High-Tech Left Behind? Lessons from the Ruhr Cybersecurity Ecosystem for Approaches to Develop "Left Behind" Places.

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Abstract

The attention to "left behind" places triggered a debate about alternative development approaches. Unlike prosperous regions and their prioritisation on high-tech sectors, strategies for left behind places should shift to the foundational economy, community-based social innovation and well-being. While supporting this emphasis, we see a tendency to neglect importance of research and teaching in high-tech areas for developing left behind places. Our case study in the old industrial region Ruhr shows, how unrelated initial funding for cutting-edge research sparked the development of today's cybersecurity ecosystem. The ecosystem contributes to a positive identification within the region and a dynamic start-up landscape.

Keywords: left behind places, entrepreneurial ecosystem, cybersecurity, high-tech sectors, regional development

JEL classification: 031, 032, 0180

I Introduction

Populism across Europe has triggered renewed attention of actors in politics and regional studies for "left behind" places, such as lagging old industrial regions and rural areas (BMI 2019, MacKinnon et al. 2021, Rodríguez-Pose 2018). Researchers criticise conventional growth-oriented economic thinking and its narrow policy prescriptions as inadequate and call for alternative development strategies for left behind places. Unlike growth regions and their prioritisation of cutting-edge research and development (R&D), technological innovation and high-tech export sectors, it is claimed that development strategies should shift to the foundational economy (Hansen 2021) and community-based social innovation (Pires et al. 2020). Furthermore, those universities located in lagging regions should become engaged universities and shift their third mission towards needs of local communities. Referring to neo-endogenous development approaches, specific place-based development policies that address well-being, quality of life, positive identification and belonging are needed to engage with lagging places and their development (MacKinnon et al. 2021).

While being sympathetic with the proclaimed shift, we identify three potential negative effects for the development of such places. First, we are concerned that the emphasis on alternative development and social well-being might lead to the perception that high-tech development and related research are misplaced in lagging regions and that high-tech industries cannot develop there. This would be mistaken, as our cybersecurity case study from the Ruhr in Germany, Europe's most populous former mining area, shows. Today, the Ruhr's competitive cybersecurity ecosystem hosts cutting-edge international research institutes, cybersecurity subsidies of high-tech companies and vibrant deep tech start-ups.

Second, as our case study indicates, high-level research and development opportunities can attract change agents and develop new (unrelated) industries in lagging regions (Marques et al. 2019). This observation challenges the proclaimed regional focus of engaged universities. If engaged universities predominantly focus their research and teaching to the needs of the low-growth or even declining regional industry and of regional

society, their ability to develop new impulses, technologies and sectors is reduced. Third, research institutes and high-tech companies of the Ruhr's cybersecurity ecosystem contribute to positive regional identity and boost the regional image and partly compensate for identity losses going along with industrial decline (Tomaney et al. 2019). Hence, identification and belonging as positive effects connected to regional development is not an exclusive argument for alternative development strategies.

To be realistic, the cybersecurity ecosystem is still a niche economy in the Ruhr that predominately employs highly skilled persons. Its private sector accounts for only 0.39% of Ruhr's total employment. Accordingly, the direct effects for the Ruhr's population are limited. However, the indirect, identity-forming aspects of the research centres and innovation sites must be considered. We therefore argue that development policies for left behind places should consider alternative and well-being oriented approaches, but not at the expense of ambitious science, innovation and high-tech sectors. A place-based combination of alternative and conventional development approaches spurs positive identification and dynamics in regional development of left behind places.

The paper is organised as follows. Section 2 reviews three new development approaches for left behind places – foundational economy, engaged university and social innovation – and outlines their potential disadvantages for regional development. Section 3 introduces our case study including used methods, while section 4 outlines the genesis of the Ruhr's cybersecurity ecosystem and its impact on the region. Finally, section 5 concludes and advances recommendations for development policies.

II A critical stance on alternative development approaches in left behind regions

Conventional economic development strategies for left behind regions mirror the dominant regional development discussions for economic centres and prospering regions (Martin 2021). Regions should become competitive industry clusters (Trippl and Tödtling 2008, Rehfeld 1999, Scheuplein and Krätke 2001), develop regional innovation systems (Doloreux and Dionne 2008), specialise in a smart way (Foray 2014, Valance et al. 2018)

and become lively entrepreneurial ecosystems (Spigel and Harrison 2018). In recent debates, the orientation towards high growth, competition and export-oriented development strategies has been criticised as insufficient for left behind regions. Despite long effort and extensive public funding, the regions could not catch up, as they were still not competitive on national scale (MacKinnon et al. 2021). In the following we critically appreciate the three alternative development approaches for left behind regions.

Foundational Economy

Contrary to the spatial concentration of many high-tech sectors in metropolitan growth areas, the foundational economy emphasises decentralised economic functions across space (Hansen 2021). This has shifted attention to the almost ubiquitous presence of local services and infrastructure as a means for developing lagging regions (MacKinnon et al. 2021, Hansen 2021, Zademach and Dudek 2022). The main development approach is to strengthen the present economic structures and their sectoral broadness as a stabilising measure instead of newly developing a narrow range of high-tech sectors (Hansen 2021). Foundational economies relate to the production and maintenance of material (e.g. water, energy and transport), social infrastructure (e.g. health, education, and care) as well as other local supplies for the local market (Heslop et al. 2019). Regional inhabitants generate a constant demand making foundational economies less prone to inter-regional competitiveness (Hansen 2021). Furthermore, while meeting the demand, foundational economies contribute to people's well-being (Froud et al. 2020) and provide employment opportunities (Engelen et al 2017). In light of socio-ecological transitions and digitalisation, there is also innovation potential, for example in the adaptation of transport and energy infrastructures (Hansen 2021).

Strengthening foundational economies as a main development approach is in line with a post-growth and pro-well-being perspective in lesser developed regions. It builds upon local consumption as the upper limit for economic growth, instead of inter-regional competition or export-oriented industries (an exception might be energy production). However, establishment of a regional export-base and the potential to create new jobs is limited. Therefore, going beyond the competitiveness and innovation paradigm is integral to

developing the foundational economy. Innovation and growth orientation may co-exist but are unrelated to foundational economy.

Engaged universities

Interest in studying universities as actors in regional development is based on their impact on the regional economy through knowledge transfer, innovation and the generation of spin-offs. Research-driven universities (Lawton Smith and Bagchi-Sen 2011), for example Stanford University and MIT, have largely shaped their local economy and were strong role models for regional development. Regional economy and technology-transfer agencies around the world strive to establish research infrastructures with a similar tech-orientation and support their interaction with the private sector in order to generate economic growth.

The focus for engaged universities on entrepreneurship and commercialisation of technological discoveries is just one out of several activities interlinking universities with regional development (Breznitz and Feldman 2012) and the Stanford model respectively Silicon Valley rarely match with non-core and lagging regions (Trippl et al. 2015, Breznitz 2021, Kempton et al. 2021). Instead of prioritising research in high-tech disciplines, universities in lagging regions should align towards regional needs. Engaged universities have dedicated "third mission" activities, linking them to their surroundings through diverse actions and practices (Compagnucci and Spigarelli 2020). These include educational programmes suited to workforce demands of the local economy, university staff consulting local decision makers and supporting local businesses, civil society, and public sector organisations (Kempton et al. 2021, Trippl et al. 2015). Engaged universities might even take over leadership as a regional player in a broad sense (Salooma 2019) and contribute to social, political, cultural and civic activities (Goddard et al., 2013). Strengthening universities´ engagement with civil society and social innovation, is also expressed in studies on universities in quadruple (research, public, private and civil sector) or quintuple (adding a sustainability dimension) helix constellations (Morawska-Jancelewicz 2021, Bellandi et al. 2021, Bayuno et al. 2020, Benneworth et al. 2020, Arocena and Sutz 2021).

Overall, engaged universities adapt knowledge generation to the needs of their environment and contextualise their activities. Instead of gaining knowledge through scientific curiosity, knowledge generation responds to regional development (Gunasekara, 2006). As the regional surrounding shapes research activities of engaged universities in lagging regions, the Silicon Valley model is partly reversed.

The diverse roles of engaged universities can support lagging regions in various ways. However, the focus on regional needs conveys the danger of "over adaptation" resulting in "lock-in" that in turn could lower capacities of universities to stimulate new regional impulses. Whereas universities in prosperous regions develop high-tech industries and gain momentum in cutting-edge research and technologies, left behind places and their universities are directed to less commercial research areas and "old" technologies of the lagging industries. Therefore, unintendedly, "over adaptation" to the regional needs tend to foster polarised regional development between core and non-core regions.

Social and community-driven innovation

Social and community-driven innovation is a development postulate of less-developed regions with emphasis on bottom-up, participatory processes that include people-centred policies and innovation practices (Pires et al. 2020). This also means development of new indicators to define and measure determinants of innovation (Terstriep et al. 2021) relating to their regional and societal transformative impact is needed.

With its focus on social needs (Howaldt et al. 2015, Marques et al. 2018), social innovation can be an instrument to empower people and stimulate self-help capacities, but also to "fill gaps caused by austerity politics" (Neumeier 2017). Even though social innovation arise across all places, an intense discussion is about the potential of social innovation for developing communities in less-developed regions (MacKinnon et al. 2021, Tiran et al. 2022). It is analysed how social innovations empower communities in peripheral rural areas (Christmann 2020a, Noack and Federwisch 2020). Case studies focus on alternative farming (Gramm et al. 2020, Plank et al. 2020) or new forms of civic engagement (Butzin and Gärtner 2017, Schubert 2018). The debate on social innovation in urban areas focuses

on prominent examples like fab labs, urban gardening, car sharing or corporate housing, starting their diffusion from (prosperous) metropolitan areas across the globe (Avelino et al. 2019). On the other hand, social innovation is an instrument to develop neighbourhoods of decline (Moulaert et al. 2011, Moulaert and van den Broeck 2018) and old-industrial regions (Tiran et al. 2022, Gonzáles and Vigar 2010, Donaldson and Court 2011). Policymaking has already incorporated the transformative potential of social innovation: The OECD recently published a methodological framework for building local social innovation ecosystems in its series on disadvantaged places and groups (OECD 2021). In another policy-paper, Christmann (2020b) discusses support instruments for social innovation in structurally weak rural regions.

Intense social interaction and practices make social innovation very place-sensitive, adjusted to local needs, and "sticky". Even though scaling social innovation has been supported from a scientific-analytical and practical-development perspective, the potential to grow in an economic sense relates to only a few examples. Adapting social practices and copying new ways of interaction are much more appropriate for the diffusion of social innovations (Rabadjieva and Butzin 2020), but do not generate effects at the original locus of innovation (Davies and Simon 2013).

Critical appreciation

The alternative development approaches summarised above, broaden the narrow understanding of economic growth for lagging regions towards social, well-being and ecological objectives. Supporting foundational economies in lagging regions potentially strengthens the quality of local provision of goods and services, engaged universities question traditional ways of innovation transfer while open up activities to the local society, and social innovation aims to empower local communities and improve quality of life. The importance of this broadening cannot be under-estimated for the development of left behind regions. However, we plea for not narrowing the discussion about lagging regions towards alternative development approaches for the following reasons:

First, amplified homogeneity in lagging regions. The emphasis on the foundational economy and the local needs of companies and society potentially shifts focus to low growth sectors and decreases economic diversity in lagging regions. If lagging regions concentrate on the foundational economy, sectoral differences vanish and may only arise from differences in natural potentials. Also, the prioritization of existing industries direct lagging regions toward low growth and old industrial sectors (because of which the regions are lagging). The homogeneity might also result in brain drain of people who wish education and employment in other but foundational sectors. High-tech promotion, support for high-growth sectors and smart specialization is recommended precisely to overcome such homogeneity of the industrial basis in lagging regions.

Second, and related to the first critique, a strong engagement of regional universities and research institutions has the potential to lower their capacity to generate impulses for regional development (over adaptation). Engaged universities potentially enforce homogeneity by prioritising regional (foundational economic) demands in research and education at cost of cutting-edge sciences and high-tech innovation. The perception that high-tech research is best located in prosperous regions displaces conventional innovation actors from lagging regions. Social innovations cannot balance out this displacement. Even though they create new dynamics, social innovations can be copied and adapted in other regions and tend to have limited export earning opportunities for regional innovators.

Third, the focus on regional demand and the foundational economy weakens the export bases in lagging regions and underpins financing difficulties of the municipalities and local citizens. To a large share, the foundational economy depends on public funds or is based on fees. For example, in Germany a large share of funding comes from national budgets and only partly from local sources. This is why higher education institutes and high-quality hospitals redirect public and/or health insurance money to lagging regions (Mäding 2009). However, other activities of the foundational economy need to be financed locally, especially for water and energy supply that local consumers pay fees for. Public services of general interest like public transportation, local culture, and recreation

facilities, are permanently funded by municipalities and depend on the municipal tax income. Trade tax generates the largest revenue of all local taxes in Germany (BBSR 2020b), and the publicly produced share of the foundational economy is exempted from trade tax. Therefore, prioritising the foundational economy over export sectors, causes an even more unbalanced relationship between needs of permanent regional public funding and regional tax revenue. The enthusiasm of lagging regions for high-tech sectors and a growing export industry, is also explained by the desire for additional local tax revenue (Zademach and Dudek 2022).

To specify our critique: Most advocates of alternative development approaches do not deny the positive effects of high-tech sectors and export industries for lagging regions but question the relations between expenses and gains. Therefore, the telling question is about the effectiveness and efficiency of development strategies based on growth and high-tech, in relation to alternative approaches for lagging regions. With Silicon Valley as a role model, in our view, expectations to conventional development strategies for lagging regions are unrealistically high. As our case study illustrates in the following, advancing a high-tech, high-growth strategy is a risky, expensive, and a long-term venture. However, its impact on regional development must be assessed against the background that alternative development strategies depend on permanent public funding, too.

III Methods and region of study

Methods

Analysis of the cybersecurity ecosystem was a part of the project InSicht.Ruhr funded by the German Ministry of Research. The aim was to develop an innovation strategy interlinking innovation in the cybersecurity ecosystem and regional structural change. The analysis followed a mixed-method approach, including semi-structured video-interviews lasting about one hour with various stakeholders. In total, we interviewed 53 people representing 44 different organisations. In a few cases, there were either two interviewees, or two persons of the same organisation were interviewed at different times. We interviewed 11 representatives of start-up companies (mostly founders themselves); ten representatives of incumbent companies, among the companies were venture capitalists and

internationally acting companies; nine key academics in cybersecurity located in the Ruhr (directors of research institutes, heads of department, etc.); seven municipal actors, i.e. chief digital officers and representatives of local/regional economic development agencies; five representatives of associations, formal networks and chambers of commerce, and three representatives of start-ups supporting infrastructure such as incubators and hubs.

The interview script included three building blocks. A first set of questions addressed the company or organisation's history including key players, drivers and barriers of its development, as well as access to financial support. This provided information about the company or organisation's embeddedness within the ecosystem and how the ecosystem's actors interact with each other. The second set of questions targeted the strengths and potential of cybersecurity in the Ruhr, i.e. its evolution, competitive expertise, important institutions and individuals that drive the ecosystem's development, activities within the network and future development paths. The third set of questions addressed weaknesses and threats, for example regarding further national and international competing cybersecurity ecosystems or thematic areas in which the Ruhr ecosystem should become stronger.

The interviewees received an invitation for an online workshop to discuss the summarised interview results and further avenues for development of the regional cybersecurity ecosystem. The invitation attracted 34 participants who discussed the results using an interactive mind mapping software (Miro board) for approximately 2.5 hours.

Further secondary sources strengthened the robustness of the interview material and allowed the assessment of cybersecurity's impact on the regional development in the Ruhr. Analyses of labour statistics revealed employment numbers and allowed comparison with other German cybersecurity regions. The computer science ranking was analysed to compare the regional research output and a company database (Markus database of creditreform) was analysed to count the number of regional cybersecurity firms alongside snowball sampling during the interviews.

Structural change and structural policy in the Ruhr

With 53 cities and municipalities, 5.1 million inhabitants and an area of 4,400 km^2, the former Ruhr mining area is one of the largest metropolitan regions in Europe. The complete phase-out of hard coal mining (which began in the early 1960s) was achieved with the closure of the last colliery in 2018 (Dahlbeck et al. 2021). The Ruhr is nevertheless a centre of heavy industries, hosting the largest steel producing facilities in Western Europe. It also hosts several hard coal power stations that are in the process of closure due to the federal plan to exit coal power generation. Owing to the early decline of coal mining, the region has applied several regional development and structural policies approaches since the 1960s, including (following Dahlbeck et al. 2021):

- subsidies for coal production and attempts to increase the productivity of the mining industries via modernisation and economies of scale,
- the foundation of full universities (the first full university, the Ruhr University of Bochum was founded in 1962), applied university as well as research and technology centres,
- social cushioning programmes to avoid layoffs (e.g. early retirements),
- programmes to retrain and transfer companies,
- strategies to diversify the industry structure (e.g. lead market approaches focusing on digital communication, leisure and events, healthcare, mobility, sustainable consumption and resource efficiency),
- identity, wellbeing and industrial culture approaches, such as the IBA Emscher Park and Ruhr.2010 European Capital of Culture,
- start-up support and entrepreneurial ecosystem approaches such as the ruhr.hub, CUBE5 and other incubator programmes.

Politically, the Ruhr is only loosely coordinated in the Ruhr Regional Association (RVR) and the Business Metropole Ruhr (the economic development agency of the Ruhr). The individual cities and municipalities are key actors in economic promotion; the Ruhr is subdivided by three administrative regions and included in the structural policies of the federal state of North Rhine-Westphalia. The Ruhr hosts 22 universities and applied uni-

versities and over 60 research institutes, including four Max-Planck and four Leibniz institutes devoted to cutting-edge research (Kriegesmann et al. 2015, 2019, Dahlbeck et al. 2021). However, the research output in terms of third-party funding and number of students is average in relation to the population compared to the national level, and the region falls behind major cities such as Munich, Hamburg and Berlin (Dahlbeck et al. 2021). In terms of economic development and living conditions, the region is still lagging and below the national average with respect to GDP per capita and disposal income, and above average in terms of the unemployment rate and social welfare recipients (BBSR-INKA, BBSR 2020). Furthermore, intraregional differences are apparent, as the South – where coal mining was terminated earlier and the full universities were founded – is catching up, whereas the Northern areas have some of the poorest cities in Germany (Bogumil et al. 2012, Dahlbeck et al. 2021).

IV Case study: cybersecurity in the Ruhr

Cybersecurity is the security of connected ICT systems and infrastructures including its communication, applications, processes, data, information, knowledge and intelligence (Pohlmann 2022) and relates to security of the state, the private sector and households. Cybersecurity or IT-Security has emerged as a designated interdisciplinary research area with a basis in computer science and connections to electrical engineering, mathematics/cryptography, psychology, law and management. Cybersecurity became a substantial market, both globally and in Germany (World Economic Forum, 2021). Following the BMWi (2013) classification, the cybersecurity market consists of three areas: software, hardware and services and is substantially growing in terms of revenue and employment. Security market revenue was 5.3 billion Euro in 2020, a growth by 5.6 percent to 2019 despite the pandemic (Bitkom 2020).

In the Ruhr, interview partners refer to cybersecurity as a lively ecosystem, because it hosts large companies and start-ups, several universities and research institutes devoted to cybersecurity, and relevant promotional and networking organisations. As table 1 outlines, we identified 80 cybersecurity companies, nine specialised research institutes and departments, and five promoter, accelerator and network organisations.

Table 1: Overview of the Ruhr cybersecurity ecosystem

	Companies	**Research institutes or department**	**Network organisations, accelerators and promoters**
Number (2020)	80 companies	9	5
Examples (year of foundation)	*G DATA* CyberDefense *AG* (1985) *secunet Security Networks AG* (1997) *AWARE7 GmbH* (2018)	*HGI* - Horst-Görtz-Institute for Cybersecurity of Ruhr University Bochum (2002) *If(is)* - Institute for internet security of the Westphalian University of Applied Sciences (2005) *MPI* - Max Planck Institute for Security and Privacy (2019)	*Eurobits e.V.* (1999) *CUBE5* (2018) *Future safe house GmbH* (2020)

Own table, own compilation; sources are webpages of the organisations

Centre of the cybersecurity ecosystem is the City of Bochum with the Ruhr University Bochum founded in 1962 and Horst-Görtz-Institute (HGI) for Cybersecurity founded in 2002. Along with a privately owned IT Security School founded 2001 and the Max Planck Institute for Security and Privacy (MPI) founded in 2019, Bochum has three research and higher education organisations for professionals in cybersecurity. Further research and education take place at the University of Duisburg-Essen, the Westphalian University of Applied Sciences Gelsenkirchen, the Hamm-Lippstadt University of Applied Sciences and at the Distance-Learning University of Hagen. The majority of the 80 identified companies are small companies with less than 50 employees and often start-ups from the HGI and these other universities. There are also three larger firms with more than 250 employees that have headquarters in the Ruhr (G Data, ESCRYPT/Bosch and secunet). Three associations representing cybersecurity are located in the Ruhr acting on the regional, national and European levels.

Evolution of the cybersecurity sector in the Ruhr

With the old department of computer science at Technical University of Dortmund founded in 1972, the Ruhr has a history in ICT. It is claimed that the world's first computer virus was developed in the Ruhr in the early 1980s, as pronounced by one of our interview partners. Furthermore, the first anti-virus software was developed by G DATA in 1987.

However, the early ICT security activities were kind of a hobby of computer scientists, as the cyberspace was in its infant stage and ICT security not that relevant. It was the foundation of HGI in 2002 at Ruhr University Bochum laying the basis of today's entrepreneurial ecosystem.

According to our interview partners, the foundation of HGI has been the result of a random meeting of the donator Horst Görtz (a successful business pioneer in cybersecurity) and the head of internationalization of Ruhr University Bochum. Görtz looked for a University to fulfil his vision of a holistic IT-Security unit, including an undergraduate course, cutting-edge research and entrepreneurial orientation. The rector of Ruhr University Bochum was excited immediately and the faculty of electrical engineering was chosen to host the HGI because it was the best fit there. At this time, Ruhr University Bochum had no department for computer science, which was only founded in 2021 due to the success of cybersecurity. In total, Görtz funded 20 million Deutschemark in the early 2000, for four endowed professorships, the foundation of the first start-up (todays isits AG), the creation of a network organization (todays eurobits e.V), and a cybersecurity building close to the University. Everything happened relatively quickly and without a lot of planning. Success factors of the early years were the high degree of freedom of the first professors. The faculty for electrical engineering was welcoming but research wise only loosely related to cybersecurity. It was also possible for HGI to offer permanent professorships in order to keep young successful researchers. Here the popularity of the cybersecurity undergraduate course helped the young HGI to claim additional professorships.

Since its foundation in 2002, HGI has increased the number of students, currently offers one bachelor and three master classes with annually about 250 incoming students (HGI website) and contribute to the regional pool of cybersecurity professionals. Other universities (e.g. if(is) founded in 2005 at Westphalian University of Applied Sciences) and private education centres followed, and today the regional density of education programmes and the high number of graduates is a positive factor encouraging firms to stay or to establish branches in the Ruhr. HGI also cooperates with the other cybersecurity research and education organisations of the Ruhr via joint professorships and joint PhD students.

Furthermore, HGI generates one new company per year on average. This is well above average in comparison to other German technology-oriented research institutes, making HGI a stronghold of start-ups in Germany (Bundesverband deutsche Startups e.V. 2020), where leading academics are involved in start-ups, or they were founders themselves. Based on our interview results, three generations of start-ups can be identified in the Ruhr since 2002.

Three firms – zynamics, Sirrix und ESCRYPT– were founded between 2005 and 2011 and constitute the first generation of HGI start-ups. The connections with HGI are strong. ESCRYPT was co-founded by one of the two founding professors of the HGI, who is currently founding professor of the MPI. All three start-ups were acquired by the global players Google, Rohde & Schwarz und Robert Bosch, resulting in a loss of independence and partly regional commitment of the companies. For example, zynamics moved to Google in Zurich. However, the acquisition of ESCRYPT underlines the strengths of cybersecurity in the Ruhr. ESCRYPT not only remains in Bochum, it also attracted the entire cybersecurity organisation of Bosch who currently builds a large headquarter at a developing site called "Mark 51°7" in Bochum. An important reason for this decision was the local supply of professionals (ESCRYPT 2021). The sales of the first generation of start-ups have enabled today's business angel scene in the region. For example, the second co-founder of ESCRYPT is now managing partner of the eCAPITAL fund investing in cybersecurity start-ups (eCAPITAL 2021).

The second generation of start-ups was founded between 2012 and 2016. Companies of this generation have diverse business models. Among them is Physec GmbH, specialised in security for the internet of things, or ripstech (now belonging to sonarsource S.A.) specialised in automated code security analyses. These start-ups are spin-offs by former PhD students who commercialised their PhD research while being at the technology centre of the Ruhr University Bochum. Another example is XignSys, specialised in secure authentication methods, digital identification and user trust. XignSys is a spin-off of the if(is) and

part of a smaller cybersecurity group in Bochum's neighbouring city of Gelsenkirchen. Overall, we identified eight start-ups in the second generation.

Eleven start-ups are identified as a part of a third generation (founding year 2017 until today), with some start-ups still in their incubation phase. Founders of this generation have different origins; some are spin-offs of HGI, if(is) (e.g. Aware7 GmbH) or University Duisburg Essen, while some are founded in the Ruhr because of accelerator programs (especially CUBE5), others are spin-offs from large companies like Thyssenkrupp AG and some are spin-offs of old start-ups (like immune).

Due to the different market segments, competition among the start-ups is low and cooperation is very common, especially between universities and companies in publicly funded research projects. Networking among founders is intensive due to many different branch events, a common study background and activities of the network organisations. The interview partners identified two relevant start-up promoters. First one, the cybersecurity incubator CUBE5 and its founding grant for cybersecurity sponsored by the German Research Ministry. Second, the ruhrHUB supports entrepreneurship in the digital economy more broadly and is sponsored by project funding of the federal state of North Rhine Westphalia. Beside the formal promotors, support of entrepreneurial oriented academics (who often have founded companies themselves) is key for the development of university spin offs as professors act as business angels. Altogether, the interviewed actors of the ecosystem (including established firms and start-ups, the local economic development agencies and two cybersecurity/IT associations) perceive the ecosystem as dense in terms of social networks and diverse with respect to actor constellation and technological competence.

Tracing this genesis of the cybersecurity ecosystem in the Ruhr outlines two aspects: First, the initial push from research and the foundation of HGI at a time where cybersecurity was a niche topic led to the basis of today's ecosystem. HGI's foundation was caused by accident, though it was only possible because of the already existing Ruhr University Bochum. It was fortunate for the ecosystem that cybersecurity became such a fast growing

market and that the first professors were very entrepreneurially-minded. Second, although initiated by the private investment of Horst Görtz, HGI and the other research institutions, companies, and supporting programmes depend on massive public funding. The whole ecosystem would not exist at this scale without continuous success in applications to basic research grants, applied research grants, as well as business promotion and regional development grants. To get such often highly competitive research grants into the region, scientists capable of writing successful applications have to be in the region first.

Current position and development impact of the cybersecurity ecosystem in the Ruhr

To assess the success and competitive position of cybersecurity in the Ruhr, table 2 compares the key strengths of the five most important cybersecurity regions in Germany, according to the interviewees. The Ruhr and Saarland are economically lagging regions to the EU State aid rules that have "c"-municipalities that are eligible for regional investment aid (Clausen 2021). The other three regions (Bonn, Darmstadt, and Munich, and their surroundings) are prosperous, with GDP per capital well above the European average. All five regions have different profiles: Munich is company-driven with large defence, ICT and automotive companies having their cybersecurity research and development operations in the city. Bonn, the former capital of Germany, is a cybersecurity region with public origin, hosting the federal office of information security (BSI) and the headquarters of the former telephone state monopoly Deutsche Telekom. The other three regions (including the Ruhr) tend to be more public research driven hosting globally leading cybersecurity research. Darmstadt benefits from proximity to the financial industry and large data centres in the Frankfurt metropolitan region, the Ruhr has developed a substantial start-up ecosystem and Saarland tends to be the most successful region in terms of accumulating excellent publicly funded research institutes in cybersecurity and ICT.

Table 2: Cyber security regions in Germany

German cybersecurity regions	**Strengths related to cybersecurity**	**Lagging region** (the EU State aid areas 2022-2027)
Ruhr Region	Unique start-up dynamic, incumbent firms, international research excellence of the HGI, strong basic and applied research.	Yes
Saarland	Research-based with various federal research institutes, among them the CISPA with outstanding international recognition.	Yes
Darmstadt & Region	Research based, related to the finance industry due to proximity to Frankfurt, and big German data centres due to central location in Germany.	No
Munich & Region	Location of global IT players like Rohde&Schwarz or Apple, cybersecurity department at the University of the German Armed Forces, Munich Security Conference, firm-based R&D dynamics, excellent IT departments at Munich's universities.	No
Bonn & Region	Defined by national level authorities (BSI), headquarter of Deutsche Telekom, university research, Fraunhofer institute.	No

Source: own table

Table 3 displays the key quantitative indicators of our regional comparison. The estimation of employees and revenue of the cybersecurity industry in the five regions bases on German standard industry classification following Hryhorivas and Leglers' (2019, BMWI 2013) approach. The approach sums up seven ICT sectors relevant for cybersecurity with specific weight factors. That allows a numerical comparison of the economic sectors relevant to cybersecurity in the respective regions. However, since cybersecurity has no specific economic sector in the standard industry classification, our approach tends to measure ICT more generally. In terms of cybersecurity employees subject to social security relative to all employees of the region, the Ruhr shows about national average sectoral specialisation at 0.39% (Table 3). With 1.35%, Munich is much more specialised in cybersecurity. With 61% employment growth (in cybersecurity) in the Ruhr, the actual development of employment was below the national average of 72% from 2008 to 2020. The same holds true for the Saarland, the other lagging region, with 33% growth. The three prosperous regions show private sector specialisation in cybersecurity and an average

growth of cybersecurity employees. Outlining these results, it is important to highlight that our method does not analyse cybersecurity directly but rather ICT specialisation.

Table 3: key quantitative indicators of leading cybersecurity regions in Germany.

	Research output [1)]	Security start-ups 2010 - 2020 [2)]	Private sector employment in cybersecurity as percent of total employment (2020) [3)]	Employment development between 2008 – 2020 [3)]
Ruhr Region	HGI rank 9, MPI rank 29	14	0.39%	+61%
Saarland	CISPA rank 2	2	0.39%	+33%
Darmstadt & Region	University of Darmstadt 15	16 (Federal State Hessen)	0.98%	69%
Munich & Region	not in top 150	35	1.35%	+68 %
Bonn & Region	University of Bonn 135	n.a.	0.80%	+65%
Germany	n.a.	194	0.47%	+72%

[1)] Source: https://csrankings.org: region: "world" in the categories: "computer security" and cryptography"; years: 2011 to 2020.
[2)] Source: Bundesverband deutsche Startups e.V. (2020): dealroom database; start-ups in "security" maximum 10 years old.
[3)] Source: Bundesagentur für Arbeit, special evaluation of Regionaldirektion North Rhine Westphalia: own calculations.

We have analysed the reputational computer science ranking (CS-Ranking) in the research fields "computer security" and "cryptography" to assess research excellence. The analysis confirms the research excellence of the Ruhr (esp. Bochum) in terms of cybersecurity, as Bochum hosts two research institutes in the top 30 CS-Rankings worldwide (the HGI at place 9 and the MPI at place 29). Saarland (CISPA at place 2) and Darmstadt (in 15th place) also host world-leading research facilities in cybersecurity. The cybersecurity regions Bonn and Munich fall behind substantially according to these rankings that measures success in basic research. They may still be very strong in applied or private sector funded R & D in cybersecurity.

We used a study of the Bundesverband Deutsche Startups to analyse founding activities in cybersecurity (Bundesverband Deutscher Startups 2020). According to this study, with 14 start-ups in 10 years the Ruhr cybersecurity ecosystem performs comparatively well,

i.e. it outperforms Darmstadt and Hessen, where Frankfurt is usually also a hotspot for start-ups, but falls behind the start-up hotspot Munich with 35 new start- ups. From our primary company data, we identified over 20 start-ups in the Ruhr in the last 10 years, suggesting that the Bundesverband study underestimates the actual business foundations in the region.

Overall, our data analysis supports the perception of the interview partners that a lively entrepreneurial ecosystem has emerged in the Ruhr. However, the private sector activities of the ecosystem have only limited effects on the industrial structure from a quantitative point of view. The fact that cybersecurity itself is still a niche market, though one that is rapidly growing (Hryhorivas and Leglers 2019, Bitkom 2020), in large part explains the limited effect on the industry structure. Public sector employment of the universities and research institutions (e.g. the MPI will host over 200 researchers when fully established), as well as employees of the accelerators, network organisations and business promoters cannot be measured with the statistic. However, they substantially contribute to the income and employment impact of the ecosystem for the region.

Finally, to fully understand the regional development contribution of the ecosystem, the impact of cybersecurity on the regional identity and the image of the region needs to be considered. Cybersecurity actors highly identify with the ecosystem, be they founders, employees, scientists, municipal employees, or local politicians. They are proud of the research excellence and distinct start-up activities, i.e. of having a dynamic ecosystem, despite being a lagging region. The interviewed founders of start-ups consider themselves as an active part of the ecosystem and a role model for the next generation. Interviewed senior employees of incumbent firms proudly acknowledge the positive development over the last twenty years and some of them actively engage in the ecosystem development, e.g. as members of network organisations. The recent project “eurobits women academy” was co-developed by the head of public affairs of secunet AG and our project InSicht.Ruhr was extensively supported by a computer scientist from G Data. The economic development agencies of several cities have also dedicated attention and project

activities to cybersecurity. Especially the City of Bochum commits own employees to cybersecurity and support a cybersecurity network organisation with staff and money.

For citizens, the dynamic development is visible in the built environment. Cybersecurity activities cluster at several sides in the Ruhr. Especially the 70 hectares area Mark 51°7 in Bochum – a brownfield of the abandoned Opel car factory – is being developed as a visible cybersecurity campus. The new MPI, labs of the Ruhr University Bochum and several cybersecurity companies like ESCRYPT/Bosch and start-ups like Physec will be located there (Bochum Perspektive 2021). Mark 51°7 receives considerable attention of local media and citizens, as Opel was an important employer in Bochum and the area development is very successful with 73% of the space being sold within seven years (Bochum Perspektive 2021).

The ecosystem's impact on the image of the Ruhr is divergent, according to the interviewees. Some actors claim that cybersecurity is one of the best kept strengths of the Ruhr; other highlight that due to the HGI, Bochum and the Ruhr are globally known as centre for cybersecurity in the community. Commercial development successes, especially Mark 51°7 and continuous start-ups will likely booster cybersecurity´s contribution to a positive image of the Ruhr as a high-tech region. However, it is too early to make a final assessment here.

IV Discussion and Conclusion

Our critical discussion of new and alternative development approaches for left behind places was motivated by the successful development of the cybersecurity ecosystem in the former mining region Ruhr. While supporting the new attention for left behind places and the emphasis on quality of life and social development goals, we see a danger that cutting edge (publicly funded) research and high-tech sectors are left behind by the alternative approaches for lagging regions. Conceptually, the new focus on the foundational

economy and regional needs tends to amplify homogeneous economic structures in lagging regions and new impulses to regional development may be minimised if universities "over adapt" to their lagging region.

As demonstrated by the genesis of the cybersecurity ecosystem in the Ruhr, initial research funding can spark dynamic ecosystem development and is a reason why talented researchers and entrepreneurs (or both in one person) settle in, return to, or remain in a lagging region. This research laid the foundation of today's successful ecosystem. Therefore, attracting researchers and research-oriented entrepreneurs to lagging regions increases the likelihood that change agents settle and stimulate new development there. Research excellence needs substantial public funding and its impact on regional development is uncertain and often only pays off in the long term. After all, the Ruhr University Bochum was already founded in 1962 and is one of the largest universities in Germany in terms of students. Furthermore, substantial luck was involved in the successful development of the ecosystem (i.e. the settlement of HGI, the entrepreneurial orientation of the first generation of academics, the rapid economic development of the cybersecurity niche). Still, establishing and supporting excellent research and universities in lagging regions increases the chance that such change agents settle and dynamic high-tech ecosystems develop.

Regardless the positive development of the cybersecurity ecosystem, its direct contributions to the regional economy are limited. Only 0.39% of Ruhr's total employment is in the private cybersecurity sector in 2020 and public research and private industry alike predominantly employ highly skilled persons. Furthermore, the ecosystem development heavily depended on public funding be it for the permanent research positions (e.g., to the estimation of one interview partner, the HGI has consumed over 100 million euros of permanent public funding until now), third party funded research projects, the start-ups support activities or the regional development projects. Considering the tremendous costs of cybersecurity ecosystem development against limited direct benefit for other Ruhr residents, alternative development approaches may rightly criticize the inefficiency of high-tech development strategies for lagging regions.

To counter this argument, first only a very small percentage of the public money spend for the cybersecurity ecosystem is actually funded by the municipalities of the Ruhr, e.g. for the own shares in state sponsored regional development projects. Rather, the cybersecurity researchers raise funds in national and EU research competitions and if not in the Ruhr, these funds would otherwise be spent in other regions. Cutting-edge and high-tech R&D is costly, be it in developed or in lagging regions. Not letting high-tech behind, gives lagging regions a fair chance to get a share of the huge budget amounts for cutting edge research. Second, a fair assessment of the efficiency of high-tech development strategies in lagging regions must also consider the expenditures of alternative approaches that depend on permanent public funding, too. Out of this funding, a substantial share needs to be financed by the municipalities, at least in the German case. Hence, sufficient local tax revenue is a support factor for the foundational economy and trade tax revenue depends on private sector profit. Without denying the importance of the foundational economy for regional economies and quality of life, development strategies that focus solely on this economy seems myopic from a fiscal point of view.

In addition, as the Ruhr case indicates, cutting-edge science and high-tech sectors contribute to positive identification with a lagging region. Even if only partly perceived by the general public, professionals of the ecosystem, regional development and politicians witness the scientific success and start-up dynamics and are motivated to further engage in the Ruhr. Although it is still too early to fully assess the positive identification aspect of the cybersecurity ecosystem for the Ruhr, it seems plausible that positive identification is not an exclusive argument for alternative development approaches.

Overall, our discussion suggests a combination of alternative and conventional development approaches for the development of left behind places. One by which the impulses from the debate on alternative development should not be considered as a rejection of conventional development approaches. Left behind places need both, quality of life with a strong foundational economy, and the chance for new impulses and the development of new industries. For new impulses, the permanent funding of well-equipped universities and research institutions appears important. Not every peripheral and sparsely populated region can host a university and world class research institutions. Specific grants for

research in lagging regions could support emergence of novel fields. They should truly be open and not impose templates on what works and what does not work for the development of lagging regions.

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