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Indicators of absorptive capacity. Conceptual framework and estimates for 25 countries and 24 UK sectors

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ABSTRACT

The paper develops a conceptual and operationalization framework for absorptive capacity (ACAP) leading to empirical indicators useful for the development of innovation policy. Applications are presented for 25 European countries and 24 UK sectors. For the country study, four dimensions are developed. Two in relations to embodiment of knowledge and two to acquisition. On the former, one dimension captures embodiment in assets and scientific activities and one in human resources both on the supply and demand side. Two dimensions capture acquisition of knowledge via social linkages and via physical and digital connectivity. Several variables contribute to each of these dimensions. ACAP values are arrived at by combining all dimensions. The sector study is developed along similar lines. It has two components related to large and medium-sized enterprises. The results show: clear strengths and weaknesses in ACAP by country and sector; and, in the sector study, more sector- than enterprise-size specificity.

"...a man must carry knowledge with him, if he would bring home knowledge"
A.P. Johnson (1709-1784) in James Boswell (1946 [1791]: 227).

1. Introduction

Following Cohen and Levinthal (1989, 1990 and 1994)'s classic papers,[1] there has been a large flourishing of academic works on the concept and empirics of absorptive capacity (ACAP). A quick recent search of the Social Science Citation Index found 741 articles with ACAP in the title. Since then, many studies have revisited the concept either in theoretical terms only (Zahra and George, 2002; Lane et al., 2006; Song et al., 2018) or in conjunction with empirical indicators and measurement (Mowery et al. 1996; Lane and Lubatkin, 1998; Tsai, 2001; Harris and Li, 2009; Camisó and Forés, 2010; Almudi et al., 2020). Most authors consider the concept at the *firm level*, in line with Cohen and Levinthal's original works (Fosfuri and Tribó, 2008; Vega-Jurado et al., 2008; Fabrizio, 2009; Flatten et al. 2011). Some researchers apply it at the *country level* (Khan, 2022; Castellacci and Natera, 2016; Keller 1996; Rogers, 2004; Criscuolo and Narula, 2008; Effelsberg, 2011; Harris and Yan, 2019; Filippetti et al., 2020; Harris et al., 2021). There are also a few attempts to apply the concept and empirics at the level of *sectors* (Griffith et al., 2004; Fabrizio, 2009). The *regional* dimension is considered in Roper and Love (2006), Mahroum et al. (2008) and Lau and Lo (2015).

The field appears, therefore, to be well-established and of great interest to researchers. Yet a brief analysis of the literature shows that the concept is still rather ambiguous and far from being agreed on in terms of theory or operationalization. Nonetheless, the wide literature emerged since Cohen and Levinthal's contributions denotes agreement on the relevance of the concept.

The relevance of ACAP derives from the recognition that the innovation performance of the analysed unit – firm, sector or country – and

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[1] Antecedents to Cohen and Levinthal's work include: Tilton (1971); Allen (1977); Mowery (1983).

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therefore its current performance in terms of productivity, competitiveness and growth may depend on the system's ability to absorb and utilize knowledge. The absorption and utilization depend not just on current activities but also on the system's ability to incorporate knowledge from the past. Moreover, it does not depend only on knowledge developed within the unit, but also on the unit's ability to learn from other units within the wider environment in which it is embedded.

The paper develops as follows. Section 2 presents our conceptualization of ACAP. In Section 3 we develop the operationalization of the concept and the methodology we use. Our empirical analysis has two components: the first one applies the concept and its operationalization at country (macro) level, and the second applies it at the sectors (*meso*) level. We present a study of 25 countries in Section 4 and of 24 sectors for a specific country – the UK – in Section 5. In Section 6 we comment on our findings, and in Section 7 we summarize and conclude the study.

The paper makes contributions in the following areas. (1) Development of a conceptual framework for ACAP with emphasis on: cumulativeness of knowledge from the past and thus history; embodiment of knowledge in labour as well as in capital assets and scientific activities; relevance of acquisition of knowledge from outside the country/sector with emphasis on both the social and physical/digital context of connectivity. (2) Development of an operationalization system that links dimensional indicators to the conceptual framework. (3) Application of the same conceptual and operationalization framework at the macro and *meso* level. (3) Empirics based on comparability and benchmarking. (4) Application to, and estimates for, countries and – for the UK – industries.

2. Conceptualizing ACAP

Knowledge and learning are at the basis of ACAP in the works of Cohen and Levinthal as well as those that followed. Our specific conceptualization takes the lead from Cohen and Levinthal works and further develops it. It is based on the following three principles, all related to knowledge.

- History matters. Knowledge is *cumulative* and past knowledge aids the development and acquisition of new knowledge. Cohen and Levinthal (1990) talk of path- and history-dependence. Indeed, the principle that history matters when it comes to learning is to be found in Dr. Johnson's eighteen's century sentence given as a motto to this paper.
- Knowledge can be developed within the unit – individual, firm, industry, region or country – and also acquired from outside the unit and further developed. The ability to acquire knowledge depends not only on the unit's own level of knowledge, it also depends on the opportunities it has to come into contact with other sources of knowledge.[2] In fact, Cohen and Levinthal (1989) saw *acquisition* from the environment as the key element in ACAP when they defined it as: "the firm's ability to identify, assimilate and exploit knowledge from the environment…" (p. 569). To this end, prior knowledge, social institutions and connectivity matter. The level of existing knowledge in the unit is one of the key elements in the acquisition, assimilation and further development of knowledge. Moreover, institutions must be open to the exchange of knowledge within them and between them. This is where the *social context* becomes relevant. Access to other sources of knowledge from which to learn implies an environment that facilitates the learning. At the firm level, and internally to it, an environment in which employees and departments cooperate. Externally to the firm and, indeed, at the macro level, social, political and economic environments that facilitate cooperation and exchanges. The third element in the acquisition of knowledge is the level and efficiency of connectivity systems: how easy or difficult it is for the unit to be in contact with other knowledge sources.
- Knowledge is embodied not only in assets, infrastructures and scientific activities, but also, and crucially so, in labour (Roper and Love, 2006; Rogers, 2004; Schweisfurth and Raasch, 2018). Indeed, labour has not only an *embodiment* function for knowledge but also a transmission and acquisition function because people can influence the level of knowledge held by other employees they come in contact with inside or outside the organization. Our ability to, collectively, learn from the surrounding environment today depends, to a large extent, on the knowledge embodied in our workforce.

We can summarize the following key elements of ACAP. (a) *Embodiment* of knowledge within the unit considered, be it the individual or the firm/institution or the sector or country. (b) *Acquisition* of knowledge from outside the unit. (c) Relevance of knowledge *accumulation* – history matters principle. These elements will drive our operationalization system.

Issues of *quality/type* of knowledge have not played much role in the theoretical or applied studies on ACAP. In macro studies issues of quality tend to be neglected in most aggregate concepts including GDP. In our countries study there is the hidden assumption that all knowledge contributing to ACAP is good independently of its origin or uses. The sectors study by its own nature discriminates between sector-related knowledge though not in the quality of knowledge within each sector. Cohen and Levinthal (1990) as well as Zahra and George (2002) tackle one qualitative element in ACAP: *diversity of knowledge*. They considered it in the context of the firm's preparedness for uncertain events. They note that tension exists between similarity and diversity of knowledge because: diversity of knowledge sources inside the firm helps to recognise valuable, external knowledge; while similarity or overlap of knowledge across units inside the firm helps the assimilation and diffusion of knowledge, as well as its commercial exploitation inside the firm. Development along similar lines would lead to specialization with related gains in productivity. Several studies suggest ambiguous results in terms of advantages of diversity versus specialization (Jacobs, 1961 and 1969; Iammarino and McCann, 2013; Lane and Lubatkin, 1998; Volberda et al., 2010). Cohen and Levinthal refer to this issue as a "trade-off between inward-looking versus outward-looking absorptive capacities" (p. 133). In the face of uncertainty as to what type of knowledge is being developed out there, the firm must be prepared for a variety of scenarios. They conclude that being prepared requires investment in *diverse* types of knowledge because this alerts the firm to the potential for acquisition and assimilation of whatever knowledge is developed in the environment.

We are neutral in the similarity versus diversity of knowledge issue and have no pre-conceived views on the benefits of the two strategies. We think, nonetheless, that it is worth finding out whether our empirical work sheds any light on the relevance of diversity of knowledge sources. We do so in the sectors study for the UK where we add a dimension *diversity of knowledge*. We were unable to develop diversity variables in the macro study.

3. Operationalization

The concept of ACAP is *qualitative* in nature (Jiménez-Barrionuevo et al., 2011) and unobservable, and, therefore, not directly measurable. The operationalization of qualitative concepts is not new in the physical and social sciences. Economics is a particular fertile field for concepts that are qualitative in nature but have been operationalized via the development of proximate indicators. Most of the operationalization is

[2] This aspect has similarities with knowledge spillovers. There are also several differences as the latter considers mainly unintentional spillovers (Arrow, 1962) while ACAP comprises unintentional and intentional knowledge acquisition from external sources. Moreover, the spillovers can be negative as well as positive and spread over a variety of fields while ACAP is confined to knowledge and knowledge acquisition.

the result of conventions among the community of users: from national income accounting to the valuation of capital to the very fuzzy concept of goodwill on which there are several international conventions (Smith, 1996 as reported in Gillies, 2004). Therefore, the qualitative nature of ACAP, and the fact that it is unobservable, and thus not directly measurable, are not obstacles to it being captured or proxied by specific indicators. Just as national accounts are social constructs in perpetual evolution (Piketty, 2014: 58), so can ACAP be.

There is a wide consensus among the research community that ACAP can be operationalized using measurable proxies. However, there is no consensus on what these proxies should be, other than they should relate to knowledge and innovation. Unlike many other qualitative concepts in economics and business on which the research or professional communities have established accepted conventions, this is not the case regarding ACAP.

3.1. Framework

In our operationalization we set ourselves two aims. First, to develop a framework from our own conceptualization as close to it as possible and applicable in both the country and sectors studies. Second, to do so in such a way that the results could be of aid in policy development. Our main empirical work consists of the development of ACAP indicators for 25 European countries and, in relation to a specific country, the UK, for sectors. Our sector study is, therefore, specific to a country in its empirics, though it could be replicated for other countries using related data.

The policy relevance of ACAP at sectors level is well illustrated in Almudi et al. (2020), a work that points out how policy intervention within countries is more effective when aimed at the sectors most relevant for innovation either because of manifested weaknesses and/or because of their leading role in innovative activities.[3] They see sectors as dependent on each other regarding innovation and ACAP because: "Sectoral knowledge capacities are interconnected. Absorptive capacity constraints (i.e. bottleneck) in a sector limit the value of innovation that is complementary to that sector. Conversely, innovation developments in one sector can overshoot adoption and use capabilities in another sector […]. In the multisectoral approach, the innovation prospects and capabilities in one sector affect the innovation prospect of another." (p. 509). Thus, for innovation policies to be effective, identifying sectors that need boosting in ACAP, or in specific dimensions of it, helps the development of industrial policies as well as policies at the macro level.

The policy issue is relevant in another aspect of our study: the dimensional aspect. Though Cohen and Levinthal's works seem to suggest operationalization mainly or only via R&D expenditure – in their case at firm level – in later works the wider community has used a multidimensional approach with a variety of variables (Vega-Jurado et al., 2008; Harris and Li, 2009; Harris and Yan, 2019; Harris et al., 2021; Flatten et al., 201; Marhoum et al., 2008). However, the fact that their approach is multidimensional does not mean that they have the same approach to dimensionality. The very concept of ACAP can, in fact, be seen as multidimensional in a variety of respects. First, because, at the firm level, there are several elements in the learning process: identification, assimilation and exploitation in Cohen and Levinthal (1989, 1990, 1994), as well as a set of organizational routines and processes in Zahra and George (2002). Second, because the effects of ACAP are multiple and extend from ability to develop additional knowledge to higher performance in innovation, competitiveness, growth, or productivity. Third, because each knowledge element can be, and has been, captured by various indicators or variables within them.[4]

Our own approach is also multidimensional, and the dimensions are derived from our conceptual framework and, directly, linked to the three conceptual principles discussed in Section 2: embodiment, acquisition and cumulation of knowledge. They are characterized by policy relevance in the sense that all the variables within a dimension deal with the same/similar elements (such as human resources or investment and capital formation or communication technologies and infrastructures) and they are, therefore, susceptible to the same type of policies. For a specific country or sector, it is possible to identify weaknesses in a specific dimension, for example the existing knowledge base or the human resources dimension, and target policies towards it.

As for the links between our conceptualization and operationalization, in the previous section we identified the following key elements in conceptualization: *embodiment* and *acquisition* of knowledge as well as relevance of *accumulation of knowledge* from the past. These elements are key to our operationalization. We consider embodiment of knowledge in both assets and scientific activities and in human resources. To capture the element of knowledge accumulation we use either stock data or data cumulated over three years and on which more in the next sub-section. In the countries study we shall develop the following dimensions in relation to embodiment: a dimension related to assets and scientific activities; and one dimension related to human resources split into two subdimensions, of which one refers to supply side of labour and the other to the demand side. In the sectors study we shall not try to distinguish between demand and supply side of labour.

Regarding knowledge acquisition, we distinguish between the role of social and business networks and the role of communication networks. The latter is considered in relation to transportation as well as digital communications.

3.2. Dimensions of ACAP

In this subsection we shall identify, in more detail, the dimensions of ACAP relevant for both our country and industry studies. Each dimension is characterized by one or more variables chosen on the basis of their conceptual affinity to the dimension as well as their measurability and comparability across countries and/or across sectors. Availability of data does play a role in our final decisions on which variables to include in each dimension.

In the applications of ACAP at firm level, authors have usually derived their variables through answers to purpose-built questionnaires. In macro applications variables are derived from established statistics collected by governments and their agencies. We shall follow the latter route for both studies though the sources of data differ. In the macro study the data derives mainly from official macro sources. In the sectors study the data derives from the UK Community Innovation Survey

[3] Almudi et al. (2020) develop a theoretical two-sector model and perform simulations. They also present two empirical applications: to commercial supersonic aviation and to advanced robotics.

[4] Multidimensionality is a characteristic of many innovation works. However, the concept of ACAP in general, including our own specific version, differs from the systems of innovation approach (Freeman, 1987, Nelson, 1992 and Lundvall, 1992). Absorptive capacity is a much narrower concept, compared with systems of innovation, because it focuses on businesses and other institutions' ability to absorb knowledge from the environment and use it to create further knowledge. The systems approach emphasises and measures current knowledge and innovation and stresses their systemic nature and interactions. Systems of innovation, therefore, considers a wider range of actors and elements, ranging from social institutions and policies to the overall economic environment. Accordingly, the empirics in systems of innovation use a wider range of individual indicators and concentrate on current levels of knowledge and innovation rather than on past and cumulative values.

(CIS)[5]. The CIS has the following advantages over ACAP purpose-built questionnaires. (a) ACAP purpose-built questionnaires provide self-assessed measures of firms' ACAP, resulting in qualitative data that is not comparable. The data is not comparable across firms or across sectors nor is it comprehensive with regards to sectors. In general, purpose-built questionnaires tend to be more specific and less objective. The subjectivity is built-in because measures tend to rely on respondents agreeing or disagreeing with specific statements which can render comparability across units problematic. (b) ACAP purpose-built questionnaires are firm related while the CIS relates to enterprises which may or may not correspond to firms.

The use of the same framework and methodology, though with different variables and data across the macro and *meso* levels, makes our study novel and adds to the existing literature.

Our first two dimensions try to capture the *embodiment* of knowledge in either capital (a) or in labour (b). The first dimension captures embodiment and cumulation of knowledge in assets (Criscuolo and Narula, 2008) and in specific activities such as R&D and scientific activities in general. We call this dimension **knowledge intensity (a)**. Within the constraints of data availability, we select for this dimension, variables that embody knowledge, such as R&D and measures of scientific activities such as patents applications and number of publications in scientific and technical journals. If the data is expressed as flow, we cumulate it over a 3-year period to take account of past knowledge performance in accordance with the first of our three principles in Section 2. Thus, both present and past activities in these areas contribute to ACAP. Similarly, successive waves of scientific activity leave their positive mark on the ability of firms/institutions, industries and countries to acquire and use knowledge.

The **human resources (b)** element provides our next dimension(s) which we shall apply at both macro and *meso* levels though in different ways as we explain below. In the macro study this dimension is split into two subdimensions: related, respectively, to the supply and demand sides. We capture the supply side with variables related to educational attainment in the potential labour force. We want to consider also the demand side for educated workforce on the part of businesses and wider institutions. What if the structure of the economy is such that firms/institutions are unable/unwilling to employ high-level graduates? To account for effects on the potential demand side of labour we include, for each country in the macro study, a variable related to the relative employment in the most advanced sectors of the economy the knowledge intensive services (KIS). In the sectors study the data does not allow us to disaggregate supply and demand side of labour and therefore our variable has elements of both. We use, from the CIS, the share of employment within each sector with specific skills related to: graphic arts, layout, advertising; design of objects or services; multimedia, web design, animation, video; software development, database management; engineering, applied sciences; mathematics and statistics.

Connectivity to other sources of knowledge is essential for the transmission and *acquisition* of knowledge. We see two sub-elements of connectivity and they identify our next two dimensions which we shall apply at both macro and *meso* levels. The **social and business connectivity dimension (c)** refers to access to sources of knowledge outside the unit (Vega-Jurado, 2008) via social and economic networks. The sources can be external to firms as well as internal (Denicolai et al., 2016). The external sources can be specific contractual linkages with firms/institutions of the private or public sector including universities (Biedenbach et al., 2018; Franco et al., 2014). Access to external knowledge sources can derive also from other, non-specific or contractual linkages, such as contacts with customers (Scaringella, 2017) and suppliers (Kafouros et al., 2020). All these connectivity linkages can be within or across countries.[6] We include both types in our country and industry studies.

Social connectivity has also a within-firm/institution connotation. Different individuals and parts of the firm may learn from each other. The firm culture, its organizational structures and its strategies can be very important facilitators or constraints to the dissemination of intra-firm knowledge (Love et al., 2011). This issue may be of particular relevance for large firms with spatially spread branches such as large transnational companies (TNCs).[7] Within firms/institutions connectivity is difficult to capture at the macro level. We shall, however, try to capture elements of it at the sectoral level for the UK as the use of data from the Community Innovation Survey allows us to.

The acquisition of knowledge is affected by the ease of communications between people operating at a distance. The second part of connectivity and our fourth dimension is about **physical and digital connectivity (d)**. This dimension captures the physical/technological infrastructure side of connectivity which allows communications between people across space. Two sub-elements contribute to it. (i) The ability and speed of access to other spatially distant firms/institutions and customers through the physical infrastructure available in the location (Roper and Love, 2018 and Drejer and Vinding, 2007), such as access to roads and international airports. (ii) Most relevant, the intensity and speed of digital communication networks, in particular the Internet. We do not use this dimension (d) in our sectoral study where the territorial dimension is not appropriate, and we do not have relevant sector-related data on digitalization. In the *meso* study we include a **diversity** dimension as discussed in Section 2.

The grouping of related variables into dimensions should allow researchers to identify fairly homogeneous areas of ACAP strengths or weaknesses, and, thus, identify areas in need of policy intervention. Policies can be applied to the whole dimension or to a specific variable within that dimension. For example, at the macro level, by improving education at secondary level, it may also be possible to improve results at tertiary level and impact on the future labour force. However, if problems appear to be on the demand side and the country cannot absorb its high-level graduates, the policies may need to address the sectoral structure.

Therefore, there are two features of our conceptualization and operationalization relevant for policy. First, and following Almudi et al. (2020), the inclusion of a study on UK sectors incorporating the same theoretical framework as the countries study in order to try and identify policy-relevant sectors. Second, our approach to multidimensionality groups fairly homogeneous variables linked to our conceptual principles. This allows the targeting for policy purposes of both dimensions and variables within them.

The specific variables included under each dimension in the two separate macro and *meso* studies will be discussed in Sections 4 and 5 respectively.

3.3. Methodology

We apply the same methodology in the macro and *meso* studies while using different types and sources of data. Any divergencies required by data will be discussed in the relevant sections. We develop indicators for every dimension each including several variables. From the dimensional

[5] The Community Innovation Survey (CIS) dataset is collected on behalf of the Department for Business, Innovation and Skills and the Northern Ireland Department of Enterprise, Trade and Investment by the Office for National Statistics (2022). The CIS is referred to in the UK as the UK Innovation Survey. We accessed the CIS via the secure access of the UK Data Service.

[6] Fabrizio (2009) in a study of pharmaceutical and biotechnology firms finds that linkages with public sector research aids both the quality and speed to firms' innovation. See also Mowery et al. (1996) and Ebers and Maurer (2014).

[7] The role of internal and external linkages for the transmission of knowledge across various parts of the TNC as well as its environment is considered in Cantwell, (1989); Castellani and Zanfei (2003) and Ietto-Gillies (2019: Chapter 20). See also Lyles and Salk (1996); Crone and Roper (2001).

indicators we arrive at a combined ACAP indicator.

In developing our indicators of ACAP, we are faced with the following methodological problems. First, the choice and allocation of variables to dimensions. Our choice and allocation are determined by the conceptual framework and therefore we seek variables that fit the meaning of each dimension. A variable is allocated to, say the 'human resources dimension', if it has to do with labour.

The second problem arises from the fact that the various variables are expressed in a variety of units. To make them comparable we *normalise* the values of the specific variables by the size of the country (e.g. R&D expenditure over GDP) and sector (e.g. share of enterprises within an industry) and we *standardise* variables to account for different units in measurements and spread of scores (e.g. number of airports, km of motorways).

Third problem: how to *aggregate* the variables into the four dimensions and then into a single composite ACAP indicator. This requires a process of double aggregation. All variables within each dimension must be aggregated to arrive at a dimensional indicator, then the four-dimensional indicators must be aggregated into a single, composite indicator as proxy for ACAP. There are two options: aggregating using simple averages and assuming equal weight as in the European Innovation Scoreboard and the Global Innovation Index (European Commission, 2022; World Intellectual Property Organization, 2023); or using a weighting scheme, when aggregating variables to dimensions, and when aggregating dimensions to ACAP. We adopt the second method. We use factor analyses to arrive at weights for variables that we use to compute the dimensions, and then a further factor analysis of the four dimensional indicators to arrive at the ACAP index. This allows us to exploit communalities in the data, how the variables hang together, while eliminating overlap between variables on aggregation.[8] We shall comment on the relevance of weights when discussing the results.

Fourth problem: how to *benchmark* the results for comparability and how to present them. We benchmark countries or sectors against the best performing one. We compute, for the dimensional indicators, distance measures that take values from zero, least performing country or industry, to one, top performing country or industry. ACAP is the weighted average based on the distance measures of the four dimensional indicators.

The strengths or weaknesses in a particular dimension are, therefore, seen in relative terms. In the macro study, each country's weaknesses are in relation to the top performing country. In the sectors study the comparison is between each sector and the best performing one.

4. The macro study

For the macro study, we collected data on variables behind the five dimensions from the statistical databases published by the World Bank, the European Union and the United Nations. The selection of variables aims to cover the dimensions as well as possible. Such selection, in turn, determines the countries for which the data is available. The smallest common denominator turns out to be those countries that provide Eurostat with results from the Community Innovation Surveys (CISs).[9]

The data are for 25 countries and our reference year is 2018, the one for which we calculate the dimensional and the ACAP indicators as in Table 1. We chose 2018 because it is the latest year for which our data was unaffected by the Covid-19 pandemic. In order to be able to cumulate data, we covered several years and three CIS waves.

In Table 1 the countries are ordered by their value of ACAP in the last column from highest to lowest. We highlight three bands of ACAP performance by presenting the results in three different vertical alignments. The top performers include eleven countries with ACAP results of between 0.8 and 0.5. The middle-ranking band includes nine countries with ACAP values from 0.4 to 0.3, and the bottom ranking one comprises 5 countries with results between 0.2 and 0.0.

The weights assigned to each indicator in the ACAP values are recorded in Appendix A, Table A.1 as: 0.31 for Dimension 1 (D1); 0.34 for D2; 0.13 for D3; and 0.22 for D4. Thus, the largest weights are assigned to the two dimensions related to embodiment either in capital or scientific activities (D1) or in labour (D2). Regarding human resources, we note that the contribution by the variable that expresses employment in the knowledge intensive side of the economy is the highest of the three with a weight of 0.39.

The results show that, on the whole, the top performing countries tend to be top on most dimensions, and similarly for the worst performing countries. However, there are significant departures, and we draw attention to these by placing an asterisk next to the value for each dimension to indicate a noticeable distance from the ACAP result in a particular value for a specific country and dimension. We note that the departures between results for a specific dimension and the total ACAP values tend to be concentrated on the social connectivity dimension D3. We consider this dimension to be the least reliable in terms of comparisons between countries. Forty-two percent of its weight derives from answers to the CIS questionnaire which, while comparable within countries and across sectors, partly for linguistic and other cultural reasons, can make comparisons across countries less reliable. Moreover, the two economics variables, FDI stocks and cumulated trade (imports and exports), are only indirect indication of cross-border linkages and knowledge exchange.

There are also some country-specific anomalies. Germany shows strong knowledge intensity and physical connectivity, but comparatively weaker social connectivity dimensions and human resources; the latter particularly on the supply side (component D2S). Education policy in Germany emphasizes, more than in other comparable countries, apprenticeships as a route to skilled employment. Apprenticeships are not captured in our indicator whose three variables relate to education attainment, first and higher degrees, and employment in KIS and this feature shows in our results for the supply and demand sides (respectively 0.4 and 0.6 for Germany in Table 1).

Finland does very well on the knowledge embodiment dimensions (D1 and D2) but less so on the acquisition ones (D3 and D4). Italy, a large country, does poorly on all dimensions, though less so on spatial connectivity and on the demand side of labour with indicators of 0.4 in both. Nonetheless, Table A.2 shows that for Italy the percentage of employment in KIS at 34.6 is low in relation to comparable countries and against an average value of 38.8 for our 25 countries (Appendix A, Table A.2).

5. A study of UK sectors

In this section we present a study of sectors, and we confine ourselves to a single country, the UK, for ease of availability of data. We apply the same theoretical framework as for the macro study with the following important differences. First, we use CIS data for the UK to estimate our dimensional indicators.[10] CIS data have been used in several studies of

[8] The technical procedure is set out in OECD (2008, p. 89-90) and is discussed in more detail in Nicoletti et al. (2000). Weights are the squared factor loadings scaled to one.

[9] The CISs are biannual surveys designed around a core questionnaire. They measure innovation performance and related activities within European countries. The UK does not deposit CIS data with Eurostat, and we extracted information from official UK publications.

[10] We access CIS data via the UK Data Service: Secure Access. The views expressed here are those of the authors and the use of CIS data does not imply the endorsement of the data owners or the UK Data Service in relation to the interpretation or analysis of the data.

Table 1
Dimensions and ACAP indicators 25 European countries. 2018.

Country	D1 Know. Int.	D2 HR	*D2S HR*	*D2D HR*	D3 Connect 1	D4 Connect 2	ACAP
Denmark	1.0	1.0	*1.0*	*0.8*	0.2*	0.6	0.8
Netherlands	0.7	0.7	*0.5*	*0.7*	0.7	1.0	0.8
Belgium	0.6	0.7	*0.5*	*0.8*	0.7	0.8	0.7
Sweden	1.0	0.8	*0.4*	*1.0*	0.5	0.2*	0.7
Germany	0.8	0.6	*0.4*	*0.6*	0.2*	0.8	0.6
Finland	0.8	0.8	*0.7*	*0.7*	0.3*	0.3*	0.6
United Kingdom	0.4	1.0	*0.9*	*0.9*	0.7	0.4	0.6
Ireland	0.3*	0.9	*0.9*	*0.7*	1.0	0.3*	0.6
Austria	0.8	0.6	*0.5*	*0.5*	0.2*	0.4	0.6
France	0.5	0.7	*0.5*	*0.8*	0.1*	0.3*	0.5
Slovenia	0.4	0.6	*0.6*	*0.4*	0.4	0.5	0.5
Spain	0.3	0.7*	*0.7**	*0.4*	0.0*	0.4	0.4
Portugal	0.3	0.4	*0.3*	*0.5*	0.1*	0.5	0.4
Czechia	0.4	0.4	*0.3*	*0.4*	0.2	0.3	0.3
Estonia	0.3	0.3	*0.2*	*0.4*	0.6	0.3	0.3
Slovakia	0.2	0.5	*0.4*	*0.4*	0.3	0.3	0.3
Croatia	0.2	0.4	*0.2*	*0.4*	0.3	0.4	0.3
Italy	0.3	0.3	*0.1**	*0.4*	0.1*	0.4	0.3
Greece	0.2	0.3	*0.2*	*0.5*	0.2	0.3	0.3
Lithuania	0.2	0.3	*0.3*	*0.4*	0.2	0.3	0.3
Hungary	0.2	0.3	*0.1*	*0.4**	0.4*	0.2	0.2
Poland	0.2	0.3	*0.4**	*0.3*	0.0	0.2	0.2
Latvia	0.1	0.3	*0.1*	*0.4**	0.2	0.1	0.2
Bulgaria	0.0	0.3	*0.3*	*0.3*	0.1	0.1	0.2
Romania	0.0	0.0	*0.0*	*0.0*	0.0	0.0	0.0

Source: Own calculations based on statistical data sources listed in Appendix A.
Note 1. D1 = Knowledge intensity; D2 = Human resources; D2S = D2 Supply side; D2D = D2 Demand side; D3 = Social and business connectivity; D4 = Physical and digital connectivity; ACAP= Absorptive Capacity.

ACAP often at country level (Harris et al., 2021; Crescenzi and Gagliardi, 2018; Harris and Li, 2009), though as far as we know not at sector-level. CIS data is enterprise level data, and we aggregate it to sector level. Unlike surveys specifically designed to assess ACAP, the CIS is innovation specific and not ACAP specific. This means that the questions asked may not cover the full ACAP relevant field. On the other hand, the answers to relevant questions may give a more objective picture than surveys where the questions are ACAP specific and the answers subjective, as discussed in Section 3.2.

Second, we drop the physical connectivity dimension because different sectors do not have a territorial characteristic in the way countries have, and we could not get relevant sector related digital variables from the CIS. Third, in the human resources dimension we do not distinguish between supply and demand side as our data does not warrant it.

Fourth, we add a **diversity dimension** following the discussion in Section 2. Diversity has two connotations, both relevant for ACAP. The first connotation refers to the intra-organizational diversity, that is the diversity of knowledge within the firm (Cohen and Levinthal,1990; Nowak, 2020). The second connotation, inter-organizational diversity, is considered in Zahra and George (2002) and refers to diversity of knowledge between the firm/organization and its external environment (Gkypali et al., 2018). Within the enterprise, diversity can be a feature of its product(s), production process(es) or resources. Thus, diversity itself can be found in a variety of elements and this feature may make a diversity dimension less homogeneous than other dimensions and more difficult for policy targeting. In the CIS we found two groups of questions related to diversity of resources, specifically in capital assets and in human resources (see Table B, Appendix B, for details), and we have used them as our variables.

The fifth difference is that, within the *meso* study, we present results for two sets of enterprises: large and medium-sized ones. In Section 3 we highlight the relevance of sector analysis in ACAP studies and refer to Almudi et al. (2020), a theoretical work that does not discuss the issue of size of enterprises and focuses only on the policy-relevance of sector versus country-level studies. However, we feel that, within sectors, getting results for both large and medium-sized enterprises may be useful for policy development. For example, do results give indication on the degree of integration between large and smaller enterprises within a sector? Should policies be targeted to the largest or to medium-size companies? We identify the two groups of enterprises from within the dataset itself on the basis of their turnover.[11] For the selection of the set of large enterprises, we compute the average turnover in a sector and include all those enterprises with a turnover of at least 1.5 times the average turnover. Medium-sized enterprises are selected as those with a turnover of at least 0.5 and <1.5 times the average sector turnover. Within each of the sectors we calculate the indicators for the ACAP dimensions and combined ACAP separately for the two sets of enterprises, the large and the medium size ones.[12]

There are nine variables, listed in Appendix B, feeding into the four dimensions and the combined ACAP indicator. The variables are taken

[11] We considered and discarded the possibility of using employment as a selector because changes in employment practices and increase in externalization strategies make employment an unreliable variable for the selection of size. Uber or McDonald might not make it into a large companies set if the selection were based on direct employment by the company itself; the first one because it does not employ its drivers and the second because it operates via franchisees (Ietto-Gillies, 2022).

[12] Our sectors are based on the divisions used for the stratified random sampling process of the survey. The UK version of CIS covers sections B to N of the Standard Industrial Classification. These are mainly manufacturing and private services. Agriculture, public administration, education, health and social care, as well as arts and entertainment are not covered.

Table 2
Dimensions and ACAP indicators for 24 sectors and for KIS. UK economy. Largest enterprises.

Sectors	D1 Know. Int.	D2 HR	D3 Connect	Ddiv Diversity	ACAP
Manufacture of computer, electronic, electric, machinery and equipment	1.0	0.8	1.0	1.0	1.0
Manufacture of transport equipment	0.6	0.6	0.8	0.6	0.7
Architectural and engineering activities and related technical consultancy. Technical testing and analysis	0.7	0.8	0.6	0.6	0.7
Other professional, scientific and technical activities	0.6	1.0	0.4*	0.6	0.6
Scientific research and development	0.8	0.5	0.6	0.6	0.6
Manufacture of food, clothing, wood, paper, publish & print	0.6	0.5	0.4	0.5	0.5
Fuels, chemicals, plastic metals & minerals, pharmaceutical products	0.6	0.5	0.6	0.4	0.5
Manufacture not elsewhere classified	0.5	0.7	0.3	0.5	0.5
Programming, consulting, information, publishing services	0.5	0.7	0.4	0.5	0.5
Advertising and market research	0.5	0.6	0.5	0.4	0.5
Renting of machinery, equipment, personal and household goods	0.6	0.4	0.4	0.4	0.5
Telecommunication	0.5	0.4	0.5	0.4	0.5
Mining and quarrying	0.3	0.5	0.5	0.3	0.4
Motion picture, video and TV programme production/ programming and broadcasting	0.3	0.5	0.3	0.4	0.4
Financial services	0.4	0.2*	0.4	0.4	0.4
Post and courier activities	0.3	0.4	0.4	0.2	0.3
Electricity, gas, water supply and sewerage	0.1	0.3	0.4	0.4	0.3
Real estate activities	0.3	0.3	0.2	0.3	0.3
Wholesale trade (incl repairs of cars and bikes)	0.2	0.4	0.2	0.3	0.3
Various professional services	0.2	0.3	0.2	0.2	0.2
Retail trade (excl cars and bikes)	0.2	0.2	0.1	0.2	0.2
Transport and storage	0.2	0.2	0.1	0.2	0.2
Construction	0.2	0.2	0.1	0.1	0.1
Accommodation and food services	0.0	0.0	0.0	0.0	0.0
Knowledge intensive services (KIS)	**0.5**	**0.6**	**0.4**	**0.5**	**0.5**

Source: Own calculations based on statistical data listed in Appendix B.
Note 1. D1 = Knowledge intensity; D2 = Human resources; D3 = Social & business connectivity; Ddiv = Diversity.
Note 2. KIS combines programming, consulting, information, publishing services; motion picture, video and TV programme production/programming and broadcasting; telecommunication; financial services; architectural and engineering activities and related technical consultancy, technical testing and analysis; scientific research and development; advertising and market research; and other professional, scientific and technical activities.

Table 3
Dimensions and ACAP indicators. 24 sectors and KIS. UK economy. Medium-sized enterprises.

Sectors	D1 Know. Int.	D2 HR	D3 Connect	Ddiv Diversity	ACAP
Scientific research and development	1.0	1.0	1.0	1.0	1.0
Fuels, chemicals, plastic metals & minerals, pharmaceutical products	0.9	0.7	0.8	0.8	0.8
Manufacture of computer, electronic, electric, machinery and equipment	0.9	0.5*	0.9	0.8	0.8
Manufacture not elsewhere classified	0.8	0.7	0.6	0.8	0.7
Programming, consulting, information, publishing services	0.7	0.5	0.6	0.6	0.6
Manufacture of food, clothing, wood, paper, publish & print	0.8	0.3*	0.6	0.5	0.6
Telecommunication	0.3*	0.6	0.8	0.6	0.6
Architectural and engineering activities and related technical consultancy. Technical testing and analysis	0.4	0.6	0.4	0.6	0.5
Manufacture of transport equipment	0.7	0.3	0.6	0.4	0.5
Advertising and market research	0.5	0.4	0.5	0.5	0.5
Retail trade (excl cars and bikes)	0.1*	0.6	0.4	0.5	0.4
Renting of machinery, equipment, personal and household goods	0.3	0.6	0.4	0.4	0.4
Financial services	0.4	0.4	0.3	0.4	0.4
Electricity, gas, water supply and sewerage	0.4	0.3	0.4	0.3	0.4
Transport and storage	0.3	0.4	0.4	0.3	0.3
Other professional, scientific and technical activities	0.3	0.5	0.3	0.3	0.3
Real estate activities	0.2	0.5	0.2	0.3	0.3
Mining and quarrying	0.4	0.3	0.2	0.2	0.2
Construction	0.2	0.4	0.1	0.3	0.2
Wholesale trade (incl repairs of cars and bikes)	0.0	0.4	0.3	0.2	0.2
Various professional services	0.1	0.3	0.1	0.1	0.2
Motion picture, video and TV programme production/ programming and broadcasting	0.2	0.2	0.3	0.0	0.2
Accommodation and food services	0.1	0.0	0.0	0.0	0.0
Knowledge intensive services (KIS)	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**

Source: Own calculations based on statistical data listed in Appendix B. Values for the sector 'post and courier services' are not reported due to low numbers of observations in this sector.

from CIS 11 and – as in the macro study – they are selected for consistency with the meaning and significance of the relevant ACAP dimension while taking account of data availability.[13] The differences in all

[13] CIS 11 (the 11th wave of the CIS) is also referred to as CIS2018 by the European Union, after the reference year 2018, or UKIS2019 in the UK, after the year during which the survey is administered. Though CIS12, collecting data for 2020, is now available, we decided to use CIS11 to avoid dealing with data affected by the Covid-19 pandemic.

variable scores across the 24 sectors is statistically significant using ANOVA tests ($p < 0.01$) for both the large and medium-sized enterprise samples.

Table 2 presents the results based on data from the largest enterprises in each sector, those with at least 1.5 times the sector average turnover. The table is organised in the same way as Table 1. The first columns D1 to Ddiv contain the distance measures for the dimensions. The last column contains the ACAP indicator. Similarly, Table 3 presents results for the medium-sized enterprises. The same sectors are represented in the two tables except for post and courier activity which does not appear in Table 3 because of too few observations.

Regarding the results in both tables, we should point out that some of the missing sectors in the CIS, specifically educational/academic and health sectors, tend to be knowledge intensive, and, therefore, their absence affects the overall ACAP picture. Many enterprises, both large and medium size, are likely to have relationships and synergies with universities and the health service sector (Fabrizio, 2009; Mazzucato, 2013).

Looking at values of all indicators by sector in Table 2, we note that 'manufacture of computer, electronic, electric machinery and equipment' ranks highest in ACAP in three of its dimensions with slightly lower values on D2 'human resources'. The lowest values are in 'accommodation and food services'. The latter sector ranks lowest also in the sample of medium-sized enterprises reported in Table 3.

The weights for the four dimensions feeding into ACAP in Tables 2 and 3, are very similar to each other; they range between 0.20 and 0.28 for the largest and between 0.21 and 0.31 for the medium-sized enterprises (Appendix B).

Regarding the aggregate sector that combines knowledge intensive services, we should first note that the lack of coverage of some public sector services – such as universities and National Health Service – affects the results particularly hard and grossly underestimates the innovation and ACAP performance of KIS. The results for KIS range between 0.4 and 0.6 on all dimensions and on ACAP in both Tables 2 and 3. They are good results but not entirely consistent with the strong results in Table 1 for the UK, a country for which the human resources indicator for employment in KIS (DS2, demand side of labour) is 0.9 and the corresponding employment ratio in KIS at 49.7 is the second highest after Sweden (Table A.2). The missing data from the CIS on education/universities and the National Health Service is affecting the results in Tables 2 and 3 doubly. First, because the data available to us miss two innovation intensive sectors with strong elements of embodied knowledge on both the capital and scientific activities side and on the labour side. Second, because these sectors have strong links with the private sector, and, therefore, we miss also on their acquired knowledge from it. In our view the discrepancy in the KIS results in Tables 2 and 3 with those in Table 1 for the UK reflect the relevance of the missing data from the CIS.

6. Lessons from the study

In our dimensional approach we distinguish between two types of knowledge affecting ACAP: embodied knowledge (represented by the dimensions knowledge intensity and by human resources) and acquired knowledge (represented by social and business connectivity and by physical connectivity). Do our results shed light on the comparative contribution to ACAP of the two types of knowledge? Yes. From the results, the embodiment of knowledge seems to play a stronger role in ACAP.

In fact, in the country study, the highest contribution to ACAP pertains to human resources and to knowledge intensity with weight of 0.34 of 0.31, respectively (Table A.1). Thus, the two embodiment dimensions together contribute 0.65 to the ACAP results. The dimensions which represent the acquisition side of knowledge contribute less and, specifically, 0.22 for dimension 4 (physical and digital connectivity) and only 0.13 for the social and business connectivity. We acknowledge, however, that the variables we managed to put together for the latter dimension may not represent it fully.

These results are not surprising. What they tell us is that, yes, knowledge can be accessed by various sources, but, in the end, to raise the level of ACAP, the countries must invest in assets, scientific activities and human resources in order to embody and consolidate the accessed and developed knowledge in its economic activities, no matter how it originated.

We stressed the role of human resources in both embodiment and acquisition of knowledge. We should, however, note that in periods of structural changes in the employment relationship (Ritter-Hayashi et al., 2021) this important dimension is not easy to fully account for in the ACAP indicator by using data on labour. The rapid evolution towards temporary or non-contractual relationships may impact on the transmission of knowledge within and outside the company/institution. To what extent can the individual employees learn from the company that employs them on a temporary or non-contractual basis? And to what extent, in such conditions, does knowledge transmit from these to other employees?

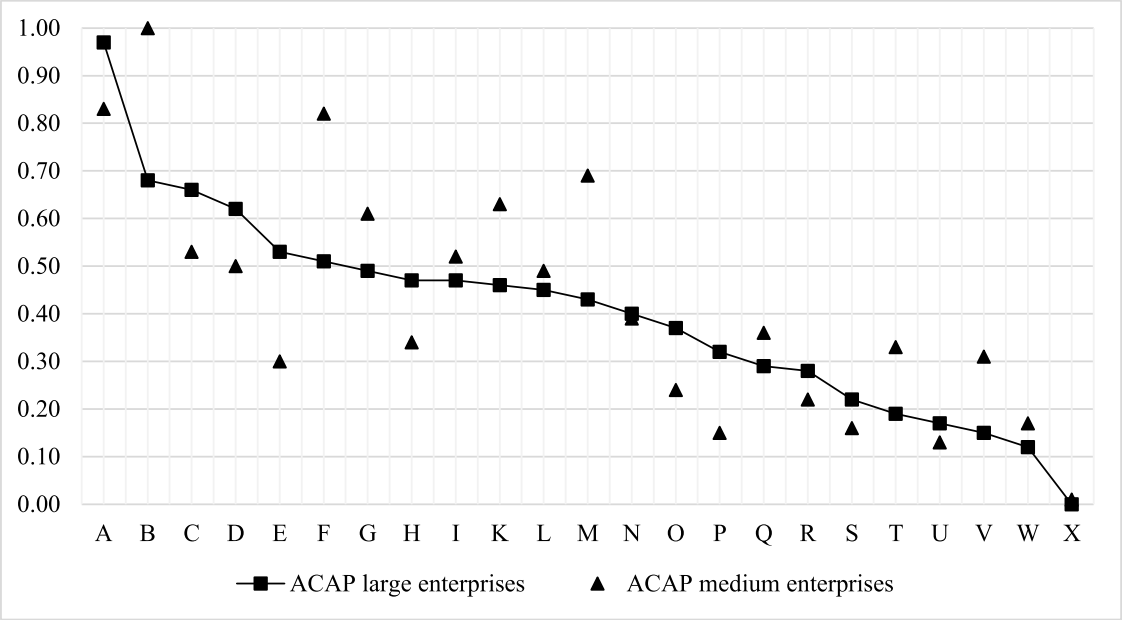
In Section 4.1 we raised the issue of demand as well as supply side of labour and introduced our plan to take account of the former in the human resources dimension of the country study via relative employment in KIS. Table A.1 shows that the weight of the HR dimension within ACAP is the highest (0.34). Moreover, the variable with the highest weight within the dimension (0.39) is employment in KIS. This points to the relevance of demand side of labour, i.e. to the relevance of whether the sectoral structure of the economy is one that requires high labour skills or not.

We have, deliberately, used the same theoretical framework in the macro and *meso* studies in order to be able to further corroborate our framework and to arrive – for the UK – at comparable results. However, the data used are very different and, at times, this makes comparisons across the two studies challenging. There are two types of data coverage problems in the sector study. First, lack of data on some sectors which are not part of the CIS (agriculture, public administration, education, health and social care, as well as arts and entertainment). This is a big problem for any study using CIS data in the assessment of ACAP for two reasons: because some of these excluded sectors are knowledge intensive; and because they are sectors that interact strongly with the private sector on which the survey is based. We have also noted in discussing the results of the sectors study that the lack of CIS data on the excluded sectors of the economy raises doubts about our results for KIS ACAP. Moreover, acquisition of knowledge from other units/sectors is part of our conceptualization and the missing sectors are bound to result in missing important information. These problems may be particularly relevant for the UK, a country on which some of the sectors on which the CIS does not report data, such as education and national health service or arts and entertainment, are knowledge intensive.

Second, there are here and there problems with coverage due to the type of questions asked or not asked, and this affects differently the four dimensions. For example, on human resources we could not get the same level of breakdown and details on educational attainment of the labour employed as in the macro study though we managed to get a variable on employment of specific high skills.

The results for the two samples of sectors, the large and medium-sized enterprises, give approximately same dimensional weights to the ACAP indicators (recorded in Appendix B). Moreover, the correlation between the ACAP results in Tables 2 and 3 is 0.8, showing a considerable degree of similarity in the ranking of sectors in the two samples. To get a more detailed picture we plot in Fig. 1 the ACAP results by sectors of large and of medium-size enterprises.

Sectors in which ACAP is low (<0.5 from sector K to X) are plotted at the right-hand side of the graph. They show closeness between the results for large and for medium-size enterprises. The left-hand side of the graph plots the two sets of results for large and medium-size enterprises exhibiting high levels of ACAP. The left-hand side exhibits greater



A Manufacture of computer, electronic, electric, machinery and equipment
B Scientific research and development
C Manufacture of transport equipment
D Architectural and engineering activities and related technical consultancy. Technical testing and analysis
E Other professional, scientific and technical activities
F Fuels, chemicals, plastic metals & minerals, pharmaceutical products
G Manufacture of food, clothing, wood, paper, publish & print
H Renting of machinery, equipment, personal and household goods
I Telecommunication
K Programming, consulting, information, publishing services
L Advertising and market research
M Manufacture not elsewhere classified
N Financial services
O Mining and quarrying
P Motion picture, video and tv programme production/programming and broadcasting
Q Electricity, gas, water supply and sewerage
R Real estate activities
S Wholesale trade (incl. repairs of cars and bikes)
T Retail trade (excl. cars and bikes)
U Various professional services
V Transport and storage
W Construction
X Accommodation and food services

Fig. 1. ACAP values for large and medium-sized enterprises by sector.

variability across the two samples of enterprises,[14] with the medium-size sample showing higher sectors-specific ACAP values in: scientific research and development (B); fuels, chemicals, plastic metals & minerals, pharmaceutical products (F); manufacture of food, clothing, wood, paper, publish & print (A); telecommunication (I); programming, consulting, information, publishing services (K); and advertising and market research (L). The overall conclusion seems the following. The divergence in ACAP results is smaller for the low-ACAP sectors compared to the high-ACAP ones. Regarding the latter, we note therefore that most sectors that show high ACAP do so for both large and medium-size enterprises.

What lessons can we draw on the specificity of sectors and size in relation to ACAP values? There is, definitely, sector specificity in the results. The relevance of the sectoral structure emerges from the results on both the sectors and countries studies. In the latter via the results for the variable employment in KIS discussed above: the UK shows a very high results (0.9) for the indicator of human resources demand to which corresponds the second highest value for employment in KIS at 49.7 percent well above the average of 38.8 (Table A.2).

Regarding size, the picture is more complex. Low ACAP seems to be a specificity of sectors more than enterprise size and it is found in both large and medium-size enterprises. For those sectors that show high levels of ACAP, size seems to matter more; in some cases, the medium-size enterprises perform better in terms of ACAP than the large ones.

This brings us to a key point in our study. The sectors study refers to one country only, the UK, and, therefore, our results are country specific. We are studying a country where large companies, mostly transnational, dominate the economy to a higher degree than in most of the other countries listed in Table 1. Large companies are likely to operate in collaboration with many smaller ones in producing elements of their value chains. This means that, when it comes to knowledge and innovation, there is likely to be a very considerable level of integration and synergies between large and medium-sized enterprises with specialization in different sections of the productive process: the medium-sized ones supplying services or material components to the large ones. The integration may take place via a variety of contractual arrangements ranging from arm-length transactions to more hands-on contracts and also via company/enterprise internal networks. In other words, the UK is a country in which we would have expected similar levels of knowledge development and ACAP in both large and medium-sized enterprises for those sectors where knowledge and ACAP are most relevant. It is encouraging to see this reflected in the results.

The above results can be of help in identifying specific sectors for

[14] The average absolute deviations between the scores for large and for medium-size enterprises is 0.16 for the sectors with ACAP values ranging from 1.00 to 0.50. It is 0.10 for those sectors with ACAP below 0.50.

policy development in two respects. First, of all the sectors with high ACAP results in the left-hand side of the graph, five (A, C, D, E and H) show performance for medium-size enterprises below those of the largest enterprises for the same sector. Detailed studies for those sectors focusing on specific segments of the value chain for the large and medium-size enterprises could elicit reasons for the discrepancy leading to policy development with the aim to raise the ACAP performance of the sector medium-size enterprises.

A second focus of attention should be the sectors with ACAP performance below 0.45 (from M to X). In some of the sectors in this list, high technology, such as robots in mining and quarrying (group O with ACAP values of 0.4 and 0.2 respectively for large and medium size enterprises), are being used in several countries. Should this technological development be encouraged in the UK?[15] Many services industries such as financial (N with ACAP of 0.4 for both groups) or professional (U with ACAP values of 0.2 for both groups) are soon going to face a big shake-up with the advent of AI. Have they got the necessary absorptive capacity to face up to the challenge? In conclusion, even in the context of several limitations, the sectors study allows us to reach conclusions on the sectors in need of attention by policy makers and in need of further studies by researchers.

The diversity dimension is represented by variables related to resources and specifically fixed capital and labour skills. The dimension contributes 0.28 and 0.31 to ACAP in the large- and medium-size enterprises studies respectively. These results seem, therefore, to align themselves with other literature that considers diversity of knowledge relevant in ACAP (Cohen and Levinthal, 1994; Zahra and George, 2002; Nowak, 2020).

7. Summary and conclusions

The paper presents a conceptualization and related operationalization of ACAP leading to the development and estimates of indicators. There are no agreed conceptualization and operationalization systems for ACAP. Our own conceptualization takes the lead from the works of Cohen and Levinthal and develops a system based on the following principles. (a) Relevance of knowledge accumulation from past activities: history matters; (b) embodiment of knowledge in assets and scientific activities as well as in human resources; (c) acquisition of knowledge from the environment alongside development within the unit. We develop an operationalization system which embodies these three principles to set out dimensions of ACAP. We apply the same conceptualization to both the macro and sector studies.

The empirical work consists, in fact, of two parts: a macro and a *meso* part. The macro part develops indicators for 25 European countries; the *meso* one applies the same approach and methodology to 24 sectors, and to KIS, for the UK economy. A KIS element is introduced also in the macro study via a specific human resources variable related to the demand side of labour skills. This element aims to pick up the relevance of the sectoral structure across countries via the demand side for labour.

In the countries study we consider four dimensions: knowledge intensity (in assets and scientific activities); human resources which comprises a supply and demand side; social connectivity; and physical connectivity infrastructure. In the sectors study we also consider four dimensions; however, the physical connectivity dimension is not included and a new dimension, diversity, is introduced. Moreover, in this study human resources is not split into supply and demand side as in the macro study.

The methodology used is the same in both the macro and *meso* studies. The dimensional indicators are arrived at as weighted averages of the variables and the final ACAP indicator as weighted average of the dimensions. The weights are calculated using factor analysis.

For the macro study we used official data from Eurostat, the United Nations and the World Bank. The reference year is 2018, the last year not affected by the Covid-19 pandemic and for which we had relevant data. In the *meso* study we use data from the UK Community Innovation Survey 2018. The indicators at *meso* level are estimated for two sectors' samples: large- and medium-size enterprises. For both samples we also give estimates of the dimensional indicators for the knowledge intensive services.

We therefore present an operationalization system coherent with, and derived from, our conceptualization framework; one that: (1) develops indicators of ACAP using variables that are measurable and comparable within the countries and within the sectors studies; (2) uses a unified system at both levels, though with appropriate specific methodological and data elements in each; (3) leads to indicators that are comparable for countries or across sectors of the UK; (4) leads to dimensions represented by several related variables within each of them. The conceptualization and related multidimensionality lead to policy relevant estimate of indicators.

The following patterns emerge from the results. In the countries study, the two dimensions that capture embodiment of knowledge (knowledge intensity and human resources) give stronger results than the two related to potential for the acquisition of knowledge (via social and physical connectivity). This we interpret as indication that investing in knowledge and embodying it in equipment and institutions as well as in labour is essential for the building up of ACAP and, eventually, for innovation. The variable related to KIS in the countries study gives strong results, a possible indication that the structure of the economy, via its effects on the demand side of labour, matters in building up absorptive capacity; a conclusion which seems supported by the sector results for the UK, though the data on the latter is more problematic as it does not include some knowledge intensive services.

The results for the *meso* study show more sector-specificity than size-specificity. Sectors with low ACAP tend to be the same in the two samples of large and medium-size enterprises. Moreover, the results at the high ACAP end show synergies between large and medium-size enterprises. We note that the results may be specific to the UK; it is possible, therefore, that other countries would not show elements of synergies between large and smaller enterprises. We use the combination of results for sectors and size of enterprises to suggest lines for further studies leading to sector-specific policy development.

We are aware that there are several limitations to the study, some related to data and some to the methodology. We consider the sector study the weaker of the two for the following reasons. (1) It is confined to a single country and the results can be seen as specific to it. (2) We use CIS data, and this introduces two sets of limitations to the study. First, the exclusion from the survey of some knowledge intensive sectors such as the educational/academic and the health sectors. Second, that our choice of variables and the format some of them come in (such as yes/no answers) limit their use as variables in our dimensions. For these reasons, some of our dimensions, such as the human resources dimension, are not as well covered as in our macro study. Third, the fact that the subject of CIS is innovation rather than ACAP. There are also advantage of using CIS data among which are the micro focus of the survey and the large, well-established survey on which the data is based.

We mentioned in Section 3 at the beginning of the paper that the concept of ACAP is now widely accepted and used in the innovation and technology literature, yet no agreed measure of ACAP has been developed. Other economics/business fields have gone through tortuous periods leading to the development of conventions and agreed methodologies for calculating, for example, national income accounts or

[15] In the case of coal mining, policy makers may need to evaluate not only the environmental damage from it but also whether it is worth supporting an industry which may be on the low end of knowledge capacity as our results seem to indicate.

goodwill in companies' reports. We here put forward the idea that it is time for the now ripe concept of absorptive capacity to be normalized into an agreed methodology and data leading to comparability across countries and sectors. We hope that our study can be seen as a contribution to the possibility of arriving at such agreed convention for the measurement of ACAP.

Authorship

We confirm that both authors made a substantial contribution to the paper including:

1. The conception and design of the study, or acquisition of data, or analysis and interpretation of data.
2. Drafting the article and revising it critically for important intellectual content.
3. Final approval of the version to be submitted.

We agree to be accountable for all aspects of the work.

CRediT authorship contribution statement

Marion Frenz: Writing – original draft, Methodology, Conceptualization. **Grazia Ietto-Gillies:** Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

We declare that we have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Variables feeding into the macro study

Table A1

Table A.1
Macro study. List of variables, sources and weights.

Variable	Source	Weights		
		Dimensions		ACAP
Dimension 1. Knowledge intensity				**0.31**
Business R&D expenditure [a, d]	Eurostat	0.26		
Government plus HE R&D expenditure [a, d]	Eurostat	0.25		
Patent application to the European Patent Office [a, c, e]	Eurostat	0.27		
Number of scientific & technical journal publications [a, e]	World Bank	0.22		
Dimension 2. Human resources				**0.34**
Graduates from tertiary education [a, e]	Eurostat	0.24		
Graduates from advanced research programmes [a, e]	Eurostat	0.36		
Employment in knowledge intensive sectors (KIS) [e]	Eurostat	0.39		
Dimension 3. Social and business connectivity				**0.13**
Foreign direct investment inward and outward stock [d]	Unctad	0.48	0.58	
Trade in goods and services (imports plus exports) [a, d]	World Bank	0.52		
Enterprises that cooperate on innovation [b, f]	Eurostat		0.42	
Dimension 4. Physical and digital connectivity				**0.22**
Business with broadband [c, g]	Eurostat	0.15		
Businesses whose processes are automatically and electronically linked to suppliers or customers/clients [c, h]	Eurostat	0.19		
Number of commercial airports [e]	Eurostat	0.35		
Length of motorway [i]	Eurostat	0.32		

Note, the weights are derived from factor analyses. Weights are based on squared factor loadings. In the case of Dimension 3, a two factor solution was obtained, grouping FDI and trade into one factor and cooperation in a separate factor. All other factor analyses arrived at a one factor solution.

[a] We cumulate variables over the three years 2016, 2017 and 2018 before normalizing by an indicator for countries' size.
[b] Data collected biannually. We are using data from CIS11 with the reference period 2016–2018.
[c] Latest available year is 2017. Years used in the analysis are therefore 2015, 2016 and 2017.
[d] Normalized by GDP.
[e] Normalized by population.
[f] Normalized by total innovation active enterprises.
[g] Normalized by total businesses.
[h] Normalized by total businesses excluding finical services.
[i] Normalized by country km^2. [k] Only available for 23 countries. [l] Normalized by all enterprises.

Table A.2
Values for the variable 'employment in KIS', 2018.

Sweden	53.8	Austria	38.6	Italy	34.6
United Kingdom	49.7	Portugal	36.7	Lithuania	34.6
Denmark	48.5	Greece	36.4	Slovakia	34.5
Belgium	48.2	Latvia	36.0	Czechia	33.3
France	46.2	Spain	35.8	Poland	31.7
Finland	45.8	Estonia	35.7	Bulgaria	30.7
Netherlands	45.8	Croatia	35.4	Romania	22.1
Ireland	44.3	Slovenia	35.2	**Average**	**38.8**
Germany	40.7	Hungary	35.0		

Source: Eurostat. Total knowledge-intensive services as a percentage of total employment.

Appendix B. Variables feeding into the meso study

Table B

Table B
List of variables and weights.

Variables		Weights		Weights	
		D	ACAP	D	ACAP
		Large Ent.		Med Ent.	
Dimension 1. Knowledge intensity			**0.26**		**0.22**
Intensity of knowledge related investment	Share of enterprises with innovation related investments within each sector. Investment in any of the following areas: internal R&D; acquisition of R&D; acquisition of advanced machinery, equipment and software for innovation; acquisition of existing knowledge; training for innovation activities; all forms of design; or market introduction of innovation.	n/a		n/a	
Dimension 2. Human resources			**0.20**		**0.21**
Intensity of knowledge through people: specific skills	Share of enterprises within each sector that either employed individuals with specific skills or obtain such skills externally. Skills in any of the following areas: graphic arts, layout, advertising; design of objects or services; multimedia, web design, animation, video; software development, database management; engineering, applied sciences; mathematics / statistics.	n/a		n/a	
Dimension 3. Social & business connectivity			**0.25**		**0.27**
Within enterprise group connections	Share of enterprise within each sector that cooperated on innovation with other businesses within the enterprise group.	0.25		0.22	
Connections with other business	Share of enterprise within each sector that cooperated on innovation with other businesses (suppliers, customers, competitors).	0.26		0.26	
Connections with other institutions	Share of enterprise within each sector that cooperated on innovation with other institutions (consultants and labs, universities, research institutes).	0.22		0.19	
International linkages	Share of enterprise within each sector that operated abroad.	0.16		0.24	
Trade	Average value of exports per employee within each sector.	0.10		0.10	
Dimension 4. Diversity			**0.28**		**0.31**
Diversity of knowledge investment activities	Average within each sector of the following. We counted how often enterprises ticked 'yes' for any of the following investment areas: internal R&D; acquisition of R&D; acquisition of advanced machinery, equipment and software for innovation; acquisition of existing knowledge; training for innovation activities; all forms of design; or market introduction of innovation.	0.50		0.50	
Diversity of skills	Average within each sector of the following. We counted how often enterprises ticked 'yes' for any of the following skills: graphic arts, layout, advertising; design of objects or services; multimedia, web design, animation, video; software development, database management; engineering, applied sciences; mathematics / statistics.	0.50		0.50	

Source: UK CIS 11 data.
Note. n/a – not applicable, because there is only one variable in the dimension. Column D – dimension weights and column ACAP – ACAP weights.

Data availability

The data in the macro study is in the public domain. The data in the meso study is confidential.

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