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Automotive regions in transition: preparing for connected and automated vehicles

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Abstract

The advent of 'connected and automated vehicles' (C/AV) is posing substantial transformation challenges on traditional automotive regions across the world. This paper seeks to examine both conceptually and empirically how automotive regions reconfigure their industrial and support structures to promote new path development in the C/AV field. Drawing on recent conceptual advances at the intersection of evolutionary economic geography and innovation system studies, we develop an analytical framework that casts light on how regional preconditions provide platforms for asset modification that underpin different routes of transformation. We distinguish between a reorientation route and an upgrading route. The framework is applied to a comparative analysis of industrial path development and system reconfiguration towards C/AV in two automotive regions, namely Ontario (Canada) and the Austrian automotive triangle.

Keywords

regional restructuring, new path development, asset modification, innovation system reconfiguration, connected and automated vehicles

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1 Introduction

Over the last decade, rapid advancements have been made in the field of connected and automated vehicles (C/AVs). Together with other mobility innovations such as battery electric engines and car sharing, C/AVs pose significant transformation challenges for traditional automotive regions. This article addresses the question of how these regions are reinventing themselves to remain important automotive locales in the era of C/AVs. More precisely, our aim is to deepen understanding of the ways in which such transformation processes take place and why they differ across regions.

Arguably, the question of how regions respond to path-breaking innovations and why they show varying transformation capacities has long been on the research agenda in Economic Geography and related disciplines. Recent work has begun to extend conventional Evolutionary Economic Geography (EEG) models, arguing for a systemic approach to innovation-based regional structural change (Binz et al., 2016, Trippl et al., 2020). This literature shows that such dynamics vary considerably across regions, reflecting highly differentiated opportunities and capacities to adapt industrial structures and the wider innovation system.

To advance understanding of variegations in regional capacities to embrace radical change, we develop an analytical framework that places varying regional preconditions at center stage and links them to asset modification processes that underpin new industrial path development and rearrangements in the organizational support structures and institutional configurations. Such change processes could come in different shapes. We contrast two routes of transformation, that is, a 'reorientation route' and an 'upgrading route'.

Taking Ontario (Canada) and the Austrian automotive triangle as empirical case studies, the article illustrates the different routes that traditional automotive regions are taking as they strive to cope with the advent of C/AVs. The reorientation route is found in Austria, where automotive and microelectronic firms pursue path renewal and diversification strategies, backed by re-alignment processes taking place in a well-established innovation system. The upgrading route is prevalent in Ontario, where C/AV development is driven by IT firms and an enormous expansion of organizational and institutional support configurations in fields such as IT and artificial intelligence.

The remainder of this article is structured in five parts. The next section synthesizes key propositions of the systemic approach to innovation-based regional restructuring and develops an analytical framework. Section 3 presents the results of our empirical investigation of C/AV development in Ontario and the Austrian automotive triangle. This is followed by a comparative analysis. Finally, section 4 concludes.

2 Innovation-Based Regional Restructuring: Systemic Conceptualizations and Routes of Transformation

Expounding how regional structural change unfolds across space and over time is a major focus for EEG research (Martin, 2010; Boschma, 2017). Over the past few years, a growing body of work on what is called 'new regional industrial path development' (Isaksen and Trippl, 2016; Steen and Hansen, 2018) has contributed to a granulated understanding of why some regions succeed in rebuilding their economic structures whilst others fail.

2.1 Systemic approach to innovation-based structural change

EEG models have significantly contributed to explaining the spatially contingent nature of regional structural change. Recent scholarly work has begun to complement the EEG literature, scrutinizing new path development activities from a systemic perspective (Binz et al., 2016; Trippl et al., 2020). Systemic conceptualizations propose several advancements over conventional perspectives (Hassink et al., 2019) that help to understand how technological and other forms of disruptions trigger substantial changes in existing, long-established industrial paths.

Systemic perspectives move beyond narrow firm and industry-led explanations advocated by traditional EEG models and argue for incorporating changes in the wider innovation system into analyses of innovation-based regional industrial path development. They highlight that regional industrial dynamics promote instability and change in the organizational and institutional support arrangements that are usually – albeit to different degrees – aligned to existing industrial paths. Put differently, new path development is inextricably linked to a transformation of the support structures of innovation systems. Systemic conceptualizations thus call for the adoption of a multi-actor approach that considers multiple firm and non-firm actors and the manifold roles they play in facilitating new path development and innovation system reconfiguration. Non-firm actors such as higher education institutes, research organizations, innovation intermediaries, policy makers, and industry associations (Dawley, 2014; Vallance, 2016) have been found to influence path development in distinct ways. They may contribute to the reproduction and – even more importantly – modification of industrial, human, institutional and infrastructural assets (Maskell and Malmberg, 1999; MacKinnon et al., 2019) that underpin restructuring efforts.

Asset modification may come in different shapes, including (i) the redeployment and recombination of existing assets; (ii) creation of new assets in the region and/or the importation of assets from elsewhere; and (iii) the (strategic) destruction of old assets (MacKinnon et al., 2019; Trippl et al., 2020) and is seen as the result of the agency exerted by multiple firm and non-firm actors (see above). Asset modification manifests itself in the generation of new (or re-combination of existing) technological and non-technological knowledge, development of the skill base, adaptation of regulatory frameworks, legitimation efforts, market formation, financial investments, and so on.

Since it is a large variety of actors that take part in asset modification, the issue of how such processes are 'orchestrated' is a pivotal question. Orchestration points to the capacities of (groups) of actors (within the region and/or beyond) to initiate the development of widely shared visions and joint strategies and to coordinate firms' and non-firms' activities in strategic ways. Asset modification and orchestration are thus crucial dimensions of new path development and RIS reconfiguration.

2.2 Unpacking change processes in the industrial and support structures

Recent conceptual and empirical studies suggest that change processes in the industrial and support structures are shaped by previous rounds of path development. Much emphasis is placed on regional preconditions such as the inherited regional asset base, historically grown industrial structures, organizational support structures and institutional configurations (Martin, 2010; Trippl et al., 2020). Consequently, transformation processes will vary significantly across different socioeconomic and institutional regional contexts, reflecting different initial conditions. We maintain that these initial conditions provide platforms for asset modification processes that undergird distinct outcomes in terms of new regional industrial path development and innovation system reconfiguration.

Industrial structures/firm sector: Recent contributions provide a nuanced understanding of regional structural change, distinguishing between different forms of new regional industrial path development such as path renewal, diversification, importation and creation (see, for instance, Tödtling and Trippl, 2013; Isaksen et al., 2018). This serves as a stepping stone for capturing different types of change processes in the industry structures/firm sector of regions. Such processes might reflect path renewal activities. In this case, asset modification is fuelled by established firms belonging to the industrial path that faces disruptive innovation. Such 'on-path' changes (Baumgartinger-Seiringer et al., 2019) require strong capacities to engage in renewal activities that push the industry into a new direction by introducing new technologies and other innovations. Asset modification may also be driven by path diversification endeavors of established firms from other sectors, which move into a new field, or by start-ups and their path creation activities. Finally, the transplantation of assets from elsewhere could play a critically important role, pointing to path importation as a way to cope with radical change.

Organizational and institutional support structures: As noted above, a system approach to innovation-based restructuring acknowledges that changes in the organizational and institutional support structures are vital to provide firms that pursue new path development activities with the needed assets. Support structures may be strongly or weakly developed and they may show different degrees of alignment with the industry under consideration (Baumgartinger-Seiringer et al., 2020). There are strong reasons to suggest that a reconfiguration of support structures takes place in different forms depending on these characteristics.

2.3 Routes of transformation

Employing a systemic approach as outlined above, we distinguish between two different routes of transformation, namely a 'reorientation route' and an 'upgrading route'. The route taken will depend on initial conditions inherited from previous rounds of regional development that provide a point of departure for innovation-based new path development processes. These conditions come in form of the industry mix, the innovation and adaptation capacities of domestic and foreign firms and their embeddedness in the region. The ways in which regions are inserted into global production networks (MacKinnon, 2012; Yeung, 2015) also matter, shaping the room of maneuver (autonomy over new product and process development) of subsidiaries and the role played by MNEs in asset modification. Quality and alignment of the organizational configurations of the support system and the institutional and policy capacities (financial resources and power of the regional policy actors in multi-level governance arrangements) constitute essential initial conditions. They vary across regions and will influence asset modification and orchestration.

Accordingly, the 'reorientation route' will likely take place in regions hosting a well-established and strongly embedded industrial path under consideration. The main impulse for transformation is expected to come from path renewal efforts of traditional firms seeking to reorient themselves to cope with radical change. This is often complemented by diversification endeavors of firms in other paths. On the one hand, the well-developed support structures – often strongly aligned to the needs of established firms – provide assets for new path development activities. On the other hand, however, the support system itself will require major modifications and reorientation. Adherence to historically developed assets unable to reorient and rigid ties between different structural elements might hamper the initiation of change in such settings (Grabher, 1993). Structural elaboration and alignment might thus be both a blessing and a curse at the same time (Baumgartinger-Seiringer et al., 2020).

In contrast, the ‘upgrading route’ is expected in regions with either a relatively weakly developed industrial path under consideration or one that is poorly embedded in innovation system structures. Support structures are either well elaborated but weakly aligned or weakly developed altogether. Despite these conditions, such regions might be attractive locations for transformations. Changing context conditions, for instance in the form of radical innovation, might open new windows of opportunity and reveal regional potentials (e.g. in form of a well-developed complementary industrial path, previously unexploited assets, etc.). To benefit and draw on new potentials, upgrading and alignment efforts in both the firm sector and the support structures are necessary. Industrial restructuring might be driven by diversification efforts of firms in complementary paths. Organizational and institutional structures to support ‘system upgrading’ are newly established or existing elements re-aligned to new requirements. Building up new system assets and embedding paths facing disruptive change into the RIS are challenging tasks that may take time.

3 Empirical case studies

In this section, we analyze new industrial path development activities and processes of innovation system rearrangement towards C/AVs in two regions, namely Ontario (Canada) and the Austrian automotive triangle. These regions have been selected for a comparative case study analysis for two reasons. First, they share some important similarities. Both Ontario and the Austrian automotive triangle (made up of the provinces of Styria, Upper Austria and Vienna) are traditional automotive supplier regions characterized by the absence of domestic OEMs. Second, despite these commonalities, the two regions differ markedly in terms of innovation capabilities residing within the automotive sector and – equally important – within complementary industrial paths. They also differ in terms of their historically grown organizational and institutional support structures. This creates varying preconditions for coping with the advent of C/AVs, allowing for empirical examination of the conceptual propositions outlined in section 2.

3.1 Methods and data

The findings from Ontario are based on forty qualitative interviews with Ontario companies, intermediaries and policymakers, participant observation in meetings between various stakeholders in the innovation system and a review of primary and secondary literature over two years (2016-2018). One of the authors also participated in an expert panel reviewing the current and potential impact of the advent of C/AVs on the automotive sector. Our empirical analysis of the Austrian case draws on twenty-five in-depth interviews conducted with representatives of Austrian firms, research organizations, intermediaries and policy stakeholders in the first half of 2019. To complement the interviews, an intensive document analysis has been carried out. Additionally, participant observation in conferences contributed to further robustness. Transcribed interviews for both case studies were analyzed using a content analysis of themes that emerged from the interviews.

3.2 The case of Ontario

Ontario is a traditional automotive region with considerable strengths in parts production and vehicle assembly. Since early investments by US-American MNEs and conclusion of landmark trade agreements such as the Canada-US Auto Pact in 1965 and the North American Free Trade Agreement (NAFTA) in 1993, the automotive sector has been one of the main drivers of growth in the provincial economy (Anastakis, 2005). Although automotive production has fallen 25 per cent from its peak in the early 2000s, it was still the largest automotive region in North America in 2017, with nearly 2.2 million vehicles produced, accounting for 18.5 per cent of manufacturing GDP. Ontario hosts five original equipment manufacturers (OEMs), over 700 parts producers in the supply chain plus 500 tool, die and mold makers, with 85 per cent of the products exported (Ontario, 2019).

Initial conditions

A series of disruptions in the North American automotive industry since the early 2000s, including the increasing shift of vehicle production to southern US states and Mexico, the impact of the 2008/09 financial crisis and shifts in consumer demand, pose a significant challenge for the sector (Yates and Holmes, 2019; Klier and Rubenstein, 2013).

Preconditions for renewal activities towards C/AVs in the region's automotive industry are mixed. Historically grown production structures, most notably the dominance of subsidiaries with limited innovation capabilities and mandates and suppliers doing most of their innovation activities abroad, have created rather weak preconditions for renewal activities. The region has traditionally prioritized production over innovation-related activities (Anastakis, 2005). Due to the absence of any domestic OEMs, Ontario's automotive industry has limited room for maneuver and autonomy over new product and process development. Additionally, the region does have a number of leading Tier 1 suppliers, including Magna International, Linamar, Wescast, ABC Technologies, and Martinrea. A key challenge for the region is that these suppliers have historically performed limited automotive/mobility R&D in Ontario and have arms-length interactions with regional actors (Gertler and Wolfe, 2004), implying that their innovation and renewal activities would not benefit the region.

In recent years, however, constraining conditions for path renewal have gradually been changing towards more enabling ones. On the one hand, the rapid growth of the ICT sector in the region provides new opportunities for renewal activities in the car sector (see below). On the other hand, institutional conditions for renewal activities have been improved through various policy initiatives. In response to the overall decline in vehicle assembly, the policy domain has shifted the focus to expand the research infrastructure for automotive R&D investment and thereby enhance the capabilities of subsidiaries and domestic Tier 1 suppliers. Hence, policies were increasingly designed to fuel the transition towards more knowledge-intensive tasks. In this regard, the federal government has worked to attract R&D through programs such as the Automotive Innovation Fund and the Automotive Supplier Innovation Fund, which provided financial incentives for MNEs to research greener and more fuel-efficient vehicles in Canada and Ontario (Holmes et al., 2017; Rutherford and Holmes, 2007). Automotive-focused policies were supported by broader funding programs to incentivize university-industry collaboration. These programs have included the Network of Centers of Excellence to close the gap between industry and academia and support the commercialization of research (Doern et al., 2016; Doern and Stoney, 2009). Funding for university research infrastructure also accelerated during the 2000s through the Canadian Foundation for Innovation (CFI) and the federal government's Knowledge Infrastructure Program.

Ontario is also home to one of the largest concentrations of information technology firms in North America. As noted above, this may well benefit path renewal activities in the automotive sector. At the same time, it creates strong conditions for diversification activities into the C/AV field by ICT firms themselves. Ontario's vibrant and R&D-driven ICT sector is spatially concentrated in three cities. Ottawa's digital economy offers access to hardware skills and experience, which allows companies to develop reliable networking technologies underlying the internet of things. Ottawa hosts R&D and production activities by established foreign firms (Alcatel-Lucent, Cisco Systems Canada, Huawei Technologies Canada, CIENA Corporation and Mitel Networks) as well as a number of newcomers (Corsa Technologies and CENX) and domestic leaders like QNX, a subsidiary of Blackberry (Haley et al., 2017). Toronto is one of the foremost hubs for artificial intelligence with Google, Uber, Nvidia, LG and Samsung all opening artificial intelligence (AI) labs in the city to tap into its leading position in machine learning and deep learning. The federal and provincial governments have strengthened this position by providing support for the Vector Institute, designed to expand the depth of research in AI (Denney et al., 2018). Finally, Kitchener-Waterloo has strengths in various ICT segments (including communications equipment manufacturing, software etc.) and is also home to the headquarters of large domestic technology companies like Blackberry Open Text and hosts one of the most vibrant start-up scenes in the region. In terms of the support structures, a vibrant system of leading research universities, incubators and accelerators, public entrepreneurship support programs, large pools of skilled workers and strong civic and industry associations are found, creating favorable conditions for path diversification.

Asset modification for C/AVs: The firm and industry level

Many interview partners stated that the future of the automotive industry in Ontario would lie in the region's ability to capitalize on the expertise residing within the ICT sector. In other words, the progressive digitization of the automotive industry reveals new potential in Ontario's regional asset base for automotive players to draw upon. Asset modification for renewal activities includes forging inter-path linkages between the automotive and the ICT sectors and enhancing the historically weak embeddedness of automotive companies in the RIS. This is evidenced by new investment strategies by MNEs and attempts to enhance university-industry partnerships.

In order to tap into the region's valuable ICT assets, the MNEs and Tier 1 suppliers seek to forge a growing range of alliances with the numerous ICT start-up and scale-up firms that are developing technologies for C/AVs. Furthermore, the MNEs are shifting the locus of their regional investment strategy away from vehicle assembly towards automotive and C/AV R&D. This strategy involves drawing upon the considerable capabilities of the regional post-secondary education system and the high quality of labor power, especially in the computer science, electrical engineering and related sciences. Accordingly, the future development and production of C/AV solutions in Ontario will require complex asset modification processes of traditional automotive actors – including OEMs, Tier 1 suppliers, systems integrators and solution providers – but also of the region's ICT actors.

Both GM and Ford are among the more active foreign OEMs who have announced major expansions of their R&D in C/AV related activities and a significant enhancement of the local human asset base. GM is expanding its Canadian Technical Centre in Toronto in close vicinity to major research centers by IBM, Huawei and others. GM has indicated that its goal is to employ 1,000 research engineers in the Centre within the next few years. It recently announced the conversion of its old Oshawa assembly plant to a test center for C/AVs and is building a new urban mobility research center in downtown Toronto to test urban mobility solutions. For its part, Ford recently announced the opening of its Ottawa Research and Engineering Centre, staffed with 300 former Blackberry employees, as well as its Waterloo Innovation Centre to help develop connectivity and infotainment software for its SYNC 3 technology that allows users to perform tasks with voice commands. It is housed in an old Blackberry building adjacent to the University of Waterloo campus (Paglinawan, 2019; St. John, 2019). Although the fundamental R&D decisions about future directions of firm strategy and decisions about new product to be allocated to Ontario are made at the MNE corporate headquarters, (e.g. in Michigan), there is growing evidence that the subsidiaries – by drawing on and bolstering the existing assets in the region – have enjoyed recent success in expanding the range of R&D activities, as well as building links to the vibrant ICT sector.

The weak link within the region's automotive industry continues to be the domestic Tier 1 suppliers who have only allocated 18 per cent of new R&D activities to facilities in Southern Ontario compared with 45 per cent in Michigan and 36 per cent in Germany and Austria (Carey, 2019). Magna, the largest Tier 1 supplier, maintains an electronic research center in the Toronto region, but is conducting most of its C/AV research in the US. The exception is Linamar, which recently announced a major investment in a new innovation center working on advanced manufacturing technologies.

The region's ICT sector does not only support path renewal activities in the automotive industry but is also moving itself towards the C/AV space. Both domestic and foreign ICT companies have been expanding their R&D capabilities in the artificial intelligence and 5G mobile technologies that are critical for the emerging field of C/AVs. Blackberry has opened an innovation center for AVs and is working with the University of Waterloo to test self-driving technology. Uber's AI research lab in Toronto complements this indigenous research, drawing on research strengths at the University of Toronto. QNX continues to conduct its world leading research in operating systems in Ottawa and Apple has quietly opened a major research center in Ottawa. Finally, telecom companies in the region have made substantial investments in a $400 million public-private network (ENCQOR) to promote and co-ordinate research into 5G technologies, including their potential for adoption in C/AVs.

The region also hosts a pool of tech (predominantly SME) companies, who are developing a wide array of new C/AV related technologies, but who face high entry barriers to new mobility markets. They don't just produce in-car technologies, but also help create solutions for sustainable public transportation systems (e.g. route optimization for fleets) and build the intelligent infrastructure needed for connected vehicles (traffic data collection and analysis). One example is Leddartech, a Quebec company that recently opened a research lab in Toronto to expand its research on Lidar technology. Our interviews suggest that in these initial stages, niche firms are pivoting between different markets, including automotive, intelligent transportation services (ITS) to expand their customer base, since their products and services have broad applicability.

Asset modification for C/AVs: The innovation system level

The continued success of Ontario in the transformation towards C/AVs will not only depend on firm-side asset modification but also on the vital role played by a wide range of system-level actors, including all three levels of government, post-secondary education organizations, intermediaries, and industry associations. Those actors are playing an increasingly active role in shaping asset modification and upgrading the innovation system for C/AV development to unfold.

Governments at multiple levels have attempted to mobilize resources and stakeholders to stimulate concerted action and promote collective strategies in the C/AV space. One goal of these orchestration efforts is to increase the historically weak MNEs' embeddedness in the innovation system and encourage them to undertake more of their R&D activities and ultimately product development and production in the C/AV space in Ontario.

Increased investments in the postsecondary research infrastructure has expanded the base of automotive research capabilities and increased the familiarity of the local subsidiaries with those capabilities. At present twenty-four Ontario colleges and eleven universities offer auto-related research initiatives and training programs, which are growing the talent pool graduating from those institutions (Ontario, 2019). Subsidiaries are exploiting the increase in local university research capacity and qualified graduates to lobby their parent companies for the additional R&D mandates in Ontario discussed above (Goracinova and Wolfe, 2019).

The provincial government has also played a key role in developing the region's capabilities in C/AV technology. In 2016, Ontario launched a ten-year pilot program to allow the testing of automated vehicles on Ontario's roads. In 2017, the initiative evolved into the 5 year, $80 million, Autonomous Vehicle Innovation Network (AVIN). It funds training, later-stage R&D projects and has created six regional technology development sites (RTDs) dedicated to specific aspects of C/AV technology and strategically located throughout the region.

In addition to these provincially led efforts, the federal government has launched the $3 million program to Advance Connectivity and Automation in the Transportation System (ACATS). This funding helps the provincial Ministry for Transportation to plan for and develop the capacity to implement automated and connected vehicles in the Greater Toronto and Hamilton areas.

State and non-state intermediaries initiated local action to develop a new bottom-up socio-technical vision for Ontario. They play a central role in asset orchestration. Since 2017, both the Waterloo and Ottawa regions have been framed as Autonomous Vehicle clusters. In each case, intermediaries are collaborating to deepen connections. Waterloo's economic development agency partnered with Ontario's automotive parts manufacturer's association (APMA) and have recently announced Project Arrow to showcase the capabilities of Ontario SMEs in C/AV technology. In Ottawa, the region's business association (Kanata North) and foreign investment attraction agency (Invest Ottawa) have partnered with QNX, the city and academia with the goal to establish Ottawa as Canada's AV capital.

Emerging outcomes and challenges

There are considerable efforts underway to accelerate the transition of Ontario from its historical role as a traditional automotive producing region to a new research and development center for C/AVs. Upgrading processes are driven by diversification activities of a dynamic domestic ICT sector and AI and other capabilities residing within the organizational support system that has been expanded over the past few years.

Strong policy initiatives have created incentive structures for different actors to work and partner in the C/AV space and both automotive firms, including GM, Ford and a growing number of foreign and domestic ICT firms are responding to the perceived opportunity by expanding their research efforts in the region. Yet, MNEs differ in their willingness to engage in collaborations with local ICT companies and universities. Global ICT domestic and foreign companies are more open than automotive OEMs and Tier 1 suppliers. The latter have exhibited limited interest in the mobility applications emerging from the Canadian ICT sector so far. ICT companies' more vibrant history with R&D in the region and embrace of open innovation makes them more accessible to regional actors.

Current developments underway in the C/AV space in Ontario reflect a growing degree of embeddedness of automotive and in particular ICT firms in the regional innovation system. C/AV-related innovation activities are occurring in pockets across the region in both small and large enterprises in the automotive and ICT sectors. Orchestration of asset modification is distributed among various actors and appears to take place in a bottom-up manner. Changing Ontario's position in global automotive production networks is a challenging task, but the underlying dynamism of the region's ICT industry gives it a competitive edge that may enable changes. Notwithstanding, a key challenge for the region is to continue to increase the historically low levels of automotive/mobility R&D that the OEMs and Tier-1 suppliers have performed in the region (Gertler and Wolfe, 2004).

3.3 The case of the Austrian triangle

The automotive industry is a key engine of the Austrian economy. In 2018, almost 400,000 employees (10 percent of the Austrian workforce) were working in companies directly or indirectly connected to the automotive industry (Kleebinder et al., 2019). The industry shows a strong geographical concentration in the provinces of Styria, Upper Austria and Vienna, here referred to as the Austrian automotive triangle. The Austrian automotive industry counts over 700 companies and covers large parts of the value chain. It hosts a number of internationally recognized firms such as AVL List, Magna Steyr, KTM or BMW's engine plant.

Initial conditions

Although Austria is not home to any domestic automotive OEMs, there are favorable conditions for path renewal. The Austrian car industry is characterized by its historically grown supplier structure and strong ties to German OEMs. It exhibits a strong innovation capacity. Per capita, only Germany applies for more patents in Europe in the automotive sector. The R&D expenditures are among the highest in Europe. In 2016, not fewer than 62 percent of the automotive firms were reporting research collaborations with universities and other research organizations (Statistik Austria, 2016). With nearly 90 percent of their products being shipped abroad (of which 75 percent to other European countries), Austrian automotive firms show a strong export orientation (WKO, 2019).

Additionally, there are enabling conditions for path diversification. Austria hosts an innovative microelectronics industry that is strongly interwoven with the automotive industry. Firms such as Infineon (semiconductors), NXP (microelectronics), AT&S (circuit boards), and AMS (sensors and chips) create large shares of their revenue with their automotive segments. These firms recognized early the importance of system understanding and consequently find themselves in promising positions to contribute to and profit from the transformation towards C/AVs.

The microelectronics and automotive paths are backed by thick innovation system structures. Especially the automotive industry exhibits a strong embeddedness in a highly elaborated organizational support structure, including research institutes, technical universities, cluster organizations and other intermediaries, lobbying organizations and so on. This holds true for both domestic and foreign players in the automotive field (Trippl and Otto, 2009). Given the large number of employees, policy actors have been showing a strong willingness to support the industry. Many interviewees pointed to a '*special culture of cooperation*' (firm representative) between automotive firms, support organizations and policy. For example, long-standing relations between firms and universities have led to strong alignment of the research and educational system to the needs of the automotive path. Various networking initiatives like 'innoregio styria' and cluster organizations provide platforms for exchange between stakeholders from different domains and are often supported by policy programs.

While most interviewees emphasized the positive dimension of these strong ties, others expressed concerns over negative lock-in effects (Grabher, 1993). In relation to the recent emission scandal, our interviews point to a system that "saw itself in a state of satisfaction" (firm representative). Authorities, firms, engineers and other actors formed a system that slowed itself down.

Asset modification for C/AVs: The firm and industry level

Climate change, the emission scandal and the diminishing importance of cars as a status symbol have led to skepticism about the automotive industry and its future role as a key sector of the Austrian economy. Consequently, many players in the automotive field welcome the advent of C/AV. Actors are almost embracing the uncertainty brought by digitalization, considering it as a way to cope with the threat of a downturn. Many Austrian suppliers see the shift from hardware and classic mechanical engineering to software as an opportunity for them to grow again and to reposition themselves within the value chain.

This holds true especially for larger R&D-driven supplier firms in both the automotive and microelectronics industry. Yet, moving into new business fields requires substantial asset modification processes. This implies the creation and redeployment of human and industrial assets (in form of retraining the work force, recruitment of IT specialists, mergers and acquisitions, etc.). The Styrian firm AVL, the world's largest independent company for the development, simulation and testing of drive systems, has announced various strategic partnerships (among others with the visual computing company Nvidia and the cyber security firm Kaspersky). AVL has also reported high job growth rates in its ICT and C/AV-related fields, but due to a lack of human assets (see also below), AVL is growing faster in other regions than in Styria. The Austrian branch of Bosch (located in Vienna) has recruited a large number of IT specialists and now employs almost 1,000 experts working at the interface between hardware and software domains. Even firms one would not associate with self-driving cars are moving towards the C/AV space and have established broad portfolios of products. For instance, ZKW, a lighting systems company, has developed headlights for automated driving equipped with sensors in strategic positions to provide a 360-degree view around the vehicle.

Digitalization and transformation towards C/AVs and the increasing importance of new powertrains and mobility services force larger suppliers to apply an expensive and high-risk 'catch-all' strategy. Our interviews have shown that even traditional automotive suppliers with historically developed expertise in traditional areas of car development and production are increasingly considering themselves as software firms. C/AV constitutes the fasted growing field (in terms of employees) in many of these firms.

However, such transitions are not frictionless. Concerning informal institutional assets or "ways of doing things", the automotive path and the IT industry have been described as two wheels rotating at different speeds. Particularly the historically developed values of predictability and determinism are often incompatible with IT and especially AI methods. Once trademarks of the industry, they are now turning into barriers. After several failures in bringing together these 'two worlds', many large companies have recognized the necessity for changes in firm culture. The introduction of flat organizational structures, a 'trust instead of control'-policy, the elimination of core working hours, self-organization models, and shared desk concepts are just representations of the underlying change in culture.

Industrial asset modification is also strongly driven by innovative and agile microelectronic firms. Some of them belong to and operate in several industrial paths. In 2019, Infineon generated 44 percent of its revenue in the automotive segment. The firm is investing over one billion Euros in new plants in Austria. Parts of this investment are designated to expand development capacities in Linz for driver assistance systems. AT&S has invested 40 million Euros in its sites in Fehring (close to Graz) and Nanjangud (India) to expand the production of high-frequency printed circuit boards. These are used in sensors for distance measurements that are crucial for C/AVs. The Styrian chip manufacturer AMS is among Austria's most R&D-intensive companies (300 million Euros worldwide in 2019) and has recently announced that – due to the growing demand for sensors for C/AVs – the company's future lies in the automotive segment. Based on their experience in system thinking, new investments and new strategic alliances, the microelectronic firms are able to reposition themselves and become strategic partners of OEMs.

However, small suppliers with limited financial capacities and those that are positioned in value chains connected to traditional combustion engine powertrains face high entry barriers to C/AV-related fields. Therefore, several support organizations have begun to actively shape innovation networks and establish links between less innovative supplier firms and the IT industry. Initiatives like 'Connected Mobility' in Upper Austria or 'AutoContact' in Styria are just two examples of such efforts, which have however shown limited success to-date.

Asset modification for C/AVs: The innovation system level

Universities and research institutes play a pivotal role in current transformation processes. Currently, there are not fewer than 16 universities in Austria offering automotive-related training programs. What is more, almost 20 research organizations are working in the field of automotive technology, several more in closely related fields such as combustion engines or automation technology (Statistik Austria, 2020). These organizations have historically grown links to the firm sector, especially to larger and well-established companies. They engage in substantial asset modification processes as evidenced by the establishment of new endowment professorships for automated mobility in Linz, Graz and Vienna, large-scale reorientation in R&D centers like 'Virtual Vehicle' in Styria or the creation of the AUDI.JKU deep learning center in Linz. However, research institutes and universities in particular are deeply embedded in the Central European engineering culture and are often rather rigidly structured. An analysis of current engineering curricula shows that a strong focus on traditional competencies prevails. IT competencies such as data analysis or basics in software engineering are still largely neglected. Furthermore, our interviewees have expressed concerns over missing IT specialists in both academia and industry. Many consider this as one of the main obstacles for the current transformation in the Austrian triangle. It is in particular universities of applied sciences (*Fachhochschulen, FH*) that have begun to respond to this challenge. In 2018, the FH Campus Hagenberg close to Linz has started the new bachelor's program 'automotive computing' with the goal to bridge the gap between classical software engineering and road-based mobility. In 2019, FH Joanneum has started Europe's first master's program for 'system testing engineering'. The program is funded by firms (such as AVL, Magna, Infineon, NXP) and designed to address the rising complexity of interwoven software, electronic and mechatronic systems due to automated driving and 5G. Nevertheless, further asset modification processes in the research and educational system are required.

Moreover, our empirical analysis revealed a growing awareness concerning the future role of infrastructural asset modification for the transformation towards C/AV. Many interview partners have highlighted the importance of opportunities for testing[1] and the digitalization of the street (sensors, high-speed internet, cameras, etc.). This has led to a new role for Austria's federally owned infrastructural operator ASFINAG. ASFINAG has positioned itself early as an active player of this transformation. Today, Austria is in a pioneering role in terms of the adaptation of infrastructure (road network, fiber optics, sensor technology & monitoring, mobile radio, C-ITS). The case of ASFINAG additionally highlights the growing need for cooperation in the automotive field beyond only industry-industry partnerships. The recently launched cooperation between ASFINAG and the big German OEM Volkswagen to test direct exchanges of information between infrastructure and cars is an interesting case in this regard.

Another central non-firm actor is the Federal Ministry of Transport, Innovation and Technology (BMVIT). This is for two reasons. First, the BMVIT is responsible for monitoring necessary adaptations within the legal framework and serves as an important consultant for lawmakers. Second, and more importantly, the federal ministry plays an important role in coordination and vision-building activities.

With respect to the adaptation of regulations and other institutions to fit the technological possibilities, one can observe rather gradual changes. Some interview partners expressed concerns about the fundamental incompatibility of (especially AI-based) C/AV-technology with Austria's highly elaborated institutional structures of regulations and standards. Issues such as data privacy are contested fields. A trade-off between asset destruction and maintaining highest standards of traffic safety remains a key challenge for consolidating change, not only in Austria but also elsewhere.

Through coordination and vision building endeavors, the BMVIT has become the main orchestrator of transformation in Austria. It has established a separate administrative department for automated driving with the main agenda to balance the interests of stakeholders, to reduce ambiguities and to form a shared vision. With the help of an expert board and network meetings, two action plans (2016-2018, 2019-2022) have been developed. Cornerstones are the active role to be taken by the public sector, thematic funding[2] in areas like AI, adaptations of legal framework conditions, information, cooperation and the modification of infrastructure.

Emerging outcomes and challenges

In the Austrian automotive triangle transformation processes towards C/AV are well under way, even though many obstacles remain. On the one hand, C/AV development is driven by highly innovative automotive incumbents. However, not all automotive firms have the capacity to engage in path renewal activities. It is mainly larger firms with strong innovation capacities and financial power to pursue large-scale asset modification strategies, while most of the smaller firms have only limited resources and struggle to enter the C/AV field. On the other hand, firms in the microelectronic industry have begun to diversify into the C/AV segment.

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[1] ALP.Lab in Styria (2017–2022) and DigiTrans in Upper Austria (2018–2023) are two research projects allowing for real-world testing in Austria. The projects are run by both the key industrial players (like AVL and Magna) and research organizations.

[2] Key programs include 'Mobilität der Zukunft' (since 2012, 70 million Euro have been provided for more than 300 projects to facilitate holistic approaches to mobility through research and innovation), 'IKT der Zukunft' (launched in 2012, 42 million Euros have thus far been spent to push research and innovation in the field of ICT), 'KIRAS' (between 2007 and 2018 approx. 84 million Euros have been invested to advance the field of 'comprehensive security', and 'AIM AT 2030' (since 2012, almost 350 million Euro have been earmarked for projects in the field of AI).

Industry dynamics are supported by changes in the organizational and institutional support structures. Universities and research institutes capitalize on their historically strong ties to the industry to play an active role in current transformation processes. However, full adaptation of research and education programs has not taken place yet. Further reorientation of support organizations to re-align to the needs of industrial players remains an important challenge (e.g. to ensure the availability of scarce human assets). Organizations like the infrastructure operator ASFINAG and the BMVIT are also key actors of change. Yet, while regulations are changed according to technical possibilities, informal institutions change only slowly. This holds particularly true for the historically grown engineering culture and orientation on determinism, precision and safety, which is said to hamper C/AV development in the Austrian automotive triangle. We found that organizations in all relevant domains have begun to tackle this obstacle but there is still a long way to go. Processes of asset destruction in this field will be long-term tasks. For consolidating transformation, different assets have to change. This requires coordination. In the Austrian case, national policy makers have taken the pivotal role in orchestrating these asset modification processes.

3.4 Comparison

As shown in the previous subsections, both in Ontario and the Austrian triangle there are major efforts underway to cope with the advent of C/AVs. However, the routes taken by the two regions differ strongly. Ontario seems to embark on an upgrading route, while the Austrian case features many elements of a reorientation route (see section 2).

These routes reflect distinct initial conditions for transformation activities. In Ontario, the automotive sector has traditionally prioritized production over innovation-related activities, creating a relatively weak initial base for renewal endeavors. The sector is dominated by foreign subsidiaries with limited innovation mandates and domestic Tier 1 suppliers that have most of their R&D located abroad. However, the advent of C/AVs has led to a shift of perspective. With its dynamic ICT sector, populated by both domestic and foreign R&D-driven companies and a vibrant start-up scene with capabilities in AI and 5G mobile technologies, Ontario's asset base has great potential, not only for the automotive industry to initiate renewal activities to upgrade from a production hub to a R&D center, but also for the ICT industry to diversify into the C/AV space. Even though many uncertainties remain, we found evidence that both sectors are already responding to these new opportunities.

While potentials for diversification activities (residing within the innovative microelectronics industry) can also be found in the Austrian triangle, initial conditions for path renewal activities in the automotive industry are more favorable when compared to Ontario. This is because many – albeit not all – Austrian automotive suppliers exhibit strong innovation capabilities. Their renewal efforts are backed by but are also partly hindered by elaborated organizational and institutional support structures.

These varying conditions are reflected in distinct asset modification processes. In Ontario, young ICT firms in interaction with universities and supported by policy are most actively pursuing asset modification. Additionally, there are first signs that subsidiaries increasingly tap into and modify the regional asset base for their R&D efforts. However, due to the limited autonomy of these subsidiaries, it is the ICT industry's endeavors that so far yield more tangible results. Endogenous asset creation and redeployment have been relatively successful, particularly in relation to knowledge, finance, infrastructure and soft institutions like visions. Despite intensifying inter-path connections, it is important to note that the emerging C/AV field is still rather fragmented, creating the challenge to integrate and coordinate standalone ventures into collaborative experiments. Another key challenge is to connect previously unlinked actors and paths and to enhance the historically weak embeddedness of automotive firms into the RIS. Notwithstanding important efforts at the federal level, orchestration is distributed among different actors and more bottom-up in nature, driven by various initiatives set by intermediaries and other actors at the provincial level.

In the Austrian Automotive Triangle, asset modification is mainly shaped by established actors, namely automotive firms and companies from the microelectronic sector. They mobilize their longstanding relations with universities and policy makers to embrace C/AVs. Asset modification covers both the creation and redeployment of knowledge, finance, infrastructure and legitimacy. One can also find evidence for strategic asset destruction in the field of soft institutional assets. The key challenge is to de-lock and re-align a well-established innovation system. There is clear evidence that not all elements are reorienting themselves at the same pace. Orchestration of asset modification is top-down in nature, driven by the national policy level but complemented by activities pursued at the provincial levels.

4 Conclusions

This paper seeks to contribute to a more thorough understanding of how regions respond to potentially path-breaking innovations that pose a threat to their historically grown industries. We maintain that this requires scrutinizing the ways in which regions nurture new industrial path development and reconfigure their organizational and institutional support structures. This focus is grounded in a systemic perspective that extends conventional EEG accounts of regional restructuring. Systemic approaches move beyond firm and industry-led explanations and incorporate changes in the wider innovation system into analyses of innovation-based structural change. This entails an investigation of how multiple agents of innovation -- including both firm and non-firm actors – modify broadly defined regional assets. Systemic approaches thus offer a comprehensive understanding of how structural change unfolds and why it differs across regions.

In order to further unpack the capacity of regions to embrace radical innovations and to deepen our understanding of how such dynamics unfold, we develop a framework that contrasts two routes of transformation, a reorientation route and an upgrading route. The article shows that these routes are contingent on specific initial conditions. A key factor in this regard is the existing asset base, which is shaped by historically grown industrial and support structures in the region. Further, routes differ in terms of the dominant types of new industrial path development and the relative importance of adaptation processes of existing support structures and the creation of new ones. This is reflected in distinct asset modification processes and the challenges involved in such endeavors.

While the ‘reorientation route’ is expected in regions with a well-established industrial path under consideration that is deeply embedded in a strongly-aligned support system, the ‘upgrading’ route is likely to be observed in regions that host a weakly developed or poorly embedded industrial path that is barely supported by the surrounding innovation system. In the former case, the main impulse for transformation is expected to come from incumbent firms and strong support structures seeking to reorient themselves. In the latter case, the main potential for change might reside in a complementary path or in other previously unexploited regional assets. Drawing on these resources requires upgrading and alignment efforts. As regards challenges, the historically developed structures promoting ‘more of the same’ rather than new activities might pose the main barrier for the initiation of reorientation. In contrast, the main challenge for the 'upgrading route' might lie in the relatively poor initial position, which requires time-consuming and resource-intensive catching-up efforts.

The framework has been applied to an empirical analysis of transformation processes in two traditional automotive regions, namely Ontario (Canada) and the Austrian automotive triangle. Both regions are trying to prepare for C/AV, albeit in different ways, illustrating that regional transformation involves diverse asset modification processes, which come together differently in specific places.

Ontario's automotive path has long been dominated by foreign subsidiaries with limited room for maneuver. The global digitalization of the automotive industry has revealed new potential in Ontario's regional asset base, which lies in its dynamic ICT sector. This has opened a window of opportunity for the Canadian automotive region to upgrade from a production hub to an R&D center. There is clear evidence that thus far asset modification has mainly been driven by young IT firms that are diversifying into the automotive space. However, there is also evidence that some automotive MNEs have begun to tap into the IT and AI competences available in the region. In contrast, we found more favorable initial conditions in the Austrian triangle due to historically strong innovative capacities. Both the automotive and the microelectronic firms, strongly backed by the research and policy domains, have started to modify regional assets to reorient well-established and strongly aligned regional and national innovation systems. However, our empirical analysis also points to the fact that strong ties and mutually reinforcing structural elements are hampering this transformation. Accordingly, not only asset creation and redeployment endeavors, but also strategic asset destruction is necessary for further change. In the Austrian triangle, the strong elaboration and alignment within the innovation system are thus both a blessing and a curse.

Arguably, our analysis is based on two traditional automotive regions only. There is a need to study new path development and system reconfiguration towards C/AVs in other automotive regions with different preconditions than those considered in this article. This would also help to further refine the conceptual framework proposed here. Future work in the field may also extend the framework to other cases to assess other industries and regional contexts facing disruptive change. This would also allow for a better understanding of the policy implications that result from a systemic perspective of industrial dynamics triggered by path-breaking innovation.

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