when treatment effects are heterogeneous across firms or over time, because already-treated firms act as implicit 'controls' for later-treated firms while no longer on their own untreated path (Goodman-Bacon, 2021; de Chaisemartin & D'Haultoeuille, 2020). The Callaway & Sant'Anna estimator avoids this by building up group-time average treatment effects - comparing firms first treated each year against a clean control group - and aggregating them into an event-study path around the year of first collaboration. Where the analysis in Section 4 asks whether collaboration is associated with higher productivity on average, this second layer asks whether a gain follows the first collaboration, how quickly, and whether firms were already on different paths beforehand.

4. Does R&D collaboration raise firm productivity?

This section looks at the association between R&D collaboration and firm performance across four estimators and three outcomes. The main findings are:

- After correcting for selection (CMP), collaboration is associated with around 33% higher labour productivity.
- The productivity gain comes from international collaboration: around 44% with CMP, about 25% with OLS and fixed effects. Domestic collaboration shows no productivity effect.
- For domestic collaboration, revenue growth follows a U-shape. Revenue growth is lowest at a domestic share of around 43% and exceeds that of non-collaborators only above about 87%, a range few firms reach.
- For international collaboration, gains appear to flatten at high intensity.
- Gains are concentrated among frontier firms - around 31% via international collaboration.
- Inside the IS-8 sectors, the international premium is around 32%, against a non-significant 7% outside them.
- The size of the international effect varies across regions and is significantly positive in the East of England the North East, South East, Wales and Scotland.

Table 2 reports the effect of any R&D collaboration across four estimators and three outcomes. Table A1 - A1B in the Appendix report the full CMP estimates, with standard errors and p-values. Where the CMP error correlation (ρ) is significant, as it is for ln labour productivity (Table A1C), we treat the CMP estimate as the preferred one[5]. Where it is not, as for revenue growth and productivity growth, OLS with industry and year fixed effects is the appropriate estimator. The pooled OLS coefficient on labour productivity is close to zero. This might reflect composition: collaborating firms tend to be in industries that are, on average, less productive, so comparing firms within the same industry raises the estimate. Once firms are compared within industry and year, collaboration is associated with around 10% higher labour productivity (0.0965). Once selection into collaboration is corrected by CMP, the estimate rises to around

[5] The instrument is strong with an χ^2 of about 31, linear F = 55.9 and about 11.5 for the international equation

33% (0.2853). Revenue growth is around 2.6 percentage points higher with industry and year fixed effects (0.0262), and the pooled OLS and CMP estimates are of similar size.

The firm fixed effects suggest that the level effect comes mainly from differences between firms rather than from changes within the same firm. We return to this point in Section 5. Overall, collaboration is associated with a higher level of productivity rather than faster productivity growth.

Table 2 The main effects of any R&D collaboration

Outcome	Pooled OLS	OLS + industry & year FE	Firm FE	CMP (selection-corrected)	N
ln labour productivity	0.0178	0.0965***	0.0104	0.2853***	46,499
Revenue growth	0.0265***	0.0262***	0.0071	0.0341*	46,499
Productivity growth	0.0083*	0.0063	0.0077	0.0132	46,042

Standard errors clustered on NACE 2-digit industry (78 clusters). * p<0.10, ** p<0.05, *** p<0.01. Controls: ln employees, ln firm age, ln beginning-of-year patent stock, exporter, foreign-owned, ln capital intensity, four largest-shareholder region dummies, industry and year fixed effects (where applicable). Table A1-A1C reports full CMP estimates, standard errors and p-values.

4.1 The domestic and international channels

When collaboration is split by type, the productivity result appears to be driven by international collaboration. Both indicators enter the same regression, so each coefficient is the effect of one channel holding the other constant. International collaboration is associated with around 25% higher labour productivity with industry and year fixed effects (0.2207), and around 44% once selection is corrected by CMP (0.3645). Only the international selection correlation is significant (ρ_{13}, Table A2C), so the CMP estimate is our preferred one. Domestic collaboration shows no positive effect on labour productivity with any estimator, and the pooled OLS estimate is negative. The pattern reverses for revenue growth. Domestic collaboration is associated with revenue growth around 3.5 percentage points higher (0.0349; 4.5 points with CMP), while international collaboration shows no effect. This might signal that firms collaborating domestically are seeking to increase their market share. Table A2-A2C in Appendix A reports the full CMP estimates.

Table 3. Domestic and international collaboration entered separately

Outcome and channel	Pooled OLS	OLS + industry & year FE	Firm FE	CMP
ln Labour Productivity - domestic	-0.1019*	-0.0115	0.0043	0.0757
ln labour productivity - international	0.1745***	0.2207***	0.0159	0.3645***
Revenue growth - domestic	0.0341**	0.0349**	0.0144	0.0448**
Revenue growth - international	0.0123	0.0103	-0.0012	0.0108
Labour Productivity growth - domestic	0.0106	0.0095	0.0076	0.0188
Labour Productivity growth - international	0.0015	-0.0024	0.0050	-0.0044

N = 46,499 (46,042 for productivity growth; CMP system N = 46,494). * p<0.10, ** p<0.05, *** p<0.01.

4.2 Is there such a thing as too much collaboration?

Table 3 assumes that the effect of collaboration is the same at every level of intensity. To relax this, we add the collaboration share and its square for each channel (Table A3). We then apply the Lind and Mehlum (2010) test, which checks whether the slope is significant and of opposite sign at both ends of the range (Table A4). This analysis uses the 40,169 firm-years for which the share is defined. Only one relationship passes the test at 5%: domestic collaboration and revenue growth. Revenue growth first falls as the domestic share rises and then increases, with a turning point at around 43% (delta-method 95% CI: 36-51%; Figure 1a[6]). The domestic share and labour productivity follow a similar U-shape, but only at 10%. For international collaboration and labour productivity, the linear term is positive and significant and the squared term negative (p = 0.052). However, the slope at the top of the range is not significant, so the test does not confirm an inverted U (Figure 1b). Domestic collaboration appears to pay off in revenue growth only once it makes up a substantial share of a firm's patenting. The 43% turning point is where revenue growth stops falling, not where it turns positive. At that point the fitted differential is at its lowest, about 1.3 percentage points below a firm with no domestic collaboration, and the curve regains that level only at a domestic share of about 87%. Around

[6] To do so, we include the collaboration share and its square for each channel. Table A3 reports the coefficients by outcome and channel

13% of firm-years sit above the 43% turning point, but only 5.6-6.7% sit above the 87% crossing point (Table A5). International collaboration is associated with higher productivity from the start, and the gain appears to flatten at high shares rather than turn negative. Few firms are in that range: 736 firm-years (1.8% of the sample), belonging to 125 firms, are above the estimated turning point of 88%, so the shape at the top should be read with caution.

Intensity appears to matter for domestic collaboration. Occasional collaboration is not associated with higher revenue growth, and returns only appear once it becomes a sizeable part of a firm's innovation activity. For international collaboration, we find no evidence that more is worse. The two domestic results measure different things. Table 3A compares firm-years with and without a domestic collaborative filing in that year, whereas the share analysis uses the proportion of a firm’s patent stock that is collaborative, on the smaller sample of firms with a patent stock. A firm can file a collaborative patent each year while collaboration remains a small part of its overall patenting.

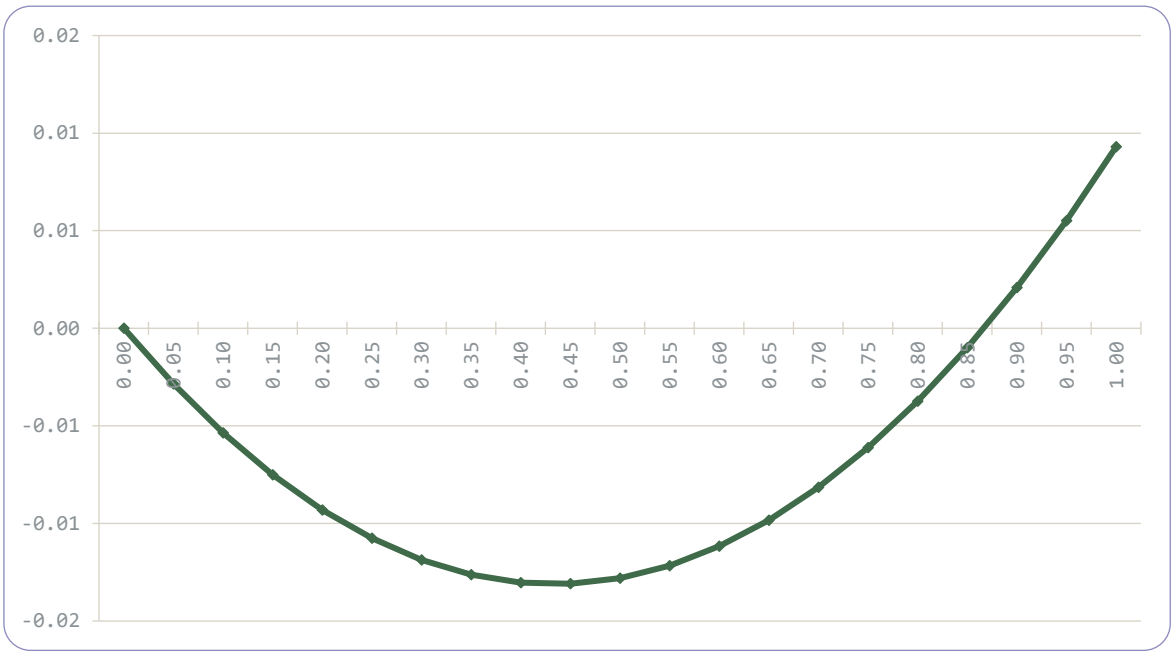


Figure 1a. Domestic intensity → revenue growth (fitted curve; turning point and confidence intervals in Table A4)

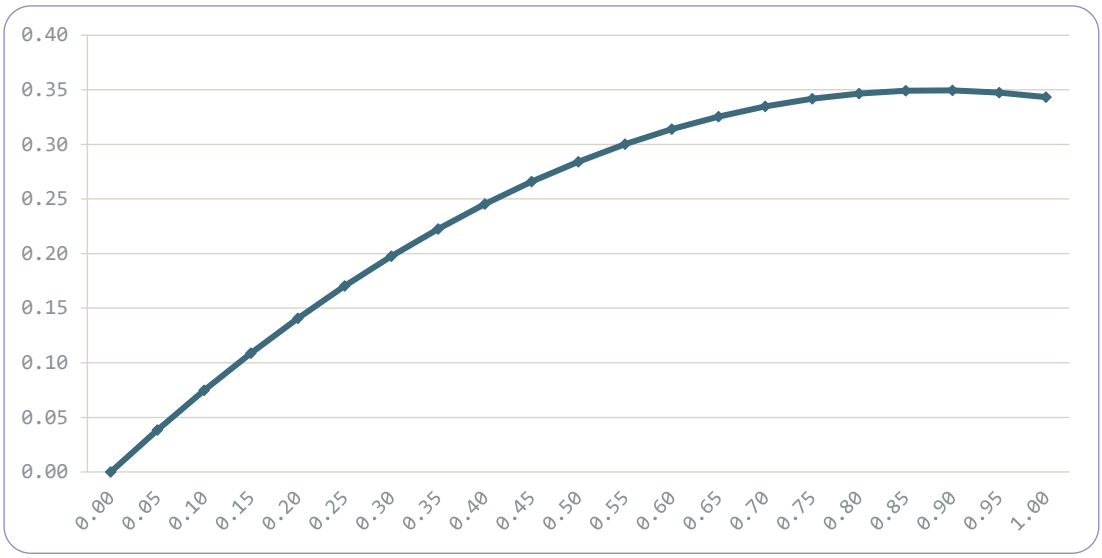


Figure 1b International intensity → productivity (fitted curve; turning point and confidence intervals in Table A4)

4.3 Who benefits from (international) collaboration: frontier firms and the IS-8 sectors

In this section we further break down our firms by productivity terciles[7]. Table 4 reports the results for ln labour productivity, and the differences are large. Among frontier firms (top tercile of their industry), any collaboration is associated with around 17% higher labour productivity (0.158). Among laggard firms (bottom tercile), the estimate is negative but not significant (-0.080). The difference between the two groups is significant ($p = 0.0025$).

The gap is widest for the international channel: around 31% for frontier firms (0.268) against a non-significant -3% for laggards (-0.035). A joint test that the effect is the same across all three terciles rejects at $p < 0.001$, and the laggard-frontier gap on its own is significant (interaction 0.303, $p < 0.001$). For the domestic channel, neither group shows a significant effect, and the difference is not significant ($p = 0.188$). Evidence that foreign R&D pays off most in industries that lag the global frontier (Belderbos, Lokshin & Sadowski, 2015) does not conflict with this: that finding compares industries, whereas ours compares firms within the same industry.

[7] using each firm's lagged position within its NACE 2-digit industry, to avoid mechanically defining the group by the current-year outcome

A similar pattern appears across sectors. The eight UK Industrial Strategy priority sectors are Advanced Manufacturing, Digital and Technologies, Life Sciences, Professional and Business Services, Financial Services, Creative Industries, Clean Energy and Defence. Together they cover just over half of the estimation sample. Inside them, any collaboration is associated with around 13.5% higher productivity (0.127), against a non-significant 3% outside them (0.031); the difference is significant at 5% ($p = 0.048$). As with the frontier result, this premium runs through the international channel: around 32% inside IS-8 (0.275) against a non-significant 7% outside (0.069; $p = 0.021$ for the difference). The domestic channel shows no difference ($p = 0.602$).

Outside IS-8, which accounts for 44.7% of the sample (20,780 firm-years), international collaboration is not associated with a significant productivity gain. Within IS-8 the international premium is large and significant; outside it cannot be distinguished from zero. Support for international collaboration may yield the clearest returns in these sectors, but the gap outside them is where the capability problem lies.

Table 4. Heterogeneity in the productivity effect of R&D collaboration

Comparison	Any collaboration	Domestic channel	International channel
Laggard firms (bottom tercile)	−0.080	−0.088	−0.035
Frontier firms (top tercile)	0.158***	0.017	0.268***
Joint test, no tercile heterogeneity (p)	0.0025	0.188	<0.001
Outside IS-8 sectors	0.031	0.009	0.069
Inside IS-8 sectors	0.127***	−0.026 (n.s.)	0.275***
Difference test, IS-8 vs not (p)	0.048	0.602	0.021

Outcome: ln labour productivity. * p<0.10, ** p<0.05, *** p<0.01. Frontier/laggard terciles are lagged one year and defined within NACE 2-digit industry × year. IS-8 = UK Industrial Strategy priority sectors.
* p<0.10, ** p<0.05, *** p<0.01.

4.4 Does geography matter?

Adding NUTS1 region fixed effects (see Table A6)[8] to the main specification changes the baseline estimates only marginally, suggesting that the main results do not depend on where collaborating firms are located. When we do interact our international collaboration[9] variable with the region (Tables 6 and see Table A7C for full estimates), we do detect significant regional variation in the size of the international effect over labour productivity. Half of the regions have a positive premium – namely East of England the North East, South East, Wales, Scotland. Five regions show no effect -East Midlands, London, South West, West Midlands. Northern Ireland shows a large, significant negative coefficient (−0.472, $p < 0.001$). This result has to be interpreted with caution because the interaction captures only *'13 switching firms'* - i.e. firms observed both collaborating and not collaborating within the sample window.

Table 5 Joint tests for regional variation in the collaboration effect

Outcome	Any collaboration	Domestic	International
ln labour productivity	0.312	0.019	0.000
Revenue growth	0.084	0.100	0.668
Productivity growth	0.084	0.020	0.411

Tables report p-values from a joint test on all region interactions. Full estimates are in the appendix, Tables A7A to A7C.

Table 6. Effect of international collaboration on ln labour productivity, by region.

Region	Effect	p	Region	Effect	p
East of England	0.3489***	0.000	Yorkshire and Humber	0.2637	0.112
North East	0.3860**	0.013	London	0.2049	0.224
Scotland	0.3619**	0.049	South West	0.1110	0.555
South East	0.3027***	0.000	East Midlands	0.0706	0.653
Wales	0.2654*	0.067	North West	0.0182	0.886
Northern Ireland	-0.4724***	0.000	West Midlands	-0.0576	0.489

Marginal effects from a single regression with region interactions, pooled OLS with NACE-2 and year fixed effects.

[8] The regional analysis is estimated on the 44,319 firm-years with a NUTS1 region.

[9] Tables A7A and A7C reports full estimates for interaction with 'any collaboration' and the 'domestic collaboration' variables respectively

5. What happens after firms start collaborating?

Section 4 establishes that collaboration and specifically international collaboration, is associated with a higher level of firm productivity, and that this association survives correcting for observable and, to some extent, unobservable selection. What it cannot establish is timing: how quickly any gain appears after a firm begins collaborating, whether it builds gradually or arrives at once, whether it fades, and whether collaborating and comparison firms followed similar trajectories before treatment. This section reports a staggered difference-in-differences analysis across all three outcomes: ln labour productivity, revenue growth and productivity growth, together with a matched-sample robustness check. Because the pre-treatment trends differ, the results are interpreted as descriptive evidence on timing rather than as causal estimates. The main findings are:

- There is no significant productivity increase in the years after a firm's first international collaboration. A single positive estimate at the end of the window (t+10) does not indicate a delayed effect.
- Productivity growth shows no effect, consistent with Section 4.
- In the years before their first international joint patent, collaborating firms were already closing the productivity gap with comparable firms.
- The matched (PSM) design finds no significant international effect on any outcome. The one result significant at 5% is +3.5 percentage points on productivity growth for any collaboration.
- For domestic collaboration, the productivity level falls after the first collaboration in the DiD, although the matched design does not confirm this.

5.1 Estimator and specification

Two complementary designs are reported. The first is a doubly robust difference-in-differences (DiD) estimator following Callaway and Sant'Anna (2021). It combines an outcome-regression adjustment with inverse-probability weighting based on the estimated propensity to be treated. The control group in each comparison is the one listed in Table 7, together with treated firms that have not yet started collaborating (not-yet-treated). Standard errors are clustered by firm. Controls are ln employees, ln age, exporter, foreign ownership, ln cumulative patent stock, ln capital intensity and 1-digit NACE. Unlike Section 4, industry enters at the 1-digit level and region dummies are not included. Group-time effects are aggregated to event time over t−5 to t+10, with one year less for the growth outcomes by construction. The second design uses

propensity score matching (PSM) as a robustness check. Firms are matched 1:1 by nearest-neighbour propensity score (0.1 caliper). The matched sample is then analysed with a regression that absorbs firm and year fixed effects, weights by the matching weights and clusters standard errors by firm. Because firm fixed effects absorb any time-invariant difference between treated and control firms, identification comes entirely from the Treated x Post interaction; the propensity score does its work in the matching step. This design trades the larger comparison pool for a much smaller sample of firms that look alike on observables before treatment. Seven treatment/control comparisons are estimated (Table 7), each for all three outcomes. This gives 21 estimates under the DiD and 19 under PSM, where two cannot be estimated because of collinearity in the matched sample. As in Section 4, no comparison isolates firms doing both domestic and international collaboration at the same time. That cell (539 firm-years in the main CMP sample) is too small to support its own group-time estimates. The DiD samples are larger than the Section 4 sample (about 4,750 to 5,700 firms, against 4,481) because the DiD requires fewer variables: it does not use the largest-shareholder region, 2-digit industry or the technology-class instrument, so firms with missing values on these remain in the sample.

Table 7. Treatment and control groups used in Section 5

Comparison	Treated group	Control group
AnyVsNever	Firms with any collaboration	Never collaborated
DomVsNever	Firms with domestic collaboration	Never collaborated
DomVsNeverDom	Firms with domestic collaboration	Not-yet-treated on domestic (may include international-only)
IntVsNever	Firms with international collaboration	Never collaborated
IntVsNeverInt	Firms with international collaboration	Not-yet-treated on international (may include domestic-only)
IntOnlyVsDom	International-only firms	Domestic-only firms
IntVsDom	International firms (incl. mixed)	Domestic firms (incl. mixed)

The two smallest comparisons (IntOnlyVsDom, IntVsDom) run on samples roughly 20-25 times smaller than the other five: about 2,000-2,400 firm-years against 47,000-57,000 (Table 6a), with matched samples of 459-735 firm-years (Table 7).

5.2 Results

5.2.1 Staggered difference-in-differences

Tables 8a and 8b report the overall ATT and the event-time paths for the seven comparisons. Tables B1a-B1e report the event-time coefficients and Tables B2 and B2b the overall ATTs. The results differ from Section 4 in important ways. For productivity growth, no comparison shows a significant effect, in line with Section 4.

For the level of labour productivity, the overall ATT is negative and significant for any collaboration (−0.050) and for both domestic comparisons (−0.077 and −0.122). The event-time coefficients become more negative from around t+2 onwards (Table B1c). For international collaboration, the overall ATT is small and not significant (0.034 in both comparisons), although the estimates at t+10 are positive (0.120, significant at 10%, and 0.152, significant at 5%). They follow negative estimates at t+9 and rest on the earliest cohorts only, so they should not be read as evidence of a delayed effect. The large negative estimate for IntVsDom (−0.797) rests on about 1,100 firms and should not be over-interpreted[10].

We also re-estimated the event study for the domestic comparisons with ln employment and ln turnover as outcomes. Employment does not rise ahead of turnover. After the first domestic collaboration both fall relative to the control group, and turnover falls by more: the post-treatment averages are −0.18 for employment and −0.26 for turnover in DomVsNever, and −0.23 and −0.36 in DomVsNeverDom. The fall in turnover per employee therefore reflects turnover declining faster than headcount. These estimates are not tabulated here but are available on request.

For revenue growth, the ATT is negative for any collaboration (−0.028) and, at 10%, for both international comparisons (−0.033). The domestic comparisons show no effect. This contrasts with the positive revenue growth estimates in Section 4.

[10] Tables B1d to B1 and B2b in appendix show DiD estimates on the two components of our labour productivity measure: turnover and employment. This is because the domestic decline could signal an adaptation by firms which decide to hire before the growth in revenue materialise, this will lower turnover per employee. However, the results seem to show that revenues decline more than employment after treatment so productivity may decline and perhaps firms retain workers against their reduction in sales. Further research supported by linked historical firm-level data to the UK Innovation survey data may help unpack this trend.

The parallel-trends assumption does not hold in this data. The joint test that all pre-treatment coefficients are zero rejects at $p < 0.0001$ in all 21 cases (Tables B3 and B3b). Most individual pre-treatment coefficients are small, but the international comparisons on labour productivity show significantly negative pre-treatment coefficients (average −0.106 and −0.103). In other words, firms that start collaborating internationally were already catching up with the control group before their first collaboration. This might mean they were on a different trajectory whether they collaborated or not.

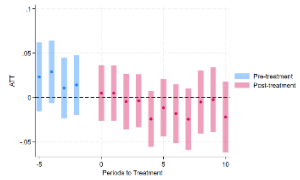
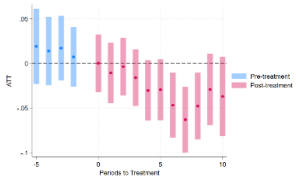
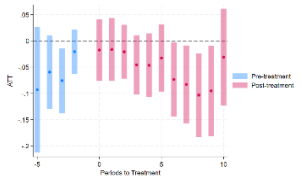
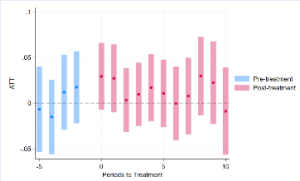
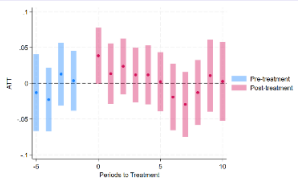
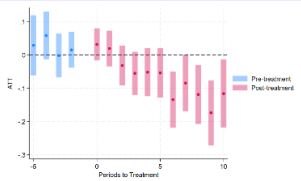
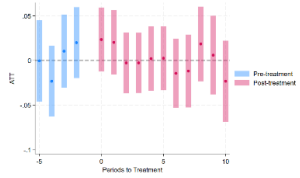
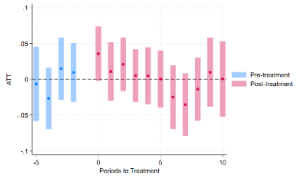
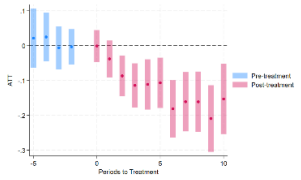
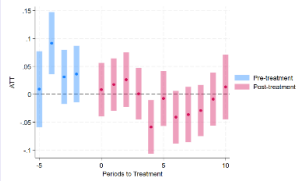
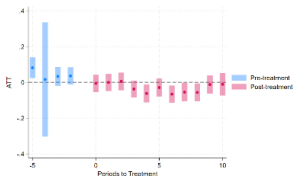
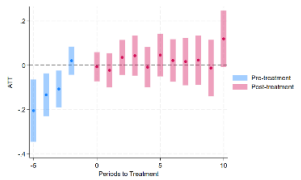
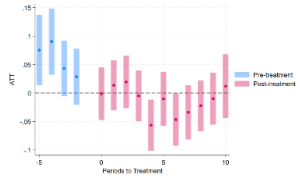
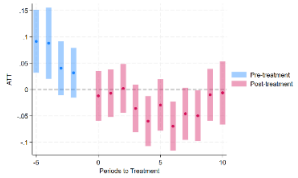
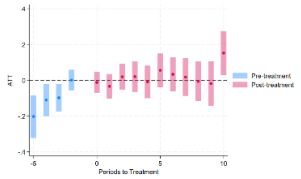
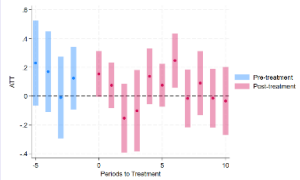
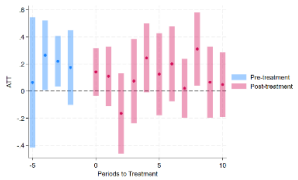
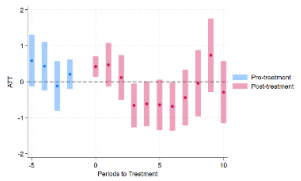
The DiD does not replicate the positive level effects found in Section 4. One possible reading is that the cross-sectional premium reflects persistent differences between collaborating and non-collaborating firms, rather than a change that follows the first collaboration. This would be consistent with the non-significant firm fixed effects estimates in Table 2A.

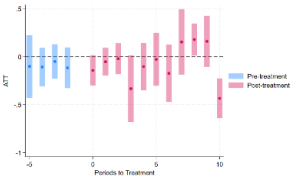
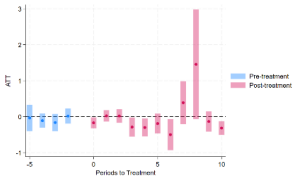
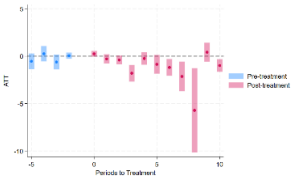
Table 8a. Staggered difference-in-differences: overall ATT by comparison and outcome

Comparison	Labour productivity growth	Revenue growth	Log labour productivity
AnyVsNever	−0.011 (0.012) N = 47,276	−0.028** (0.014) N = 47,800	−0.050* (0.029) N = 53,658
DomVsNever	0.015 (0.014) N = 47,410	0.011 (0.017) N = 47,933	−0.077** (0.032) N = 53,786
DomVsNeverDom	0.002 (0.014) N = 48,785	0.006 (0.016) N = 49,317	−0.122*** (0.032) N = 55,357
IntVsNever	−0.014 (0.018) N = 47,891	−0.033* (0.018) N = 48,421	0.034 (0.039) N = 54,315
IntVsNeverInt	−0.018 (0.017) N = 50,050	−0.033* (0.018) N = 50,598	0.034 (0.038) N = 56,829
IntOnlyVsDom	0.048 (0.052) N = 2,041	0.093 (0.067) N = 2,059	−0.167 (0.200) N = 2,394
IntVsDom	−0.083 (0.063) N = 2,050	−0.066 (0.080) N = 2,070	−0.797*** (0.220) N = 2,406

Note: Overall ATT from Callaway-Sant'Anna staggered DiD not-yet-treated firms as controls. Controls: ln employees, ln age, exporter, foreign-owned, ln cumulative patent stock, ln capital intensity and 1-digit NACE. Standard errors clustered by firm in parentheses. N is the number of firm-years with non-missing outcome and controls in each comparison sample. * p<0.10, ** p<0.05, *** p<0.01.

Table 8b. Event-time estimates since first R&D collaboration, by comparison and outcome

Comparison	Labour productivity growth	Revenue growth	Log labour productivity
AnyVsNever	 N = 47,276 firm-years (4,747 firms)	 N = 47,800 firm-years (4,801 firms)	 N = 53,658 firm-years (5,369 firms)
DomVsNever	 N = 47,410 firm-years (4,859 firms)	 N = 47,933 firm-years (4,913 firms)	 N = 53,786 firm-years (5,490 firms)
DomVsNeverDom	 N = 48,785 firm-years (4,890 firms)	 N = 49,317 firm-years (4,945 firms)	 N = 55,357 firm-years (5,523 firms)
IntVsNever	 N = 47,891 firm-years (4,990 firms)	 N = 48,421 firm-years (5,047 firms)	 N = 54,315 firm-years (5,630 firms)
IntVsNeverInt	 N = 50,050 firm-years (5,049 firms)	 N = 50,598 firm-years (5,106 firms)	 N = 56,829 firm-years (5,704 firms)
IntOnlyVsDom			

Comparison	Labour productivity growth	Revenue growth	Log labour productivity
	N = 2,041 firm-years (963 firms)	N = 2,059 firm-years (972 firms)	N = 2,394 firm-years (1,127 firms)
IntVsDom	 N = 2,050 firm-years (920 firms)	 N = 2,070 firm-years (929 firms)	 N = 2,406 firm-years (1,085 firms)

5.2.2 Propensity-score-matched difference-in-differences

The matched-sample design restricts attention to control firms that closely resemble treated firms on observables at the point of matching. It then estimates the treatment effect within that sample using firm and year fixed effects. Table 10 reports the 19 estimates.

At 5%, only one Treated × Post coefficient is significant: productivity growth in the AnyVsNever comparison (+3.5 percentage points). At 10%, the domestic comparisons are positive for labour productivity (0.074 and 0.071) and, in DomVsNever, for productivity growth (0.036). The IntOnlyVsDom estimate on labour productivity is negative (−0.188) but rests on 123 firms. No international comparison shows a significant positive effect on any outcome.

The matched estimates on the productivity level are positive but mostly not significant. They therefore confirm neither the Section 4 level effect nor the negative DiD estimates. The domestic comparisons are positive in the matched sample but negative in the DiD, which suggests the domestic results might be sensitive to the choice of control group. For the same domestic comparisons, the matched estimates for employment are small or weakly positive, and those for turnover are positive, so the matched design does not confirm the fall found in the DiD.

Table 9. PSM-matched fixed-effects DiD, all outcomes

	Int. vs Never	Int. vs Never-Int.	Any vs Never	Dom. vs Never	Dom. vs Never-Dom.	Int.-only vs Dom.-only	Int. (any) vs Dom.-only
Panel A. ln labour productivity							
Post (main effect)	−0.027 (0.052)	0.003 (0.060)	−0.046 (0.039)	−0.045 (0.039)	−0.043 (0.040)	0.062 (0.106)	−0.102 (0.100)
Treated × Post (ATT)	**0.027 (0.052)**	**−0.013 (0.060)**	**0.063 (0.040)**	**0.074 (0.042)**	**0.071 (0.042)**	**−0.188* (0.096)**	**0.077 (0.096)**
Observations (matched)	7,995	8,908	16,661	10,971	11,559	525	735
R^2	0.812	0.819	0.820	0.820	0.811	0.861	0.863
Clusters (firms)	565	599	1,143	789	806	123	141
Panel B. Revenue growth							
Post (main effect)	−0.026 (0.036)	−0.026 (0.025)	−0.001 (0.014)	−0.015 (0.022)	−0.010 (0.022)	−0.004 (0.109)	−0.026 (0.042)
Treated × Post (ATT)	**0.004 (0.037)**	**−0.001 (0.025)**	**−0.012 (0.014)**	**0.026 (0.022)**	**0.018 (0.023)**	**−0.065 (0.110)**	**omitted**
Observations (matched)	7,348	8,200	15,301	10,065	10,597	459	656
R^2	0.155	0.154	0.145	0.141	0.134	0.388	0.198
Clusters (firms)	557	594	1,118	767	784	114	134
Panel C. Labour productivity growth							
Post (main effect)	−0.026 (0.033)	−0.023 (0.027)	−0.033* (0.014)	−0.028 (0.018)	−0.012 (0.017)	0.002 (0.107)	−0.052 (0.038)
Treated × Post (ATT)	**0.030 (0.033)**	**0.017 (0.028)**	**0.035* (0.015)**	**0.036 (0.019)**	**0.018 (0.017)**	**−0.074 (0.108)**	**omitted**
Observations (matched)	7,322	8,173	15,252	10,033	10,563	459	656
R^2	0.097	0.094	0.103	0.112	0.105	0.361	0.187
Clusters (firms)	557	594	1,117	765	783	114	134

Note: Nearest-neighbour (1:1) propensity-score matching, 0.1 caliper, logit on ln employees, ln age, exporter, foreign-owned, ln cumulative patent stock and ln capital intensity. Post-matching linear regression with matching weights, firm and year fixed effects absorbed, same covariates, standard errors clustered by firm. 1.treated_grp is collinear with (absorbed by) the firm fixed effect and is omitted from every specification, so identification runs entirely through Treated × Post. In the Int. (any) vs Dom.-only comparison, Treated × Post is omitted for revenue growth and productivity growth because of collinearity in the matched sample. Standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01

6. Implications for UK innovation policy

International R&D collaboration is strongly associated with higher labour productivity, but three different designs find no productivity gain after firms start collaborating. Firms that begin collaborating internationally were already on a rising productivity path beforehand.

The findings suggest that capability largely comes before international collaboration, although collaboration may also add to it. International collaboration may provide access to specialised knowledge, technologies and capabilities, but firms that enter these relationships are not representative of the wider business population. They already differ from non-collaborating firms in ways that are only partly captured by the available data. Collaboration may act both as a source of external knowledge and as an indicator of firms' existing capacity to identify and use that knowledge.

International R&D collaboration should be treated as one component of a wider capability-building strategy. Policies that combine internal capability development with carefully targeted access to international knowledge networks are more likely to widen participation and strengthen knowledge diffusion than policies focused solely on increasing the number of collaborative projects.

6.1 Collaboration and absorptive capacity

The statistically significant productivity premium identified in Section 4 is concentrated among firms near the productivity frontier. The corresponding estimates for laggard firms are not statistically significant. This pattern is consistent with an absorptive-capacity interpretation: firms need sufficient prior knowledge and internal capability to recognise the value of external knowledge, assimilate it and apply it commercially (Cohen & Levinthal, 1990). Evidence on technology diffusion similarly suggests that organisational and managerial capabilities influence whether firms benefit from technologies and knowledge developed at the frontier (Andrews, Criscuolo & Gal, 2015). Industries that lag the global frontier may have the most to gain from foreign knowledge (Belderbos, Lokshin & Sadowski, 2015), but our results suggest that within any industry it is the more capable firms that are able to use it. Support aimed at catching-up industries therefore needs to reach beyond their leading firms.

The report does not directly measure absorptive capacity, so this mechanism should be treated as an interpretation rather than a separately tested causal channel. Nevertheless, the results

suggest that policies designed solely to increase the number of international collaborations may have uneven effects. Firms with established R&D, managerial and technological capabilities may be better placed to benefit, while firms further behind the frontier may require capability-building support before or alongside international partnership opportunities. Policy support could integrate internationalisation measures with investments in internal R&D, managerial capability, technology adoption and the organisational capacity required to use external knowledge.

6.2 Domestic and international collaboration as different instruments

Section 4 suggests that domestic and international collaboration are associated with different dimensions of firm performance. International collaboration is associated with higher labour productivity, while domestic collaboration is associated with higher revenue growth. The domestic revenue-growth relationship is also non-linear: the positive association emerges only when domestic collaboration represents a substantial share of a firm's patenting activity.

These distinctions should nevertheless be interpreted alongside Section 5. The positive domestic revenue-growth result is not reproduced in the staggered DiD analysis, while the matched estimates are positive but statistically insignificant. The evidence supports distinguishing between domestic and international collaboration, but it does not justify treating the estimated outcome of each channel as certain across all empirical specifications. The DiD also shows the productivity level of domestic collaborators falling after their first collaboration, although the matched design does not confirm this. One possible explanation is that these firms expand employment ahead of turnover. We tested this, and the evidence does not support it: employment falls after the first domestic collaboration, and turnover falls by more.

One possible explanation is that these firms expand employment ahead of turnover. We tested this, and the evidence does not support it: employment falls after the first domestic collaboration, and turnover falls by more.

A differentiated policy approach remains appropriate. Domestic collaboration may facilitate market access, supply-chain relationships, procurement opportunities and commercial scaling. International collaboration may provide access to more diverse and specialised knowledge. Because some highly innovative firms pursue both domestic and international relationships,

policy instruments should also accommodate mixed strategies rather than require firms to choose a single channel.

6.3 IS-8 sectors and regions

Section 4 finds that the statistically significant productivity premium from international collaboration is concentrated within the eight Industrial Strategy priority sectors. Within IS-8, the estimated international collaboration premium is around 32%, compared with a smaller and statistically insignificant estimate outside these sectors. This does not mean collaboration has no value outside IS-8; the association is clearest in sectors where firms may already have stronger innovation capabilities and complementary assets. The regional estimates also show variation. Positive international collaboration coefficients are identified in regions including the East of England the North East, South East, Wales and Scotland, while estimates in some other regions are not statistically significant. These results identify differences in the size of the association, not differences in how quickly benefits emerge. The timing analysis is not estimated separately by region or sector.

This creates a policy trade-off. Concentrating support in priority sectors and stronger innovation ecosystems may generate more readily measurable firm-level benefits. However, such targeting may also reinforce existing differences between sectors, firms and places. A broader productivity strategy should combine support for established international innovators with measures that allow less productive firms, non-priority sectors and weaker regional innovation systems to develop the capabilities required to participate effectively.

6.4 Limitations of the evidence

Because these findings run against a common expectation, four objections are likely.

1. Patents capture only part of firms' collaboration. That is true: our findings apply to formal R&D partnerships that produce jointly owned patents.
2. The benefits of collaboration may take longer to appear than our data allow. We follow firms for up to ten years, longer than most evaluation horizons, and find no consistent gain over that period.
3. The selection correction in Section 4 might be read as evidence of a causal effect. It shows that the premium is not explained by how collaborative a firm's technology field is; it does not show that the premium appears after collaboration begins, and the timing evidence indicates that it does not.

4. Findings might be read as an argument against funding international collaboration. They are not. International partnerships serve goals beyond productivity, including access to science and economic security, and they are associated with large productivity advantages among capable firms. The case is for pairing collaboration support with capability building, and for judging each scheme against its own objectives.

6.5 Recommendations

Four recommendations follow from the evidence:

- Pair collaboration support with capability building. Programmes that fund or broker international R&D partnerships should be combined with support for internal R&D, management practices and technology adoption, particularly for firms below the productivity frontier.
- Design domestic and international instruments separately. The two channels are associated with different outcomes, revenue growth and productivity respectively, and should be supported and evaluated on those terms, while still allowing firms to pursue both.
- Look beyond the IS-8 sectors and leading regions. The premium is clearest where capabilities are already strong. Spreading the benefits requires building the capability of the firms, sectors and places that currently gain little.
- Evaluate over longer horizons and with linked data. Any productivity effect of collaboration is not visible in the short to medium term. Evaluations of collaboration schemes should follow firms for several years and link collaboration records to firm-level performance data.

6.6 Limitations of the evidence

Several limitations qualify these findings. First, labour productivity is measured as turnover per employee, which reflects prices and mark-ups as well as efficiency. Second, the selection correction assumes that the collaboration rate in a firm's technology field affects its productivity only through its own collaboration; differences in productivity across technology fields could violate this. Third, The leave-one-out strategy for our instrument could be biased by the technology-class peer rate that could correlate with field-level productivity (e.g. biotech, pharma). Fourth, the parallel-trends assumption does not hold in the difference-in-differences analysis, so those estimates describe timing rather than establish causal effects. The large falls in employment and turnover after first collaboration may partly reflect firms shrinking or leaving the sample over time, so they should not be read as effects of collaboration. Because collaboration is dated by the first jointly filed patent, and joint R&D typically begins earlier, part of the pre-collaboration improvement may reflect early effects of the collaboration itself. Survey

data on collaboration by partner location, such as the UK Innovation Survey linked to business records, could address several of these limitations in future work, and also allow the researchers to capture collaboration and process innovation that do not results in a joint patent.

7. Conclusion

This report asks whether R&D collaboration, and international collaboration in particular, helps explain differences in UK firms' productivity and growth. The answer is qualified. Internationally collaborating firms are markedly more productive than comparable firms, and the premium remains after correcting for selection into collaboration. It is concentrated among frontier firms and in the IS-8 sectors. Domestic collaboration is associated with faster revenue growth rather than higher productivity, which may reflect commercial motives such as market access, supply-chain relationships and joint bids.

The timing analysis tempers this. In the years before their first international joint patent, collaborating firms were already closing the productivity gap with comparable firms, and none of our designs finds a significant productivity increase afterwards. The premium appears to reflect, at least in part, which firms collaborate. International collaboration looks as much like a marker of capability as a source of it.

For policy, this points to capability as the binding constraint. Increasing the number of collaborations is unlikely on its own to close the gap between frontier and laggard firms. Combining access to international knowledge networks with investment in firms' capacity to absorb and use that knowledge offers a better prospect. Future work should test this directly, using measures of absorptive capacity, longer follow-up and sources of variation in collaboration that are independent of firms' own trajectories.

REFERENCES

Andrews, D., Criscuolo, C., & Gal, P. N. (2015). *Frontier firms, technology diffusion and public policy: Micro evidence from OECD countries*. OECD Productivity Working Papers, No. 2. OECD Publishing.

Andrews, D., Criscuolo, C., & Gal, P. N. (2016). The best versus the rest: The global productivity slowdown, divergence across firms and the role of public policy. OECD Productivity Working Papers, No. 5. OECD Publishing.

Aschhoff, B., & Schmidt, T. (2008). Empirical evidence on the success of R&D cooperation - happy together? Review of Industrial Organization, 33(1), 41-62.

Belderbos, R., Carree, M., & Lokshin, B. (2004). Cooperative R&D and firm performance. Research Policy, 33(10), 1477-1492.

Belderbos, R., Cassiman, B., Faems, D., Leten, B., & Van Looy, B. (2014). Co-ownership of intellectual property: Exploring the value-appropriation and value-creation implications of co-patenting with different partners. Research Policy, 43(5), 841-852.

Belderbos, R., Leten, B., & Suzuki, S. (2013). How global is R&D? Firm-level determinants of home-country bias in R&D. Journal of International Business Studies, 44(8), 765-786.

Belderbos, R., Lokshin, B., & Sadowski, B. (2015). The returns to foreign R&D. Journal of International Business Studies, 46(4), 491-504.

Berchicci, L. (2013). Towards an open R&D system: Internal R&D investment, external knowledge acquisition and innovative performance. *Research Policy, 42*(1), 117-127.

Bernard, A. B., & Jensen, J. B. (1999). Exceptional exporter performance: Cause, effect, or both? Journal of International Economics, 47(1), 1-25.

Bloom, N., Schankerman, M., & Van Reenen, J. (2013). Identifying technology spillovers and product market rivalry. *Econometrica, 81*(4), 1347-1393.

Callaway, B., & Sant'Anna, P. H. C. (2021). Difference-in-differences with multiple time periods. *Journal of Econometrics, 225*(2), 200-230.

Castellani, D., & Du, J. (2023). *Innovation without borders: A rapid review of international R&D collaboration between firms*. Innovation Research Caucus Insight Paper 008.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly, 35*(1), 128-152. https://doi.org/10.2307/2393553

de Chaisemartin, C., & D'Haultfœuille, X. (2020). Two-way fixed effects estimators with heterogeneous treatment effects. *American Economic Review, 110*(9), 2964-2996.

Du, J., & Ribaudo, D. (2026). *Global reach, local roots: Understanding the internationalisation of R&D among UK firms*. Innovation and Research Caucus.

Fernald, J., & Inklaar, R. (2025). The UK productivity “puzzle” in an international comparative perspective. *Oxford Bulletin of Economics and Statistics, 87*(4), 691-710.

Frenz, M., & Ietto-Gillies, G. (2009). The impact on innovation performance of different sources of knowledge: Evidence from the UK Community Innovation Survey. Research Policy, 38(7), 1125-1135.

Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics, 225*(2), 254-277.

Griffith, R., Redding, S., & Van Reenen, J. (2004). Mapping the two faces of R&D: Productivity growth in a panel of OECD industries. Review of Economics and Statistics, 86(4), 883-895.

Grimpe, C., & Kaiser, U. (2010). Balancing internal and external knowledge acquisition: The gains and pains from R&D outsourcing. *Journal of Management Studies, 47*(8), 1483-1509.

Hagedoorn, J. (2003). Sharing intellectual property rights - an exploratory study of joint patenting amongst companies. Industrial and Corporate Change, 12(5), 1035-1050.

HM Government. (2025). *The UK’s modern Industrial Strategy*. Department for Business and Trade.

Hottenrott, H., & Lopes-Bento, C. (2016). R&D partnerships and innovation performance: Can there be too much of a good thing? *Journal of Product Innovation Management, 33*(6), 773-794.

Jibril, H., & Roper, S. (2022). Of chickens and eggs? Exporting, innovation novelty and productivity (ERC Research Paper No. 101). Enterprise Research Centre.

Kafouros, M. I., & Forsans, N. (2012). The role of open innovation in emerging economies: Do companies profit from the scientific knowledge of others? *Journal of World Business, 47*(3), 362-370.

Laursen, K., & Salter, A. (2006). Open for innovation: The role of openness in explaining innovation performance among UK manufacturing firms. *Strategic Management Journal, 27*(2), 131-150.

Lind, J. T., & Mehlum, H. (2010). With or without U? The appropriate test for a U-shaped relationship. *Oxford Bulletin of Economics and Statistics, 72*(1), 109-118.

Lokshin, B., Belderbos, R., & Carree, M. (2008). The productivity effects of internal and external R&D: Evidence from a dynamic panel data model. Oxford Bulletin of Economics and Statistics, 70(3), 399-413.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. Econometrica, 71(6), 1695-1725.

Nieto, M. J., & Rodríguez, A. (2022). Internationalisation of innovation in SMEs: Trends and evidence. *Journal of Small Business Management, 60*(3), 453-472.

Office for National Statistics. (2025b). *Trends in UK business dynamism and productivity: 2025*. Office for National Statistics.

Office for National Statistics. (2026). *Productivity flash estimate and overview, UK: April to June 2026 and January to March 2026*. Office for National Statistics. [ons.gov.uk]

Ribaudo, D., Marin-Cadavid, C., & MacBryde, J. (2024). *Innovation and productivity in manufacturing: A rapid review on R&I policies*. Innovation and Research Caucus.

Rodríguez, A., & Nieto, M. J. (2016). Does R&D offshoring lead to SME growth? Different governance modes and the mediating role of innovation. *Strategic Management Journal, 37*(8), 1734-1753.

Roodman, D. (2011). Fitting fully observed recursive mixed-process models with CMP. *The Stata Journal, 11*(2), 159-206.

Sampson, R. C. (2005). Experience effects and collaborative returns in R&D alliances. Strategic Management Journal, 26(11), 1009-1031.

The Productivity Institute. (2025). *The UK productivity slowdown: A review of timing, magnitude, and drivers*. Institute for Productivity Manchester Working Paper No. 48.

Wagner, J. (2007). Exports and productivity: A survey of the evidence from firm-level data. The World Economy, 30(1), 60-82.

APPENDIX A

The three outcomes are ln labour productivity, revenue growth and productivity growth (the growth rate of labour productivity). Any collaboration equals 1 if the firm has any collaborative patent family in the year; domestic collaboration and international collaboration are the equivalent indicators for each channel. The peer collaboration rate is the average of any collaboration across all other firms in the same technology class and year, the firm itself excluded, where a firm's technology class is its most frequent 3-digit IPC class; the domestic and international peer collaboration rates are built the same way. The peer group is defined by technology, not industry, while NACE 2-digit industry enters every equation as a fixed effect and as the clustering variable.

Table A1. Second stage: The outcome equation of the CMP system

Dependent variable: ln labour productivity, revenue growth or productivity growth, as named in the first column

CMP system	Dependent variable (equation 1)	Regressor	Coefficient	Std. err.	z	P>|z|	N
ln labour productivity	ln labour productivity	Any collaboration	0.2853***	0.0744	3.83	0.000	46,499
Revenue growth	Revenue growth	Any collaboration	0.0341*	0.0178	1.92	0.055	46,499
Productivity growth	Productivity growth	Any collaboration	0.0132	0.0098	1.34	0.179	46,494

Table A1B. First stage: the collaboration equation of the CMP system (probit)

Dependent variable: Any collaboration

CMP system	Dependent variable (equation 2)	Instrument	Coefficient	Std. err.	z	P>|z|	$\chi^2(1)$	N
ln labour productivity	Any collaboration	Peer collaboration rate	2.2459***	0.3991	5.63	0.000	31.66	46,499
Revenue growth	Any collaboration	Peer collaboration rate	2.2062***	0.3982	5.54	0.000	30.69	46,499
Productivity growth	Any collaboration	Peer collaboration rate	2.2038***	0.3969	5.55	0.000	30.84	46,494

Note: Any collaboration is the dependent variable here; the outcome variable is the dependent variable of the other equation in the same system, named in the first column. A probit first stage has no F-statistic, so instrument strength is the Wald $\chi^2(1)$ on the instrument, computed as the square of the first-stage z. The linear analogue of the same first stage gives F(1,77) = 55.9. Table A1 reports full CMP estimates, standard errors and p-values

Table A1C. Error correlation in the CMP system

CMP system	Parameter	Coefficient	Std. err.	z	P>|z|	ρ_{12}	Std. err.
ln labour productivity	atanh(ρ_{12})	-0.1223	0.0386	-3.17	0.002	-0.1217	0.0380
Revenue growth	atanh(ρ_{12})	-0.0123	0.0176	-0.70	0.486	-0.0123	0.0176
Productivity growth	atanh(ρ_{12})	-0.0116	0.0123	-0.94	0.345	-0.0116	0.0123

Note: The CMP estimator estimates atanh(ρ) and also reports ρ itself; both are shown. The z and P>|z| are the test of H_0: ρ = 0. ρ is negative and significant for ln labour productivity, so OLS is biased downward and the correction raises the estimate. For revenue growth and productivity growth ρ is not different from zero, so collaboration is not endogenous there and OLS is the appropriate estimator.

Table A2. Second stage: The outcome equation of the CMP system

Dependent variable: ln labour productivity, revenue growth or productivity growth, as named in the first column

CMP system	Dependent variable (equation 1)	Regressor	Coefficient	Std. err.	z	P>|z|	N
ln labour productivity	ln labour productivity	Domestic collaboration	0.0757	0.0902	0.84	0.401	46,499

CMP system	Dependent variable (equation 1)	Regressor	Coefficient	Std. err.	z	P>|z|	N
ln labour productivity	ln labour productivity	International collaboration	0.3645***	0.0796	4.58	0.000	46,499
Revenue growth	Revenue growth	Domestic collaboration	0.0448**	0.0203	2.20	0.028	46,499
Revenue growth	Revenue growth	International collaboration	0.0108	0.0107	1.01	0.311	46,499
Productivity growth	Productivity growth	Domestic collaboration	0.0188	0.0122	1.54	0.123	46,494
Productivity growth	Productivity growth	International collaboration	-0.0044	0.0097	-0.45	0.651	46,494

Note: These are the CMP figures in Table 3.

Table A2B. First stage: the two collaboration equations of the CMP system (probit)

Dependent variable: Domestic collaboration and international collaboration

CMP system	Dependent variable (equation 2)	Instrument	Coefficient	Std. err.	z	P>|z|	$\chi^2(1)$	N
ln labour productivity	Domestic collaboration	Domestic peer collaboration rate	3.0623***	0.6020	5.09	0.000	25.87	46,499
ln labour productivity	International collaboration	International peer collaboration rate	2.8447***	0.8387	3.39	0.001	11.50	46,499
Revenue growth	Domestic collaboration	Domestic peer collaboration rate	3.0322***	0.6011	5.04	0.000	25.44	46,499
Revenue growth	International collaboration	International peer collaboration rate	2.7955***	0.8222	3.40	0.001	11.56	46,499
Productivity growth	Domestic collaboration	Domestic peer collaboration rate	3.0279***	0.5999	5.05	0.000	25.47	46,494
Productivity growth	International collaboration	International peer collaboration rate	2.7971***	0.8213	3.41	0.001	11.60	46,494

Note: Each collaboration indicator is the dependent variable of its own equation and carries its own instrument. $\chi^2(1)$ is the square of the first-stage z in each equation.

Table A2C. Error correlations in the CMP system

CMP system	Parameter	Pair	Coefficient	Std. err.	z	P>|z|	ρ	Std. err.
ln labour productivity	atanh(ρ_{12})	Outcome with domestic collaboration	-0.0630	0.0413	-1.52	0.127	-0.0629	0.0411
ln labour productivity	atanh(ρ_{13})	Outcome with international collaboration	-0.0984	0.0298	-3.30	0.001	-0.0980	0.0296
ln labour productivity	atanh(ρ_{23})	Domestic with international collaboration	0.2150	0.0352	6.11	0.000	0.2117	0.0336
Revenue growth	atanh(ρ_{12})	Outcome with domestic collaboration	-0.0149	0.0163	-0.91	0.362	-0.0149	0.0163
Revenue growth	atanh(ρ_{13})	Outcome with international collaboration	-0.0029	0.0143	-0.20	0.841	-0.0029	0.0143
Revenue growth	atanh(ρ_{23})	Domestic with international collaboration	0.2191	0.0348	6.29	0.000	0.2156	0.0332
Productivity growth	atanh(ρ_{12})	Outcome with domestic collaboration	-0.0147	0.0134	-1.10	0.273	-0.0147	0.0134
Productivity growth	atanh(ρ_{13})	Outcome with international collaboration	0.0012	0.0119	0.10	0.917	0.0012	0.0119
Productivity growth	atanh(ρ_{23})	Domestic with international collaboration	0.2189	0.0348	6.29	0.000	0.2154	0.0332

Note: ρ_{12} and ρ_{13} are the selection correlations. ρ_{23} is the correlation between the two collaboration equations, not a selection effect on the outcome. Of the two selection correlations, only ρ_{13}, the international one, is significant for ln labour productivity, and it is negative.

Table A3. Quadratic in the collaboration share, by outcome and channel

Outcome	Share	Linear	Std. err.	P>|t|	Squared	Std. err.	P>|t|	N
ln labour productivity	Domestic share	-0.2200	0.1342	0.105	0.2892**	0.1400	0.042	40,169
ln labour productivity	International share	0.7936***	0.2295	0.001	-0.4503*	0.2283	0.052	40,169
Revenue growth	Domestic share	-0.0605*	0.0305	0.051	0.0698**	0.0345	0.047	40,169
Revenue growth	International share	-0.0424	0.0330	0.204	0.0289	0.0361	0.426	40,169

Note: Both shares and both squares enter the same regression, one regression per outcome. Controls, fixed effects and clustering as in report Tables 2 and 3. * p<0.10, ** p<0.05, *** p<0.01.

Table A4. Lind-Mehlum (2010) test, by outcome and channel

Outcome	Share	Slope at 0 (t)	Slope at 1 (t)	Turning point	95% CI, delta	95% CI, Fieller	P>|t|	Verdict
ln labour productivity	Domestic share	-0.220 (-1.64)	0.358 (2.13)	0.380	[0.18, 0.58]	[-1.36, 0.71]	0.053	U-shape at 10%
ln labour productivity	International share	0.794 (3.46)	-0.107 (-0.43)	0.881	[0.45, 1.31]	—	0.334	Not confirmed
Revenue growth	Domestic share	-0.061 (-1.98)	0.079 (2.01)	0.434	[0.36, 0.51]	[-0.06, 0.81]	0.025	U-shape at 5%
Revenue growth	International share	-0.042 (-1.28)	0.015 (0.37)	0.733	[-0.06, 1.52]	—	0.356	Not confirmed

Note: The test asks whether the slope is significant and of opposite sign at the two ends of the range of the share, which is 0 to 1 in every case. P>|t| is the one-sided overall test of the shape * p<0.10, ** p<0.05, *** p<0.01. Two intervals are given for the turning point: the delta-method one, which is the source of the 43% turning point quoted in Section 4.2, and the Fieller one, which is what Lind and Mehlum recommend because a turning point is a ratio. A dash in the Fieller column means that interval is unbounded, not that the turning point is missing: a Fieller interval is finite only when the squared term is significant at 5%, which these two rows are not. The point estimate and the delta interval still stand. All four rows are the regressions in Table A3, on 40,169 firm-years.

How many firms sit at high shares

Table A5. Where the firm-years sit on each share, estimation sample of 40,169

	Domestic share, n	%	Firms	International share, n	%	Firms
exactly 0	23,669	58.9%	—	30,165	75.1%	—
at or above 0.25	8,678	21.6%	1,071	3,912	9.7%	479
at or above 0.50	5,129	12.8%	705	2,081	5.2%	281
at or above 0.75	2,689	6.7%	397	975	2.4%	149
at or above 0.90	2,196	5.5%	341	709	1.8%	122
exactly 1	2,156	5.4%	335	593	1.5%	106
above its own turning point	5,366	13.4%	—	736	1.8%	125

Note: Turning points are 0.434 for the domestic share against revenue growth and 0.881 for the international share against ln labour productivity, from Table A4 - the two pairs plotted in Figures 1a and 1b. Firm counts are distinct firms contributing at least one firm-year at or above that level.

Table A6. Main results with NUTS1 region fixed effects

Outcome and channel	OLS	CMP	N
ln labour productivity, any collaboration	0.0916***	0.2531***	44,319
Revenue growth, any collaboration	0.0271***	0.0335*	44,319
Productivity growth, any collaboration	0.0080	0.0122	43,883 / 44,313
ln labour productivity, domestic	-0.0089	0.0627	44,319
ln labour productivity, international	0.2044***	0.3306***	44,319
Revenue growth, domestic	0.0367**	0.0467**	44,319
Revenue growth, international	0.0107	0.0108	44,319
Productivity growth, domestic	0.0117	0.0192	43,883 / 44,313
Productivity growth, international	-0.0009	-0.0022	43,883 / 44,313

Note: OLS absorbs NACE 2-digit industry, year and NUTS1 region; CMP enters the same three as dummies. Both clustered on NACE 2-digit. Controls as in Tables 2A and 3. Productivity growth N is 43,883 under OLS and 44,313 under CMP. First stages are strong throughout: any collaboration z 5.15-5.24, domestic z 4.63-4.66, international z 3.63-3.64. The six domestic and international CMP estimates are newly estimated; the original Part A ran CMP for any collaboration only. * p<0.10, ** p<0.05, *** p<0.01.

Table A7A. Region interacted with collaboration: marginal effects by region - any collaboration

Region	ln LP effect	p	Rev growth effect	p	Prod growth effect	p
East Midlands (England)	0.0916	0.290	-0.0165	0.342	-0.0001	0.997
East of England	0.1679**	0.014	0.0274	0.102	0.0113	0.457
London	0.0286	0.802	0.0224	0.177	-0.0073	0.584
North East (England)	0.0929	0.336	-0.0335	0.211	-0.0545**	0.048
North West (England)	-0.0264	0.784	0.0427**	0.022	0.0150	0.364
Northern Ireland	-0.2637	0.191	0.0554	0.152	0.0931**	0.018
Scotland	0.1561	0.232	0.0151	0.521	-0.0341	0.231
South East (England)	0.1500***	0.009	0.0387*	0.054	0.0221**	0.049
South West (England)	0.1404	0.314	0.0374**	0.032	0.0094	0.471
Wales	0.0974	0.717	0.0696	0.276	0.0618	0.177
West Midlands (England)	0.0615	0.241	0.0459*	0.073	0.0231	0.184
Yorkshire and The Humber	0.1151	0.162	-0.0037	0.883	-0.0048	0.803

Table A7B. Region interacted with collaboration: marginal effects by region - domestic collaboration

Region	ln LP effect	p	Rev growth effect	p	Prod growth effect	p
East Midlands (England)	0.0799	0.455	-0.0128	0.578	-0.0172	0.299
East of England	-0.0999	0.273	0.0409	0.149	0.0189	0.510
London	-0.1014	0.180	0.0241	0.198	-0.0101	0.515
North East (England)	-0.0479	0.692	-0.0408	0.204	-0.0511	0.150
North West (England)	-0.0744	0.427	0.0532**	0.015	0.0127	0.466
Northern Ireland	-0.0116	0.970	0.0718	0.222	0.1364**	0.027
Scotland	0.0753	0.648	0.0560	0.236	0.0045	0.851
South East (England)	-0.0108	0.855	0.0568**	0.015	0.0263	0.163
South West (England)	0.1277	0.291	0.0267*	0.051	0.0039	0.761
Wales	-0.0330	0.928	0.1113*	0.070	0.0916**	0.027
West Midlands (England)	0.1428	0.108	0.0413	0.196	0.0328	0.134
Yorkshire and The Humber	0.0616	0.414	0.0002	0.994	-0.0028	0.883

Table A7C. Region interacted with collaboration: marginal effects by region - international collaboration

Region	ln LP effect	p	Rev growth effect	p	Prod growth effect	p
East Midlands (England)	0.0706	0.653	-0.0236	0.284	0.0052	0.817
East of England	0.3489***	0.000	0.0052	0.785	-0.0106	0.467
London	0.2049	0.224	0.0033	0.921	-0.0090	0.773
North East (England)	0.3860**	0.013	0.0086	0.837	-0.0265	0.390
North West (England)	0.0182	0.886	0.0252	0.499	0.0150	0.637
Northern Ireland	-0.4724***	0.000	0.0255	0.578	0.0362	0.224
Scotland	0.3619**	0.049	-0.0099	0.826	-0.0501	0.380
South East (England)	0.3027***	0.000	0.0058	0.660	0.0065	0.666
South West (England)	0.1110	0.555	0.0475	0.155	0.0166	0.485
Wales	0.2654*	0.067	0.0027	0.968	-0.0205	0.608
West Midlands (England)	-0.0576	0.488	0.0453	0.286	0.0074	0.740
Yorkshire and The Humber	0.2637	0.112	-0.0085	0.819	-0.0097	0.782

Marginal effects from a single pooled OLS regression with region interactions. NACE 2-digit and year dummies. Clustered on NACE 2-digit. All twelve regions. * p<0.10, ** p<0.05, *** p<0.01.

Appendix B (supplement): ln employment and ln turnover

This supplement adds two outcomes to Appendix B: ln employment and ln turnover. They decompose the change in ln labour productivity (ln LP = ln turnover − ln employment) reported in Table B1c, and are estimated with the same specifications as the other outcomes: the Callaway-Sant'Anna event study (Tables B1d-B1e, B2b, B3b, Figures B1) and the PSM-matched fixed-effects DiD (Table B4). Table numbering continues from Appendix B and can be changed to fit the final layout.

Event-study estimates

Table B1d. Event-study coefficients, t−5 to t+10: ln employment

	AnyVs Never	DomVs Never	DomVs NeverDom	IntVs Never	IntVs NeverInt	IntOnlyVs Dom	IntVs Dom
Pre-treatment average	**−0.005** (0.030)	**0.022** (0.036)	**0.007** (0.035)	**−0.073*** (0.044)	**−0.072*** (0.039)	**0.671*** (0.359)	**−0.135** (0.210)
Post-treatment average (t0 to t+10)	**−0.204***** (0.036)	**−0.178***** (0.039)	**−0.229***** (0.038)	**−0.176***** (0.047)	**−0.210***** (0.045)	**−0.218** (0.253)	**−0.964***** (0.313)
t−5	**−0.037** (0.049)	**−0.042** (0.059)	**−0.032** (0.057)	**−0.050** (0.065)	**−0.097** (0.062)	**−0.606** (0.562)	**−0.062** (0.535)
t−4	**0.028** (0.043)	**0.062** (0.051)	**0.029** (0.050)	**−0.139**** (0.062)	**−0.112**** (0.053)	**0.341** (0.330)	**−0.165** (0.317)
t−3	**0.017** (0.034)	**0.086**** (0.042)	**0.078**** (0.040)	**−0.072** (0.048)	**−0.055** (0.043)	**2.885**** (1.128)	**−0.541*** (0.319)
t−2	**−0.029** (0.023)	**−0.018** (0.028)	**−0.046*** (0.025)	**−0.032** (0.039)	**−0.023** (0.031)	**0.063** (0.347)	**0.227** (0.269)
t0	**0.011** (0.019)	**0.023** (0.025)	**0.012** (0.024)	**0.031** (0.029)	**0.012** (0.026)	**0.576** (0.628)	**0.654** (0.448)
t+1	**−0.102***** (0.025)	**−0.086**** (0.038)	**−0.103***** (0.036)	**−0.101***** (0.038)	**−0.112***** (0.033)	**−0.437** (0.374)	**−0.178** (0.459)
t+2	**−0.139***** (0.028)	**−0.133***** (0.035)	**−0.165***** (0.034)	**−0.141***** (0.040)	**−0.152***** (0.038)	**−0.415** (0.311)	**−0.085** (0.243)
t+3	**−0.175***** (0.032)	**−0.149***** (0.038)	**−0.185***** (0.037)	**−0.195***** (0.047)	**−0.208***** (0.043)	**−1.015**** (0.410)	**−0.139** (0.319)
t+4	**−0.133***** (0.036)	**−0.139***** (0.043)	**−0.169***** (0.042)	**−0.152***** (0.052)	**−0.180***** (0.049)	**0.741*** (0.382)	**0.010** (0.305)

	AnyVs Never	DomVs Never	DomVs NeverDom	IntVs Never	IntVs NeverInt	IntOnlyVs Dom	IntVs Dom
t+5	**−0.212***** (0.041)	**−0.204***** (0.047)	**−0.258***** (0.046)	**−0.185***** (0.058)	**−0.219***** (0.055)	**−0.040** (0.601)	**−2.514***** (0.693)
t+6	**−0.256***** (0.046)	**−0.225***** (0.053)	**−0.279***** (0.051)	**−0.188***** (0.064)	**−0.211***** (0.061)	**−0.550** (0.503)	**−1.010***** (0.385)
t+7	**−0.287***** (0.053)	**−0.277***** (0.058)	**−0.321***** (0.056)	**−0.155**** (0.073)	**−0.231***** (0.068)	**−0.153** (0.435)	**−1.981***** (0.465)
t+8	**−0.319***** (0.059)	**−0.250***** (0.062)	**−0.329***** (0.061)	**−0.287***** (0.079)	**−0.309***** (0.076)	**−0.861**** (0.385)	**−2.972***** (1.008)
t+9	**−0.291***** (0.065)	**−0.219***** (0.067)	**−0.316***** (0.065)	**−0.199**** (0.085)	**−0.291***** (0.081)	**0.635** (0.476)	**−1.693** (1.205)
t+10	**−0.346***** (0.071)	**−0.296***** (0.072)	**−0.407***** (0.070)	**−0.359***** (0.089)	**−0.408***** (0.086)	**−0.877** (0.925)	**−0.696*** (0.377)
N (firm-years)	106,758	107,014	108,885	108,556	111,905	3,231	3,239
Firms	13,130	13,308	13,345	13,689	13,760	1,701	1,653

Note: Event-time ATT(e) from Callaway-Sant'Anna staggered DiD, not-yet-treated firms as controls, long differences relative to the year before treatment, e = −1, aggregated with estat event over t−5 to t+10. Pre- and post-treatment averages are the means of the event-time coefficients in each window. Controls: ln age, exporter, foreign-owned, ln cumulative patent stock, ln capital intensity and 1-digit NACE; ln employees is not used as a control because it is (or is mechanically linked to) the outcome. Standard errors clustered by firm in parentheses. N is the number of firm-years (firms) with non-missing outcome and controls in each comparison sample. Coefficients are in log points (×100 for approximate per cent). * p<0.10, ** p<0.05, *** p<0.01.

Table B1e. Event-study coefficients, t−5 to t+10: ln turnover

	AnyVs Never	DomVs Never	DomVs NeverDom	IntVs Never	IntVs NeverInt	IntOnlyVs Dom	IntVs Dom
Pre-treatment average	**−0.053** (0.042)	**0.075** (0.048)	**0.060** (0.046)	**−0.142**** (0.059)	**−0.134***** (0.049)	**0.959*** (0.514)	**−0.110** (0.356)
Post-treatment average (t0 to t+10)	**−0.211***** (0.045)	**−0.256***** (0.051)	**−0.355***** (0.049)	**−0.146**** (0.061)	**−0.176***** (0.059)	**−0.629** (0.401)	**−2.142***** (0.606)
t−5	**−0.095** (0.076)	**0.045** (0.077)	**0.077** (0.075)	**−0.296***** (0.098)	**−0.189**** (0.080)	**−0.560** (0.827)	**−0.617** (0.883)
t−4	**−0.055** (0.051)	**0.117*** (0.061)	**0.084** (0.058)	**−0.169**** (0.077)	**−0.153**** (0.067)	**0.264** (0.616)	**0.320** (0.444)
t−3	**−0.051** (0.044)	**0.076** (0.053)	**0.070** (0.051)	**−0.095** (0.069)	**−0.130**** (0.061)	**3.571***** (1.364)	**−0.649** (0.554)

	AnyVs Never	DomVs Never	DomVs NeverDom	IntVs Never	IntVs NeverInt	IntOnlyVs Dom	IntVs Dom
t−2	**−0.010** (0.046)	**0.061** (0.044)	**0.011** (0.041)	**−0.008** (0.059)	**−0.065** (0.052)	**0.562** (0.531)	**0.506** (0.459)
t0	**−0.018** (0.037)	**0.056** (0.038)	**−0.010** (0.036)	**−0.015** (0.053)	**−0.029** (0.048)	**0.391** (0.313)	**0.478*** (0.273)
t+1	**−0.114***** (0.040)	**−0.117***** (0.045)	**−0.199***** (0.043)	**−0.133**** (0.062)	**−0.153***** (0.055)	**−0.784** (0.615)	**−0.901**** (0.427)
t+2	**−0.125***** (0.040)	**−0.144***** (0.051)	**−0.235***** (0.049)	**−0.103*** (0.058)	**−0.149***** (0.053)	**−0.760** (0.529)	**−0.573** (0.400)
t+3	**−0.170***** (0.045)	**−0.175***** (0.054)	**−0.286***** (0.053)	**−0.157**** (0.064)	**−0.195***** (0.061)	**−0.593** (0.902)	**−1.499**** (0.654)
t+4	**−0.154***** (0.049)	**−0.233***** (0.059)	**−0.297***** (0.059)	**−0.146**** (0.069)	**−0.186***** (0.067)	**−0.122** (0.550)	**−0.542** (0.460)
t+5	**−0.173***** (0.052)	**−0.218***** (0.062)	**−0.314***** (0.059)	**−0.101** (0.075)	**−0.147**** (0.073)	**−0.011** (0.916)	**−5.214***** (1.507)
t+6	**−0.255***** (0.059)	**−0.309***** (0.069)	**−0.427***** (0.066)	**−0.169**** (0.080)	**−0.202***** (0.078)	**−0.613** (0.559)	**−2.293***** (0.560)
t+7	**−0.293***** (0.063)	**−0.327***** (0.071)	**−0.437***** (0.073)	**−0.161*** (0.088)	**−0.201**** (0.084)	**−1.319**** (0.618)	**0.959** (0.866)
t+8	**−0.379***** (0.069)	**−0.419***** (0.075)	**−0.543***** (0.073)	**−0.277***** (0.092)	**−0.311***** (0.090)	**−1.570**** (0.756)	**−6.184**** (2.479)
t+9	**−0.341***** (0.074)	**−0.470***** (0.081)	**−0.583***** (0.080)	**−0.222**** (0.106)	**−0.253**** (0.101)	**0.464** (0.684)	**−5.185**** (2.494)
t+10	**−0.300***** (0.081)	**−0.461***** (0.087)	**−0.576***** (0.085)	**−0.125** (0.108)	**−0.107** (0.105)	**−2.002*** (1.203)	**−2.604***** (0.724)
N (firm-years)	53,658	53,786	55,357	54,315	56,829	2,394	2,406
Firms	5,369	5,490	5,523	5,630	5,704	1,127	1,085

Note: Event-time ATT(e) from Callaway-Sant'Anna staggered DiD not-yet-treated firms as controls, long differences relative to the year before treatment, e = −1, aggregated with estat event over t−5 to t+10. Pre- and post-treatment averages are the means of the event-time coefficients in each window. Controls: ln age, exporter, foreign-owned, ln cumulative patent stock, ln capital intensity and 1-digit NACE; ln employees is not used as a control because it is (or is mechanically linked to) the outcome. Standard errors clustered by firm in parentheses. N is the number of firm-years (firms) with non-missing outcome and controls in each comparison sample. Coefficients are in log points (×100 for approximate per cent). * p<0.10, ** p<0.05, *** p<0.01. ln turnover is constructed as ln labour productivity + ln employees, so its sample is restricted to firm-years with observed labour productivity and is smaller than the employment sample; the two outcomes are therefore not estimated on identical samples. Both outcomes are winsorised at the 1st and 99th percentiles within year.

Table B2b. Staggered difference-in-differences: overall ATT by comparison, ln employment and ln turnover

Comparison	ln employment	ln turnover
AnyVsNever	**−0.231***** (0.039) N = 106,758	**−0.220***** (0.050) N = 53,658
DomVsNever	**−0.204***** (0.041) N = 107,014	**−0.287***** (0.054) N = 53,786
DomVsNeverDom	**−0.255***** (0.040) N = 108,885	**−0.384***** (0.053) N = 55,357
IntVsNever	**−0.190***** (0.049) N = 108,556	**−0.112*** (0.064) N = 54,315
IntVsNeverInt	**−0.234***** (0.048) N = 111,905	**−0.152**** (0.064) N = 56,829
IntOnlyVsDom	**−0.222** (0.240) N = 3,231	**−0.780**** (0.345) N = 2,394
IntVsDom	**−0.793***** (0.280) N = 3,239	**−1.988***** (0.548) N = 2,406

Note: Overall ATT from Callaway-Sant'Anna staggered DiD not-yet-treated firms as controls, aggregated with estat simple. Controls: ln age, exporter, foreign-owned, ln cumulative patent stock, ln capital intensity and 1-digit NACE. Standard errors clustered by firm in parentheses. N is the number of firm-years with non-missing outcome and controls in each comparison sample. ln turnover is constructed as ln labour productivity + ln employees, so its sample is restricted to firm-years with observed labour productivity and is smaller than the employment sample; the two outcomes are therefore not estimated on identical samples. Both outcomes are winsorised at the 1st and 99th percentiles within year. * p<0.10, ** p<0.05, *** p<0.01.

Assessing pre-trends

The joint χ^2 test that all pre-treatment ATT(g,t) coefficients equal zero rejects at $p < 0.0001$ in all 14 cases for the two new outcomes, from $\chi^2 = 577.4$ to $\chi^2 = 13150.9$ (Table B3b). Several individual pre-treatment coefficients are also significant, so the event-study paths should be read descriptively, as for the other outcomes in Appendix B.

Table B3b. Pre-trend test results: ln employment and ln turnover

Comparison	Outcome	χ^2	d.f.	p-value	N
AnyVsNever	ln employment	13150.9	136	<0.0001	106,758
AnyVsNever	ln turnover	1734.4	136	<0.0001	53,658
DomVsNever	ln employment	7655.3	136	<0.0001	107,014
DomVsNever	ln turnover	4763.9	135	<0.0001	53,786
DomVsNeverDom	ln employment	7421.1	136	<0.0001	108,885
DomVsNeverDom	ln turnover	4791.2	136	<0.0001	55,357
IntVsNever	ln employment	3708.5	136	<0.0001	108,556
IntVsNever	ln turnover	926.5	136	<0.0001	54,315
IntVsNeverInt	ln employment	3385.3	136	<0.0001	111,905
IntVsNeverInt	ln turnover	580.4	136	<0.0001	56,829
IntOnlyVsDom	ln employment	931.9	72	<0.0001	3,231
IntOnlyVsDom	ln turnover	615.8	62	<0.0001	2,394
IntVsDom	ln employment	666.6	87	<0.0001	3,239
IntVsDom	ln turnover	577.4	75	<0.0001	2,406

Note: Joint χ^2 test from estat pretrend (H_0: all pre-treatment ATT(g,t) = 0). N is the number of firm-years in the comparison sample.

Matched-sample estimates

Table B4. PSM-matched fixed-effects DiD: ln employment and ln turnover

	AnyVs Never	DomVs Never	DomVs NeverDom	IntVs Never	IntVs NeverInt	IntOnlyVs Dom	IntVs Dom
Panel A. ln employmentf							
Post (main effect)	0.070** (0.034)	0.013 (0.037)	−0.045 (0.036)	0.013 (0.040)	0.034 (0.036)	−0.084 (0.080)	−0.210 (0.139)
Treated × Post (ATT)	−0.013 (0.040)	0.024 (0.045)	0.079* (0.046)	0.026 (0.050)	0.027 (0.046)	0.138 (0.088)	0.246* (0.139)
Observations (matched)	24,709	18,102	18,706	13,251	14,895	727	897
R^2	0.888	0.888	0.896	0.892	0.897	0.963	0.955
Clusters (firms)	1,689	1,276	1,299	952	1,022	176	182
Panel B. ln turnover							
Post (main effect)	−0.023 (0.032)	−0.046 (0.037)	−0.016 (0.037)	−0.010 (0.038)	0.030 (0.039)	−0.274*** (0.105)	−0.046 (0.104)
Treated × Post (ATT)	0.088** (0.041)	0.109** (0.048)	0.090* (0.054)	0.051 (0.051)	0.038 (0.047)	0.266** (0.114)	0.063 (0.114)
Observations (matched)	23,789	17,475	17,978	12,832	14,456	712	880
R^2	0.911	0.906	0.908	0.913	0.915	0.959	0.960
Clusters (firms)	1,675	1,266	1,292	942	1,012	172	178

Note: Treated × Post is the coefficient on the interaction in a regression of the outcome on treated-group and post-treatment indicators with firm and year fixed effects, estimated by reghdfe on the propensity-score-matched sample (1:1 nearest neighbour, caliper 0.1, logit on ln employees, ln age, exporter, foreign-owned, ln cumulative patent stock and ln capital intensity; matched weights applied). Controls in the outcome regression: ln age, exporter, foreign-owned, ln cumulative patent stock and ln capital intensity (ln employees excluded). Standard errors clustered by firm in parentheses. ln turnover is constructed as ln labour productivity + ln employees, so its sample is restricted to firm-years with observed labour productivity and is smaller than the employment sample; the two outcomes are therefore not estimated on identical samples. Both outcomes are winsorised at the 1st and 99th percentiles within year. * p<0.10, ** p<0.05, *** p<0.01.

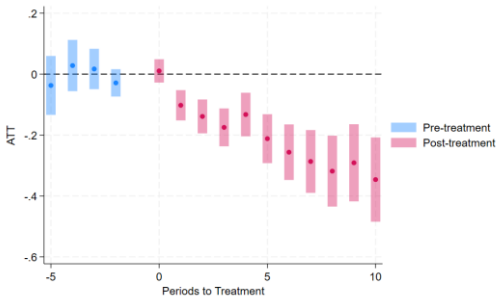
Event-study plots

Figure B1. Callaway-Sant'Anna event-study estimates, t−5 to t+10: ln employment (left) and ln turnover (right)

Note: Dots are event-time ATT(e) estimates and bars are 95% confidence intervals (blue: pre-treatment, red: post-treatment), from csdid2 aggregated with estat event; specification as in Tables B1d-B1e. Panels are drawn on the vertical scale chosen by Stata for each comparison, so scales differ across panels.

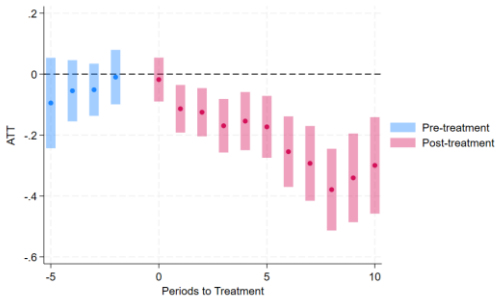
AnyVsNever

ln employment



N = 106,758 firm-years (13,130 firms)

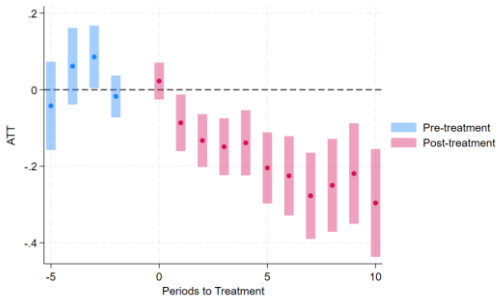
ln turnover



N = 53,658 firm-years (5,369 firms)

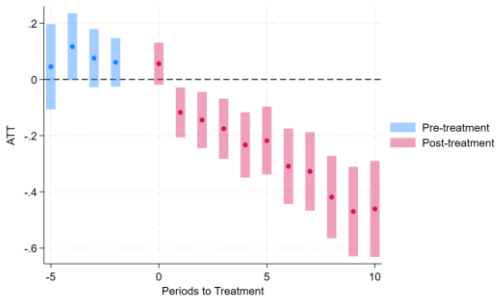
DomVsNever

ln employment



N = 107,014 firm-years (13,308 firms)

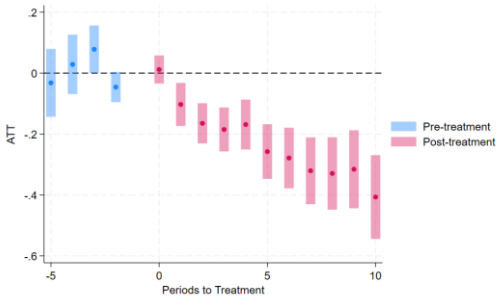
ln turnover



N = 53,786 firm-years (5,490 firms)

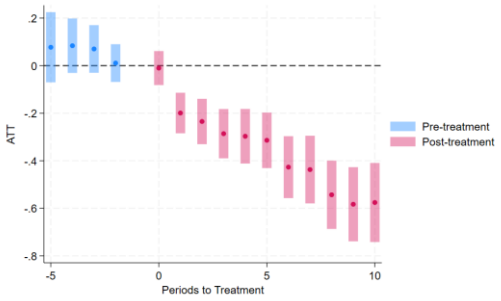
DomVsNeverDom

ln employment



N = 108,885 firm-years (13,345 firms)

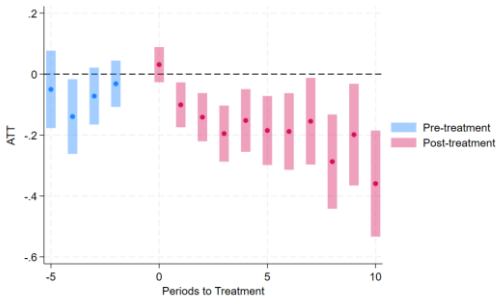
ln turnover



N = 55,357 firm-years (5,523 firms)

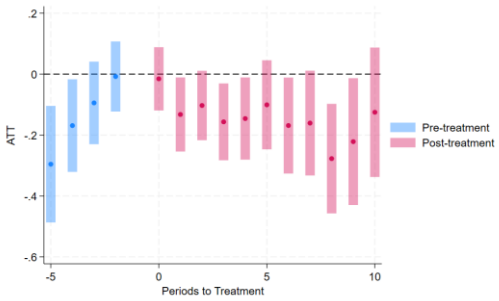
IntVsNever

ln employment



N = 108,556 firm-years (13,689 firms)

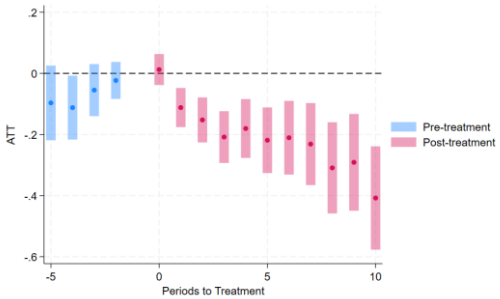
ln turnover



N = 54,315 firm-years (5,630 firms)

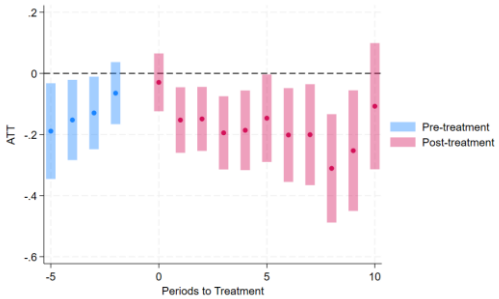
IntVsNeverInt

ln employment



N = 111,905 firm-years (13,760 firms)

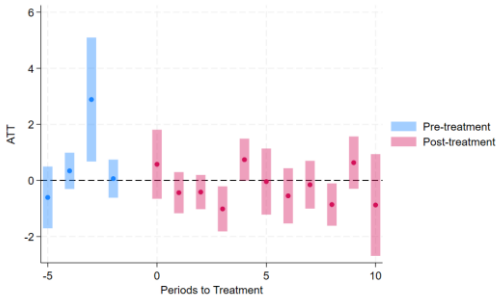
ln turnover



N = 56,829 firm-years (5,704 firms)

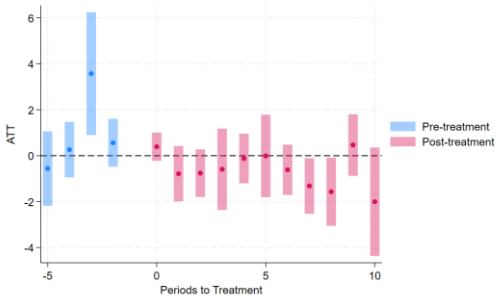
IntOnlyVsDom

ln employment



N = 3,231 firm-years (1,701 firms)

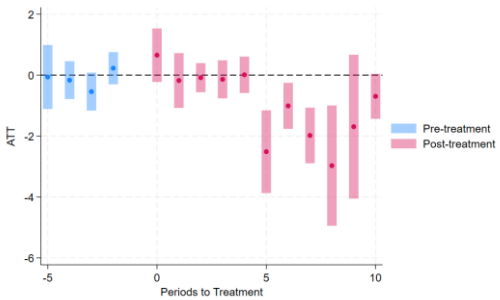
ln turnover



N = 2,394 firm-years (1,127 firms)

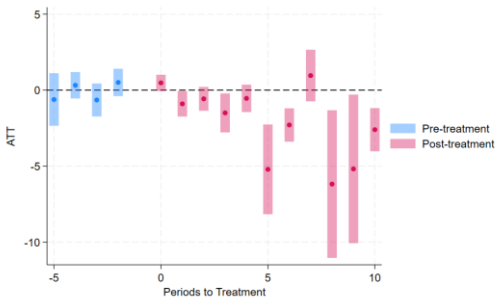
IntVsDom

ln employment



N = 3,239 firm-years (1,653 firms)

ln turnover



N = 2,406 firm-years (1,085 firms)



www.ircaucus.ac.uk

Email info@ircaucus.ac.uk **Twitter** @IRCaucus

INNOVATION & RESEARCH CAUCUS

Delivered with ESRC and Innovate UK