Why Industry 4.0 is not enhancing national and regional resiliency in the global automotive industry

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Abstract: The post 2000 period has witnessed the rise of countries offering low-cost labour as important hubs for automotive manufacturing. As that occurred, automotive 'semi-periphery' countries faltered: struggling to retain vehicle production, unable to obtain mandates for more knowledge-intensive aspects of automotive value chains. For them, Industry 4.0 (I4.0) is considered an ideal tool to enhance competitiveness. That is because even though they have high labour costs and lack a homegrown automaker, they do have well-educated workforces. Here, we examine the technological upgrading strategies of manufacturers in a prototypical semi-periphery location: Ontario, Canada. We find that few firms there are making investments in I4.0-oriented technologies sufficient to upgrade their position within global production networks (GPNs). Consequently, notwithstanding the prominence of I4.0, our results indicate that I4.0 is unlikely to spur economic resilience in automotive semi-peripheries. Even so, targeted deployment of industrial policy measures may augment I4.0's applicability in those locations.

Keywords: Industry 4.0; automotive industry; global production networks; GPNs; automotive semi-periphery; industrial policy; resilience.

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1 Introduction

In recent years, I4.0 has gained prominence in many advanced manufacturing industries and economies. By merging advancements in information and communication technology (ICT) with traditional manufacturing operations, I4.0 deploys digital technologies to secure enhancements in firm productivity, supply chain traceability, and product quality. More critically, it is suggested that I4.0 holds added potential to reshape existing industrial geographies and supply chains, an outcome of lead firms adopting new manufacturing technologies and altering their sourcing channels (Schwab, 2016; OECD, 2018; World Economic Forum, 2018; Helper et al., 2019; Deloitte, 2019).

In recognition of its wide-ranging implications for economic development, policymakers in advanced economies have seized on I4.0 as a possible remedy for manufacturing decline (European Parliament, 2015; Gabriel and Pessl, 2016; US Office of Science and Technology Policy, 2018). In turn, a policy consensus has emerged within international bodies that emphasises the virtues of I4.0 for enhanced economic development. Influential bodies such as the World economic forum (WEF) and the organisation for economic cooperation and development (OECD) have proposed that I4.0 adoption offers countries and regions a viable pathway to long-term economic growth (see Schwab, 2016; World Economic Forum, 2018; OECD, 2018). Their underlying suggestion is that localities that are early adopters of I4.0 are most likely to experience first-mover advantages, thereby spurring upgrading in their manufacturing industries. It is also submitted that such forms of industrial upgrading can be stimulated through policy measures including targeted investments in education and research and development (R&D), measures facilitated by enhanced linkages between public research institutions and private companies.

However, as the global value chain (GVC) and GPN literature exposes, not all advanced economies – and not all sectors within those countries – respond in comparable ways to similar industrial policy strategies and tools. As a by-product of the power dynamics evident in numerous global industries, the GVC/GPN literature shows that policymakers in some jurisdictions are better positioned to respond to pressing macro-economic and regulatory changes than others (see Sturgeon and Florida, 2000; Coe et al., 2008; Rutherford and Holmes, 2008; Sturgeon et al., 2008; Pavlinek, 2020). It is for that reason that this paper assesses the proliferation and effect of I4.0 in a specific category: the automotive semi- periphery. Following Mordue and Sweeney's (2020b) definition, semi-peripheral automotive jurisdictions are those that possess neither a domestically headquartered automaker (an attribute of core automotive countries like the

US, Germany, or Japan) nor low-cost labour (the distinguishing feature of the group of jurisdictions known as the automotive integrated periphery that include Mexico as well as countries in Central and Eastern Europe and North Africa). These characteristics have tended to mute the effect of industrial policy interventions aimed at gaining expanded mandates for automotive production and automotive R&D (see Pavlinek, 2018; Mordue and Karmally, 2020a; Sweeney et al., 2020). Nevertheless, automotive semi-peripheral jurisdictions are also characterised by a broad base of automotive manufacturing, well-educated workforces, and the headquarters location of at least some large automotive parts suppliers – all features considered to be supportive of the introduction and development of the complex processes and systems incumbent in I4.0. This article, therefore, seeks to examine the following research question: can I4.0 spur industrial upgrading and economic development in the automotive semi-periphery? Furthermore, by examining I4.0 in the automotive semi-periphery, implications are revealed for the large and emerging group of jurisdictions known as the automotive integrated periphery.

In their recent article, Mordue and Sweeney (2020b) identified six countries as holding attributes consistent with the automotive semi-periphery: The UK, Spain, Belgium, Sweden, Austria and Canada. This paper explores the above research question through a case study of I4.0 implementation in Canada's automotive industry located predominantly in the southern portion of the province of Ontario. Canada provides an ideal case study for several reasons. For one, it exhibits all the characteristics of automotive semi-peripheral jurisdictions. Despite Canada's now two-decades-long decline in vehicle manufacturing output, the country retains five original equipment manufacturers (OEMs), including Toyota, Stellantis, Honda, Ford, and General Motors and approximately 550 automotive parts manufacturers. Beyond that, Canada's automotive industry is situated primarily in the southern portion of the province of Ontario, immediately adjacent to the state of Michigan and the cluster of automotive R&D and manufacturing located therein. Additionally, the country is home to a highly skilled and educated labour force, ranking among the top-5 most capable countries to carry out a transition to I4.0 (Economist Intelligence Unit, 2018).

To investigate I4.0 adoption in the Canadian automotive industry – and assess whether I4.0 presents a viable tool to promote economic development in the automotive semi-periphery – our study employs a mixed-methods research design, including an extensive survey and interviews with company executives. Our research provides crucial insights into,

1. the strategic dilemmas that automotive firms face when adapting their existing manufacturing processes
2. the challenges confronting Canada and other semi-peripheral and integrated peripheral jurisdictions in their efforts to upgrade their position within the global automobile industry.

The remainder of the paper has five parts. The next section reviews the economic geography of automobile production. It describes the stratification of the global automotive industry and the key attributes of each layer. Emphasis is placed on semi-peripheral automotive countries. That section also includes a discussion of I4.0. From there, we review Canadian policies designed to enhance its knowledge intensity and encourage I4.0 adaptation within its automotive industry. After that, we explain the methodology we employed. Next, we present and discuss the key findings from our survey of automotive parts manufacturers and interviews with key industry actors. Then, we contextualise our results in terms of our primary research question. We also consider the concept of resilience, including further discussion of 'resistance' as introduced by Sweeney et al. (2020). A short conclusion follows where policy options are introduced for semi-peripheral automotive countries navigating the opportunities and challenges I4.0 presents.

2 The stratification of automotive countries and the promise of Industry 4.0

For many policymakers and industry stakeholders, particularly those in economically advanced locations with higher labour costs, the attractiveness of I4.0 stems from the diminution of their sources of competitive advantage. This is especially true for automotive producing jurisdictions vying for (re)investment in an industry that has endured a significant and ongoing cycle of territorial and organisational restructuring throughout the first two decades of the 21st century. Within the global automobile industry, recent restructuring has contributed to increased levels of uneven development and the trifurcation of automotive producing jurisdictions into the core, semi-periphery, and integrated periphery. As we discuss in this section, those three types of automotive jurisdictions are distinguished by their differing collection of territorial assets (e.g., the presence of a domestic OEM, supplier sector characteristics, and the cost of local labour) which, in turn, influences the effectiveness of policies deployed by embedded stakeholders. In the context of the automotive semi-periphery, we argue that the advancement of public policies necessary to encourage development is made especially challenging due to their lack of a clear- cut competitive advantage in either manufacturing or innovation.

Since the early 2000s, a substantial literature has emerged devoted to explaining the dynamics shaping development in a wide range of automotive producing jurisdictions. This work draws from and builds knowledge around multiple concepts and theories, including GVCs, GPNs, uneven development, and the international division of labour (Rutherford and Holmes, 2008; Sturgeon et al., 2008; Sturgeon and Van Biesebroeck, 2011; Pavlinek and Zizalova, 2016; Sweeney et al., 2020; Pavlinek, 2020). One segment of this research integrates several of these concepts by categorising automotive-producing jurisdictions according to their position within value chains and production networks. Until recently, researchers have tended to categorise automotive-producing countries as core or integrated periphery with the prior deriving power within the automotive value chain via their status as hosts of a domestically-headquartered automaker and the latter via their offer of relatively low-cost labour within broader continental production networks (Sturgeon and Florida, 2000; Chanarron, 2004; Domanski and Gwosdz, 2009; Jacobs, 2016; Pavlinek, 2018, 2020). Examples of core automotive nations are the US, Japan, Korea and Germany, while integrated peripheries consist of countries such as Mexico, Central and Eastern Europe, and, more recently, North Africa.

Further developing this scholarship, studies have emerged that identify and examine the developmental dynamics of a separate group of automotive-producing localities labelled the automotive semi-periphery (Pavlinek, 2018; Mordue and Sweeney, 2020b; Mordue and Karmally, 2020a; Sweeney et al., 2020). Following Mordue and Sweeney's (2020b) definition, semi-peripheral automotive jurisdictions are those that lack many of the territorial assets endogenous to the core, such as a domestically headquartered automaker and the clustering of R&D and managerial functions within automotive GVCs/GPNs. Instead, they are home to a well-educated workforce (one presumed to be capable of performing knowledge-based activities) and labour costs that are now high vis-à-vis the emergent integrated periphery. They also provide the headquarters location for at least some large automotive parts suppliers. Automotive semi-peripheral jurisdictions also tend to retain significant (but generally declining) levels of automotive production. These countries - which include Canada, the UK, Austria, Belgium, Sweden, Finland, the Netherlands, and previously Australia - have experienced a diminution of their competitive advantages throughout the 21st century, a consequence of the rise of new members of the automotive integrated-periphery and those countries' access to labour that is significantly lower cost. As well, the labour quality of the newly constituted automotive integrated periphery has shown itself to be of a sufficiently high level to accommodate the type of advanced manufacturing that automotive production requires (Pavlinek et al., 2009; Alvarez-Medina and Carrillo, 2014; Mordue, 2017).

The identification of the automotive semi-periphery was initially raised by Pavlinek (2018); however, because his focus was the integrated periphery in general and Slovakia in particular, his discussion of semi-peripheral automotive jurisdictions was incidental to his article. Following Pavlinek, others have placed a sharper emphasis on the competitive dynamics and strategic dilemmas facing firms and policymakers within the automotive semi-periphery (see Carey, 2019; Mordue and Sweeney, 2020b). For example, Mordue and Sweeney (2020b) emphasise that the automotive industry is dynamic with entry and exit into the core, semi-periphery and integrated periphery being fluid in nature. These forces are demonstrated by the introduction of new members of the integrated periphery as well as the shifting of countries previously considered integrated periphery to the semi-periphery. It also entails the downgrading of previously core automotive countries to the status of semi-periphery. In recent decades, examples of previously integrated peripheral countries moving to a semi-peripheral status include Belgium and Canada. Meanwhile, countries such as Sweden and the UK (once core automotive nations) dropped to the status of semi-periphery, a consequence of the loss or sale of their homegrown automakers.

While it is generally the case that countries and their embedded automotive industries move between core, semi-periphery, and integrated periphery categories over the longue durée, the 21st century has brought several macro-economic trends and heightened levels of restructuring. Since 2000, for example, the extent to which manufacturing has congregated in automotive integrated periphery countries is captured in Table 1. It shows that vehicle production in the 23 countries constituting the automotive integrated periphery climbed by more than 100% between 2000 and 2019. Moreover, when the countries that straddle definitions of both integrated periphery and core are included (i.e., China and India) alongside the 23 pure integrated peripheries, data from Table 1 shows such countries' overall production climbed by 265% after 2000.

Table 1 Vehicle production patterns in major auto producing countries: 2000 and 2019 (Volume > 100,000 in 2000 and/or 2019)

		2000	2019	
Type	*Country*	*Light duty vehicle production*	*Light duty vehicle production*	*Variation (2019 vis-à-vis 2000)*
Core	FRANCE	3,348,361	2,202,460	–34.2%
Core	GERMANY	5,526,615	4,661,328	–15.7%
Core	ITALY	1,738,315	915,305	–47.3%
Core	USA	12,799,857	10,880,019	–15.0%
Core	JAPAN	10,140,796	9,684,298	–4.5%
Core	SOUTH KOREA	3,114,998	3,950,617	26.8%
	TOTAL (Core)	36,668,942	32,294,027	–11.9%
Core and integrated periphery	CHINA	2,069,069	25,720,665	1,143.1%
Core and integrated periphery	INDIA	801,360	4,516,017	463.5%
	TOTAL (Core and integrated periphery)	2,870,429	30,236,682	953.4%
Integrated periphery	PORTUGAL	246,724	345,704	40.1%
Integrated periphery	SPAIN	3,032,874	2,822,355	–6.9%
Integrated periphery	CZECHIA	455,492	1,433,963	214.8%
Integrated periphery	HUNGARY	137,398	498,158	262.6%
Integrated periphery	POLAND	504,972	649,864	28.7%
Integrated periphery	ROMANIA	78,165	490,412	527.4%
Integrated periphery	SLOVAKIA	181,783	1,100,000	505.1%
Integrated periphery	SLOVENIA	122,949	199,102	61.9%
Integrated periphery	SERBIA	12,740	35,115	175.6%
Integrated periphery	RUSSIA	1,205,581	1,719,784	42.7%
Integrated periphery	UZBEKISTAN	32,273	271,113	740.1%

Notes: Because the global pandemic caused significant disruption to production volume and patterns in 2020, the data upon which our framework is based stops at the year 2019.)

Source: Year-by-year vehicle production from OICA.net (2021). Exceptions are: Morocco production in 2000 is from Jaidi, Msadfa (2017), Vietnam production in 2000 is from Ellison (2010), Pakistan production in 2000 is from Pasha and Ismail (2012), Labour costs assumptions are based on gross national income (GNI) per capita from World Bank (2018). "High" labour cost countries were established on the basis of whether their GNI per capita was among the highest 25 countries GNI per capita in either or both of 2000 (for countries that made 100,000 vehicles or more in 2000) or in 2018 (for countries that made 100,000 vehicles or more in 2019)

Table 1 Vehicle production patterns in major auto producing countries: 2000 and 2019 (Volume > 100,000 in 2000 and/or 2019) (continued)

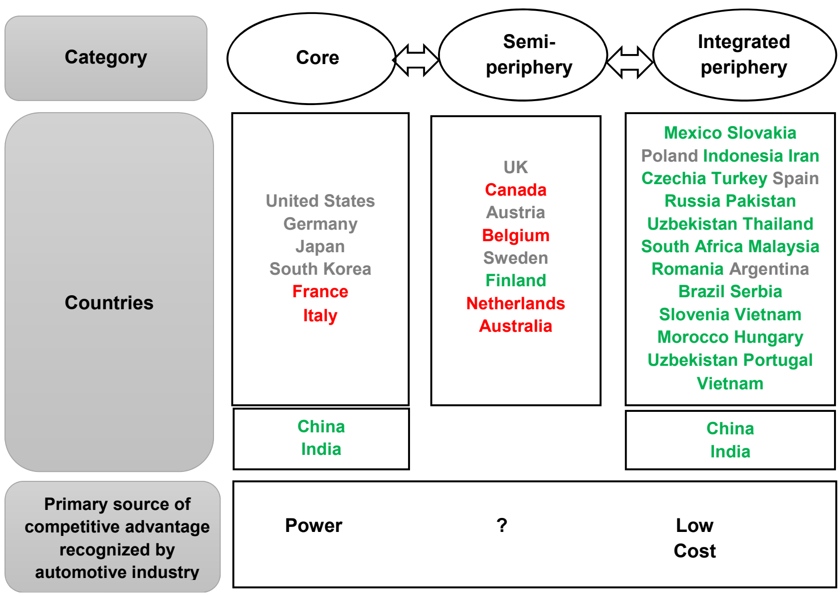
		2000	*2019*	
Type	*Country*	*Light duty vehicle production*	*Light duty vehicle production*	*Variation (2019 vis-à-vis 2000)*
Integrated periphery	TURKEY	430,947	1,461,244	239.1%
Integrated periphery	MEXICO	1,935,527	3,986,794	106.0%
Integrated periphery	ARGENTINA	339,632	314,787	–7.3%
Integrated periphery	BRAZIL	1,681,517	2,944,988	75.1%
Integrated periphery	INDONESIA	292,710	1,286,848	339.6%
Integrated periphery	IRAN	277,985	821,060	195.4%
Integrated periphery	MALAYSIA	282,830	571,632	102.1%
Integrated periphery	PAKISTAN	46,997	186,716	297.3%
Integrated periphery	THAILAND	411,721	2,013,710	389.1%
Integrated periphery	VIETNAM	13,239	250,000	1,788.4%
Integrated periphery	MOROCCO	17,359	394,652	2,173.5%
Integrated periphery	SOUTH AFRICA	357,364	631,983	76.8%
	TOTAL (integrated periphery)	12,098,779	24,429,984	101.9%
Semi-periphery	AUSTRIA	141,026	179,400	27.2%
Semi-periphery	BELGIUM	1,033,294	285,797	–72.3%
Semi-periphery	FINLAND	38,926	114,785	194.9%
Semi-periphery	NETHERLANDS	267,319	176,113	–34.1%
Semi-periphery	SWEDEN	301,343	279,000	–7.4%
Semi-periphery	UNITED KINGDOM	1,813,894	1,381,405	–23.8%
Semi-periphery	CANADA	2,961,636	1,916,585	–35.3%
Semi-periphery	AUSTRALIA	347,122	5,606	–98.4%
	TOTAL (semi-periphery)	6,904,560	4,338,691	–37.2%

Notes: Because the global pandemic caused significant disruption to production volume and patterns in 2020, the data upon which our framework is based stops at the year 2019.)

Source: Year-by-year vehicle production from OICA.net (2021). Exceptions are: Morocco production in 2000 is from Jaidi, Msadfa (2017), Vietnam production in 2000 is from Ellison (2010), Pakistan production in 2000 is from Pasha and Ismail (2012), Labour costs assumptions are based on gross national income (GNI) per capita from World Bank (2018). “High” labour cost countries were established on the basis of whether their GNI per capita was among the highest 25 countries GNI per capita in either or both of 2000 (for countries that made 100,000 vehicles or more in 2000) or in 2018 (for countries that made 100,000 vehicles or more in 2019)

Data from Table 1 also shows that as recently as 2000, the 14 countries representing the automotive core and semi-periphery – countries whose common trait is high labour cost [the gross national income (GNI) per capita of all 14 was among the top 25 in the world] – constituted 74.4% of the major auto producing countries' global vehicle production. However, by 2019, the notion that automotive manufacturing was the preserve of the most economically advanced (i.e., highest labour cost) locations had dissolved. Table 1 shows that by 2019 vehicle production in automotive core and semi-peripheral countries had dropped by 6.9 million; that by then, 59.9% of the vehicles produced in major auto producing countries were assembled in countries offering low-cost labour (relative to pure core and semi-periphery countries).

Figure 1 Framework for categorising the largest auto producing nations (>100,000 units annually in either 2000 or 2019) (see online version for colours)



Key Attributes			
Homegrown automakers	Yes	No	No
Automotive R&D spending	High	Low – Medium	None – Low
Labour costs	High	High	Low - Medium
Foreign ownership	Low – Medium	Medium – High	High
Homegrown Top 100 Suppliers	High	Low – Medium	None – low

Legend

Green font	denotes production increase of 33% or greater between 2000 and 2019
Red font	denotes production decrease of 33% or greater between 2000 and 2019
Gray font	denotes production within 33% (up or down) of 2000 level in 2019

Source: Framework adapted from Pavlinek (2018) and Mordue and Sweeney (2020b)

While Table 1 presents global trends with respect to production, Figure 1 captures key factors influencing those developments. It also encompasses broader attributes of each strata. Building on Table 1, Figure 1 (adapted from Pavlinek, 2019 and Mordue and Sweeney, 2020b) illustrates that the preponderance of countries experiencing significant vehicle production growth (which we classify as a production volume increase of 33% or more over the period 2000–2019) were those whose primary sources of competitive advantage was the offer of low-cost labour (indicated in green): integrated peripheries. Meanwhile, the challenges confounding the automotive semi-periphery are illustrated via the fact that that category mostly comprises countries experiencing significant declines (33% or more) which Figure 1 shows in red.

Figure 1 also encapsulates each categories' source(s) of competitive advantage. For automotive R&D and knowledge-based activities, the tendency has been for them to remain anchored in core locations in general and proximate to OEMs' headquarters specifically (Calabrese, 2001; Sturgeon et al., 2008; Pavlínek, 2012; Klier et al., 2014; Goldman et al., 2016; Lampón et al., 2016; Pavlinek, 2018). On top of that, recent evidence shows that firm-level investments in R&D for even frontier technologies – which constitute advancements disconnected from the traditional automotive industry such as new propulsion systems or technologies facilitative of connected and autonomous vehicles (CAVs) – are also clustering in the core (see Carey, 2019; Mordue and Sweeney, 2020b; Mordue and Karmally, 2020a).

Figure 1 also highlights semi-peripheral automotive countries' ambivalent source(s) of competitive advantage. For example, Canada, North America's sole automotive semi-peripheral country, has experienced a degeneration of its automotive industry disproportionate to the size of its industry or market during the post 2000 period (see Klier and Rubenstein, 2008; Stanford, 2017; Sturgeon and Van Biesebroeck, 2011; Carey and Holmes, 2017). Meanwhile, European semi-peripheral countries have experienced declines on a similar scale, the result of European automotive manufacturing investments shifting to nearby integrated automotive peripheries in Eastern Europe, Turkey and, more recently, Morocco (Chanaron, 2004; Pavlínek et al., 2009; Pavlinek, 2018). Only Finland, a minor actor, has experienced growth.

Within the automotive semi-periphery, the above stated macro-economic trends have created both developmental dilemmas and an urgency on the part of policymakers to recreate the conditions for sustainable economic growth in their jurisdictions. However, and notwithstanding the significant attributes that Figure 1 shows automotive semi-peripheries possess – including, for example, their well- educated workforces, the existence of a large automotive manufacturing base, and their proximity to the core – such jurisdictions have proven incapable of attracting significant mandates for automotive manufacturing or R&D. Recent research suggests that the automotive semi-periphery's limited ability to influence policy directed change is a by-product of unequal power dynamics in the global automotive industry (Mordue and Sweeney, 2020b; Carey, 2019; Sweeney et al., 2020). As the GVC/GPN literature demonstrates, economic globalisation has granted large automotive multinational corporations (MNCs) power over national and regional governments. It has also enhanced MNC's freedom to select their most desired locations for investment (Sturgeon and Florida, 2000; Coe et al., 2008; Rutherford and Holmes, 2008, 2014; Sturgeon et al., 2008; Sturgeon and Van Biesebroeck, 2010; Pavlinek, 2020). By inference, more captive automotive jurisdictions (i.e., the automotive semi-periphery) have even less ability to influence the competitive strategies of globally oriented firms than either core or integrated peripheral automotive countries (Rutherford and Holmes, 2008; Pavlinek, 2012; Mordue and Sweeney, 2020b; Sweeney et al., 2020).

Recently, Sweeney et al. (2020) illustrated how the automotive semi-periphery's marginal status within GPNs inhibits policymakers' efforts to upgrade their automotive industries and render them more resilient.[1] In their examination of the Canadian government's attempts to enhance the knowledge-intensity of its automotive industry located primarily in the province of Ontario, they found that the local sector's semi-peripheral status – informed by its lack of a clear competitive advantage – inhibited policymakers' efforts to encourage year-over-year growth in production and employment (i.e., enhance resilience). Instead, they determined that upgrading in the Canadian automotive semi-periphery remained modest, conforming to what they deemed a resistant growth pathway, defined as a slow decline, but failure to disappear outright. For Canada's automotive sector, resistance (to going away) was manifest in the retention of significant (but declining) manufacturing capacity alongside relatively low levels of corporate R&D.

Sweeney et al.'s (2020) research reveals that for industry actors in semi-peripheries the challenges are stark: persistent decline and irresolute sources of competitive advantage limits their ability to improve local development outcomes. Recently, however, I4.0 has emerged as a potential panacea. First coined in 2011 at the Hanover Fair in Germany, I4.0 entails the merger of cyber and physical systems in manufacturing operations through the adoption of advanced digital technologies and tools such as additive manufacturing (i.e., 3D printing), augmented reality, autonomous robotics, big data and analytics, cybersecurity, the internet of things, simulation, and cloud technologies (Helper et al., 2019; Business Development Bank of Canada, 2017).

A consensus has emerged that I4.0 will have a transformative effect on manufacturing industries. Its anticipated impacts include mass customisation, improved productivity, enhanced traceability, heightened integration within supply chains, and more rapid technology-enabled decision-making (Brettel et al., 2014, Shrouf et al., 2014; Hofmann and Rüsch, 2017). While some envision significant and rapid job loss resulting from I4.0, others anticipate greater coordination, heightened innovation, and enhanced workplace accord (Brynjolfsson and McAfee, 2011; Autor, 2015; Frey and Osborne, 2017). Beyond that, others argue that I4.0 holds potential to reshape existing industrial geographies and supply chains (Schwab, 2016; OECD, 2020; World Economic Forum, 2018; Helper et al., 2019; Deloitte, 2019).

In sum, while recent research on the geography of the automobile industry exposes three orientations (core, semi-periphery, and integrated periphery), only the core and integrated periphery display compelling and sustainable trajectories. Core automotive jurisdictions are sustained by knowledge-based activities and a residual base of manufacturing, whereas integrated peripheries are emerging as centres for vehicle manufacturing. By contrast, the automotive semi-periphery struggles to present a compelling competitive advantage as a location for either knowledge-based activities or manufacturing, a situation that makes policymaking there both more vital and more difficult. Recently, I4.0 has emerged as a potential issue for industry actors in the semi-periphery to restructure their sectors and render them more resilient. It is for that reason that the remainder of this paper is devoted to examining whether I4.0 represents a viable path forward for localities comprising the automotive semi-periphery. As the next section describes, Canada and its embedded automotive industry is prototypical in that regard and is thus, the focus of our case study.

3 The Canadian automotive semi-periphery

Canada and its regionally embedded automotive sector exhibit all the primary characteristics associated with an automotive semi-peripheral jurisdiction. Although the country lacks a homegrown OEM, it hosts a still sizable, yet weakening base of automobile manufacturing with five OEMs operating major assembly plants within its borders. It also hosts a large automotive parts sector that includes about 550 manufacturers, four of which are locally headquartered and rank among the world's top 100 automotive suppliers in terms of revenue (Magna, Linamar, Martinrea and Multimatic) (Automotive News, 2020). Moreover, Canada is home to a growing number of non-traditional automotive suppliers with expertise in software and digital technologies, a highly educated and well-trained workforce, and considerable research expertise in its colleges and universities (Tanguay, 2018; Invest in Ontario, 2019; Global Affairs Canada, 2019). Finally, and notwithstanding its positive features, Canada's record in the post-2000 era suggests its automotive sector holds an ambiguous source of competitive advantage. Indeed, the challenges Canada's automotive sector has encountered parallel several other semi-peripheral automotive jurisdictions in the early 21st century (see, for example, Lampon et al., 2016; Pavlinek, 2018; Mordue and Sweeney, 2020b).

Evidence of the Canadian automotive industry's declining source of competitive advantage can be observed most starkly at the level of vehicle production. Upon reaching peak production in 1999 at just over 3 million units, the country's production of motor vehicles fell to 1.9 million units by 2019 (OICA, 2020). Meanwhile, between 1999 and 2018, total revenues in assembly and parts fell 19% from $123 billion to $99 billion, and employment dropped by 31% from 168,697 to 117,132 (Statistics Canada 2020a, authors calculations). As a by-product of the restructuring associated with the North American Free Trade Agreement (NAFTA) and the rise of Mexico as the 'new' North American automotive integrated periphery, the industry in Canada lost considerable assembly and OEM parts capacity (Sweeney, 2017, 2020; Sweeney and Mordue, 2017; Yates and Holmes, 2019). This restructuring was highlighted by the closures of final assembly plants in Canada by FCA in 2003, Ford in 2004 and 2011, and GM in 2009 and 2019.[2] Only one new assembly plant was added: that, by Toyota in 2008.

Compounding Canada's current challenges are its long-standing difficulties securing mandates for the more knowledge-intensive aspects of vehicle development. Between 2000 and 2018, investments in automotive R&D in Canada declined by 36% from $411 million to $261 million, while R&D intensity in the Canadian automotive sector - a measure of companies' shares of R&D spending to revenue – declined 28%, from an already low 0.36% to 0.26% (Statistics Canada 2020b, authors calculations). Canada's persistent struggle to attract mandates for more knowledge-intensive aspects of the automotive industry is an outcome of several interrelated factors. These include elements endemic to the country overall: high levels of foreign ownership in Canada's broader manufacturing sector (Britton, 1980, 1996; Council of Canadian Academies, 2018) and the tendency for foreign-owned firms to situate their primary R&D headquarters in their home countries (Smardon, 2014; Carey, 2019). They also encompass factors that are a consequence of the structure of Canada's automotive industry and its status as an automotive semi-periphery. This includes, for example, the tendency for large multinational parts corporations, including those that are headquartered in Canada, to perform most of their R&D near the corporate headquarters of the OEMs in core automotive jurisdictions (Mordue and Sweeney, 2020b; Carey, 2019).

In response to Canada's deteriorating position within the global automotive industry, its policymakers have reworked the scope and scale of their industrial policies and programs. Increasingly, Canadian automotive policymakers have moved away from the 'big-game' hunting of Foreign direct investment (FDI) attraction that typified their approach from the late 1970s to the early 2000s, focusing instead on internal, more organic forms of development and innovation (see Sweeney and Mordue, 2017; Holmes et al., 2017; Sweeney et al., 2020). Critical in that regard has been an emphasis on gaining mandates for R&D associated with product innovations, new technologies and improved manufacturing processes, a pivot that has been widely endorsed by the Canadian automotive industry's key actors:

> … "innovation must become THE pathway to automotive industry growth in Canada. While the industry focuses on manufacturing competitiveness through groups such as CAPC, we have not historically focused on Canada as a growth location for invention, research and development (R&D) and engineering of new automotive products and technologies".
>
> Canadian Automotive Partnership Council (2016)

Consistent with its knowledge-intensive ambitions, Canada has sought to foster the adoption of I4.0 in its automotive industry. These efforts follow on the heels of several reports that have cited the importance of I4.0 for stimulating enhanced levels of automotive-related development in the Province of Ontario (see PwC Canada, 2019; Innovation, Science and Economic Development Canada, 2019; CME, 2020). Their suggestion is that policy measures designed to encourage firm-level investment in I4.0-related technologies will enhance productivity. Beyond that, it is suggested that widespread I4.0 adoption will enhance Canada's profile as a destination for investment, an outcome of lead firms (such as the automotive OEMs) adopting enhanced expectations for product tracing and shifting their sourcing to suppliers uniquely capable of instituting such technologies. The inference is that Canadian-based suppliers – and the superior workforces to which they have access – are uniquely positioned to meet those expectations (Kazzaz and Mordue, 2019; Yates and Holmes, 2019; Prism Economics, 2020).

While some research about the automotive industry in Canada confirms the efficacy of developing a more research-intensive profile (see Wolfe and Goracinova, 2017; Wolfe, 2018; Katz-Rosene, 2019) others question the feasibility of doing so (see Rutherford and Holmes, 2008; Holmes et al., 2017; Carey, 2019). Indeed, Canada's semi-peripheral and increasingly marginal status within the global automotive industry suggests that innovation-centred policies have yielded minimal success (Mordue and Sweeney, 2020b; Sweeney et al., 2020). This includes measures directed at frontier automotive technologies, where core automotive country's advantages are less entrenched (Carey, 2019; Mordue and Karmally, 2020a).

Thus, using Canada as a lens on the automotive semi-periphery, it has been established that:

1 automotive manufacturing in the semi-periphery is in decline

2 industrial policy measures have not reversed this now two-decades-old trend

3 despite the capabilities of its labour force, efforts to gain mandates for R&D have had limited success.

Accordingly, we now turn attention to assessing the efficacy of another industrial policy measure that draws from the objectives of industry actors (including policymakers) in automotive semi-peripheries to sustain manufacturing and exploit the knowledge-intensive capabilities of those countries' labour forces. Our focus is I4.0, considering whether it presents a viable tool to spur resiliency in the manufacturing portion of the Canadian automotive industry. In doing so, we will assess its applicability for other automotive semi-peripheral and integrated peripheral jurisdictions.

Going forward, our case study of I4.0 in the automotive semi-periphery will focus on Canada. If the automotive industry in Canada, an economically advanced nation with a knowledge-intensive profile, is unable to gain traction through I4.0 implementation, it is even less likely that members of other non-core automotive countries (including automotive integrated peripheral countries) will realise enhanced levels of development through I4.0 implementation. Thus, Canada provides a unique and valuable platform for assessing the applicability of I4.0 to non-core automotive countries: it retains a substantive base of automotive manufacturing; even so, declining production and employment levels expose its vulnerabilities (and motivations); its workforce is capable of accepting and adapting the instruments of I4.0.

4 Methodology

To evaluate the degree to which I4.0 is contributing to industrial upgrading and economic development in the Canadian automotive semi-periphery, we employed a mixed methods research design (Maxwell and Mittapalli, 2010; Teddlie and Tashakkori, 2009; Cresswell and Clark, 2018). The first stage of our research comprised an online survey examining Canadian automotive parts executives' assessment of the recent performance of their facilities, the I4.0-oriented tools they employed, and the competitive dynamics influencing their adoption. The survey also investigated the barriers limiting company adoption of I4.0 and their timelines for additional investment. Initial contact was made by emailing 550 automotive parts manufacturers identified via the Automotive policy research centre's (APRC's) supplier database.[4] From this, we received 106 responses, accounting for just under 20% of the Canadian automotive parts manufacturing base. As shown in Table 2, our sample included tier-1 suppliers (N = 37), tier-2/3 suppliers (N = 69), Canadian owned companies (N = 75), and non-Canadian-owned firms (N = 31). The largest proportion of companies made plastic or stamped parts (N = 43). Most respondents were either general managers or plant managers (N = 27) within their organisations.[5]

Table 2 Profile of survey respondents

Tier (N)	*Country of ownership (N)*	*Sub-industry (N)*	*Respondents position (N)*
Tier 2/3 (69)	Canada (75)	Plastic parts (22)	General/plant manager (27)
Tier 1 (37)	USA (16)	Tool, die and mould making (21)	President/owner (22)
	Europe (4)	Stamping and castings (18)	Engineering manager (22)
	Japan (4)	Engine and engine parts (13)	Vice President/C-Suite (16)
	Other (7)	Other (12)	Other manager (17)
		Seating and interiors (10)	

In the second stage of our research, we sought additional insight into the I4.0 implementation strategies of companies in the Canadian automotive industry through interviews with corporate executives. The composition of our interview subjects is shown in Table 3. Our interviewees included an equal number of executives representing tier-1 (N = 5) and tier-2/3 (N = 5) companies. Most of our interviewees were from Canadian-owned companies (N = 6) that produced stamped and/or cast parts (N = 4). Half of our interview subjects (N = 5) were engineering managers within their organisation. The interviews were semi-structured and designed to elicit conversation. In the interviews, corporate executives were asked to explain their companies' motivation for implementing I4.0 related tools. Additionally, they were asked to identify any competitive and public policy barriers that limited their company's adoption.

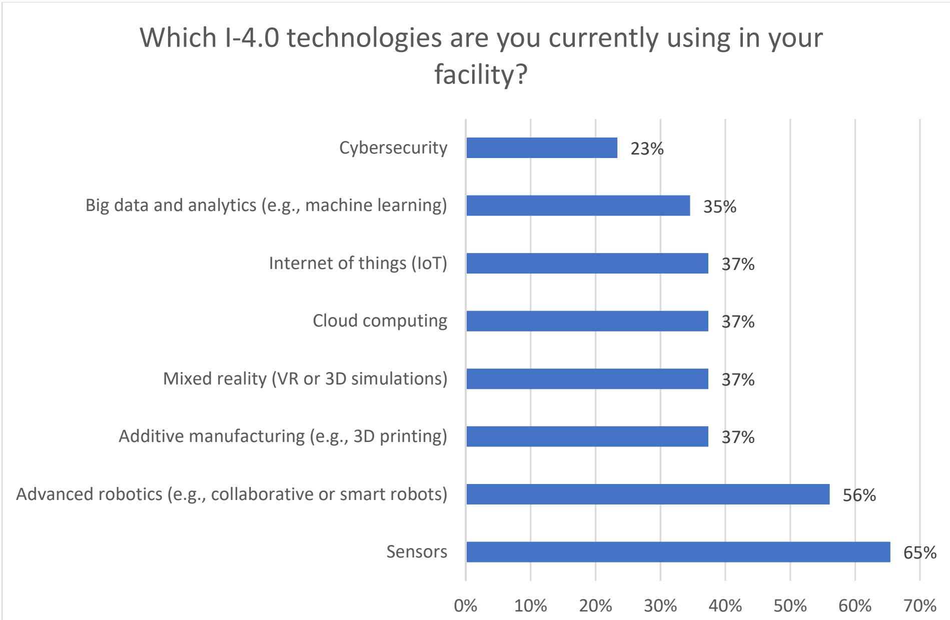
Table 3 Profile of interview subjects

Tier (N)	*Country of ownership (N)*	*Sub-industry (N)*	*Respondents position (N)*
Tier 1 (5)	Canada (6)	Stamping and castings (4)	Engineering Manager (5)
Tier 2/3 (5)	USA (2)	Plastic parts (3)	President/Owner (3)
	Europe (2)	Tool, die and mould making (2)	General/Plant Manager (2)
		Electronic parts (1)	

5 Results

This section examines the results of our survey and interview material to consider the extent to which I4.0 is contributing to the resilience of the Canadian automotive semi-periphery. It does so by first examining which I4.0 tools and technologies Canadian automotive companies are adopting. Next, it considers the extent to which those tools are being used. From there, a discussion ensues of the key barriers limiting adoption and their implication for development within the Canadian automotive sector.

Figure 2 I4.0 technology adoption in the canadian automotive supplier sector (see online version for colours)



Source: Survey

5.1 I4.0 adoption in the Canadian automotive industry

Despite the efforts of Canadian policy makers to encourage the application of I4.0-related technologies in their automotive industry, our combined survey and interview material revealed that the sector remains in the very early stages of adoption. This result was shown most clearly in our survey questions examining which I4.0-oriented tools Canadian automotive supplier companies have employed so far. As shown in Figure 2, most companies have restricted their implementation of I4.0 tools to sensors (65%) which many consider to be less advanced and more ubiquitous forms of I4.0 technology (Bagheri et al., 2015; Deloitte, 2020; Helper et al., 2019; Kazzaz and Mordue, 2019). Meanwhile, few of the facilities we surveyed had deployed more advanced aspects of I4.0, such as big data analytics and machine learning (35%), cloud computing (37%) or cybersecurity solutions (23%). These results align with the I4.0 adoption patterns observed in other advanced automotive jurisdictions (i.e., automotive core and semi-periphery countries). Those studies, consistent with our own, indicate that most automotive companies are adopting the basic tools of I4.0 (like sensors), but are delaying investment in more advanced and expensive instruments (e.g., tools to facilitate tracing solutions, machine learning and artificial intelligence) (see Helper et al., 2018, 2019; Deloitte, 2020).

Notably, our survey revealed a reluctance by automotive suppliers in Canada to engage with I4.0 in a transformative way. For example, as indicated, most companies have employed sensors (65%); however, such tools are typically designed to support incremental productivity or quality improvement (Drexler, 2017; Helper et al. 2018, 2019; Deloitte, 2020; CME, 2020). Meanwhile, Figure 2 shows that relatively few firms are employing the tools considered critical to reshaping or adapting their current operation's source(s) of competitiveness.[6] For example, only 35% had implemented big data and analytics, tools that could be employed in predictive maintenance, limiting production downtime, and optimising workflow (Auschitzky et al., 2014; Kurtz and Shockley, 2015; CME, 2020).

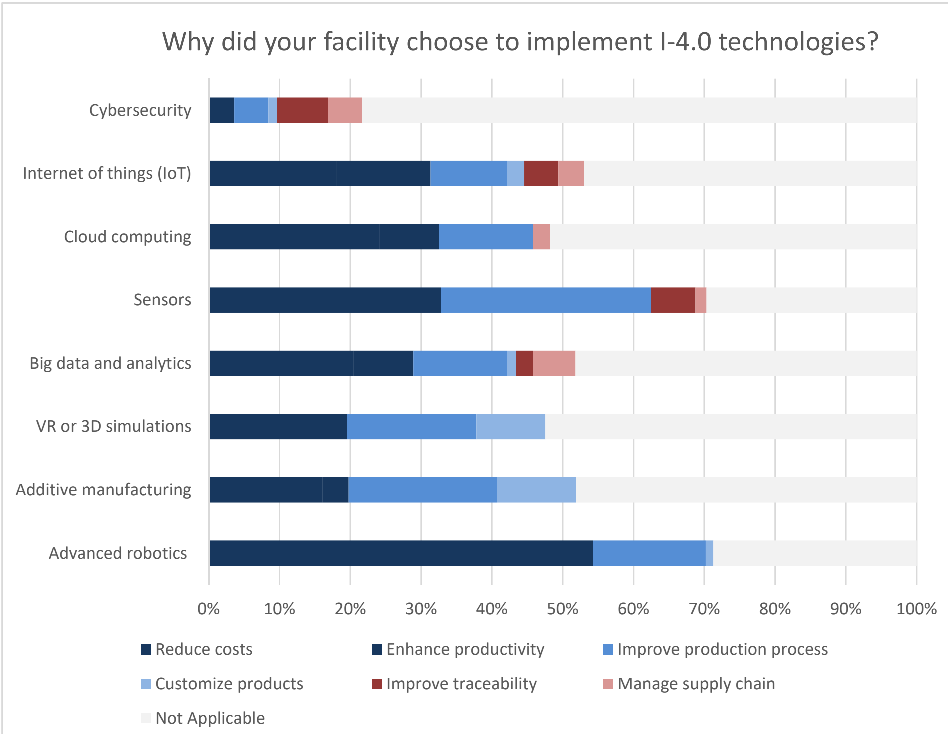
Our interviews provided deeper insight into Canadian automakers' reluctance to invest in the more advanced aspects of I4.0. Key in that regard was the sector's focus on return on investment and an enduring emphasis on realising tangible and incremental improvements to their existing operations. This preoccupation is reflected in the comments of a tier-1 stamping and casting executive who explained:

> "Right now, we're seriously looking at improving how the plant floor is scheduled. We have looked at autonomous vehicles and getting rid of all the forklifts on the floor and using collaborative robots. But unfortunately, with everything that we've looked at so far, we cannot find enough labour savings to make it financially profitable" (Tier-1 plastic parts executive).

Interviews also revealed that suppliers' reluctance to invest in the more advanced tools associated with I4.0 was an outcome of the fact that automotive lead firms neither mandated nor valued such investments. Illustrative in that regard is the comment of a tier-1 supplier in explaining the expectations they hold of their own suppliers in terms of the traceability of their products: "We simply require them to meet our supply chain requirements. How they do that is their business" (Tier-1 stamping and casting executive).

Figure 3 provides greater clarity concerning the expectations and motivations driving suppliers I4.0 implementation strategies in the automotive semi-periphery. It corroborates the comments of our interview subjects, confirming companies' disinclination to employ new manufacturing technologies to fundamentally alter their business practices. Our survey results demonstrated that the majority of respondents implemented new manufacturing technologies to address their core competencies; that is, those aimed, not at distinguishing their capabilities on a global or macro-regional scale, but rather – and merely – increasing their competitiveness vis-à-vis low-cost competitors (i.e., those located in the integrated periphery). Figure 3, for instance, shows that the primary motivations for Canadian firms implementing I4.0 technologies were reducing costs, enhancing productivity, or improving their production processes (shown in shades of blue in Figure 3), motivations that speak to incrementalism and the reinforcement of existing sources of competitiveness within global or regional supply chains. By contrast, other influences, such as those that could cause lead firms to alter their sourcing channels or re-shore segments of manufacturing to core or semi-peripheral automotive jurisdictions (e.g., supply chain management and enhanced traceability) were less frequently identified as motivating factors (Figure 3, shown in shades of red). To illustrate, when one tier 2/3 executive was asked to explain the main reason for their company's implementation of new manufacturing technologies, they explicitly did not mention ambitions to differentiate their company via customising products, increasing traceability or any other means by which to improve the management of their own or their customers' supply chain. Instead, that person identified that their company's motivations were more rudimentary and premised on maintaining cost competitiveness within broader GVCs: "I saw China, Thailand, Vietnam, and others knocking on the door here, and knew that if we don't get going, we are going to get run over. It was kind of obvious to me that we needed to make a change to our operations." (Tier 2/3 stamping and casting executive).

Figure 3 Factors influencing I4.0 adoption in the canadian automotive supplier sector (see online version for colours)



Source: Survey

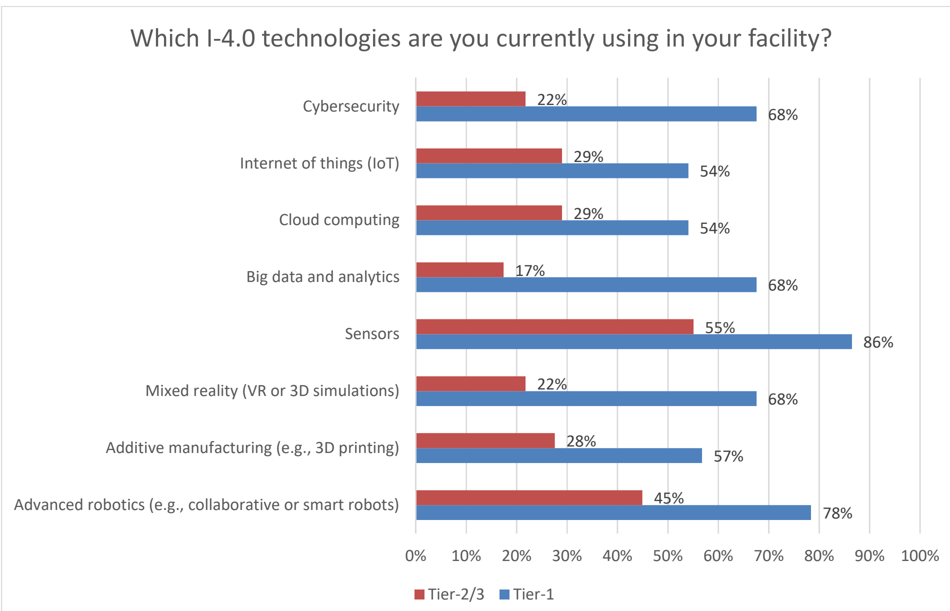
In sum, our combined survey and interview material revealed that although Canadian automotive companies are implementing some I4.0 tools, the majority are reluctant to employ its more advanced and transformative features. Moreover, we observed that very few companies are using I4.0 to upgrade their position within GVCs/GPNs and that the majority are instead employing new manufacturing technologies to buttress their current sources of competitiveness. As we will demonstrate in the next sub-section, these results, coupled with several barriers, limit the near- term viability of I4.0 to spur enhanced levels of industrial upgrading and economic development (i.e., resilience) in the Canadian automotive industry.

5.2 Barriers limiting I4.0 adoption in the Canadian automotive industry

The previous subsection provided insight into the extent to which a mixture of tools associated with I4.0 are being implemented within the Canadian automotive supplier sector. It also offered insight into the companies' motivations for doing so. Here, we more deeply identify and examine the most critical dynamics limiting implementation in the Canadian automotive industry. First, we consider asymmetries between tiers. After that, we assess barriers to implementation that key actors have observed. The impediments we describe include financial hurdles, firm-customer gaps in terms of customer expectations, and labour force availability.

While we found that most suppliers across the Canadian automotive industry were reluctant to invest in new I4.0 technologies, tier-2/3 operators were particularly laggard. As illustrated in Figure 4, tier-1 operators were significantly more likely to have implemented new manufacturing technologies associated with I4.0 than the tier-2/3s ($p \leq 0.05$).[7] This result was exposed in the tier-1s more widespread use of both basic I4.0-oriented tools such as sensors (86% vs. 55%) as well as their experimentation with more advanced solutions like cybersecurity (68% vs. 22%) and big data and analytics (68% vs. 17%).

Figure 4 I4.0 technology adoption by tier (see online version for colours)



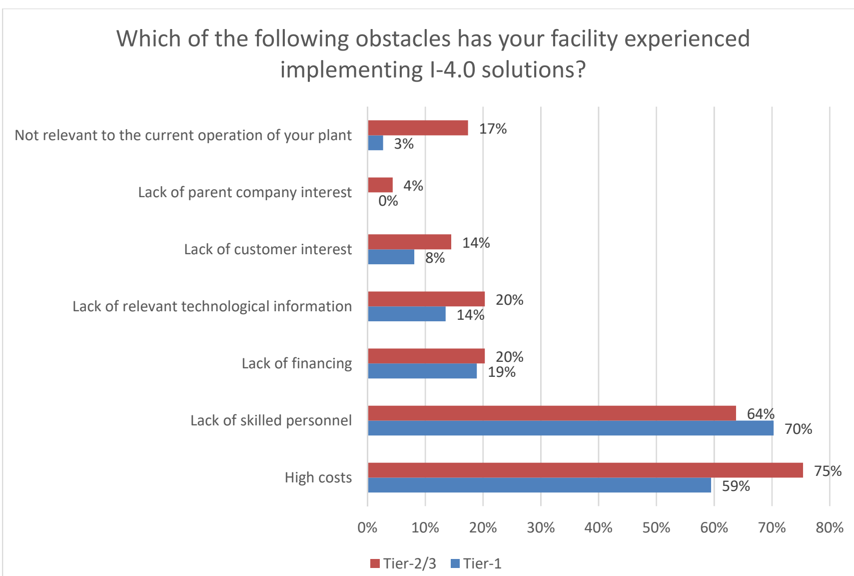
Source: Survey

Our research highlighted three main barriers that limit I4.0 implementation in the Canadian automotive industry. First, our survey showed that the most frequently cited factor restraining firm-level investment was I4.0s high costs. Subsequent interviews revealed that cost and financing-based apprehension also encompassed concerns about limits on access to government support programs. The sector's cost-based concerns are shown in Figure 5. While Figure 5 shows that both tier-1 and tier-2/3 suppliers viewed the high costs associated with I4.0 as the most significant barrier, tier-2/3 respondents' concerns about cost were elevated (75% of tier-2/3s said it was an obstacle compared with 59% for tier-1s). We observed similar issues during our interviews with the tier-2/3 respondents reporting that their spending on less expensive I4.0 technologies like sensors and edge computing represented still costly undertakings that their companies were unlikely to recoup in the near-term. Those interviews also revealed that many tier-2/3 manufacturers thought a significant push from the government was necessary for them to consider further I4.0 investment. For example, one tier-2/3 executive observed,

> "there's a lot of guys like me out here who just don't have the money to automate, and we're serving the tier-1s who, for the most part, have already upgraded their operations. If you want to keep the supply chain here, you need to help the guys at the bottom of the food chain." (Tier 2/3 tool, die and mould making executive).

Interviews with tier-2/3 executives also exposed their displeasure with automotive funding programs in Canada. For example, in discussing one program, an executive remarked: "we put in an application and didn't hear anything for 16-months. Honestly, I don't know what they're looking for; they want us (tier-2/3 companies) to be involved, but they make it impossible for 99% of our companies to participate" (Tier 2/3 stamping and casting executive). These sentiments align with past research, which has observed critical barriers to government efforts to forge a more knowledge – intensive profile for Canada's automotive sector, particularly amongst small to medium enterprises (SMEs) and tier-2/3 companies (Rutherford and Holmes, 2008; Holmes et al., 2017; Carey, 2019).

Figure 5 Barriers limiting i4.0 adoption in the canadian automotive supplier sector (see online version for colours)



Source: Survey

The second obstacle that our research exposed was lack of customer interest in I4.0 implementation. Granted, the survey results provided in Figure 5 do not explicitly point to a 'lack of customer interest' as constituting a significant impediment to I4.0 implementation. However, our interviews conveyed a more nuanced understanding. Through them, executives consistently revealed that their firm's limited application of the more advanced I4.0-oriented tools originated from an absence of binding industrial frameworks and perceived customer concern. For instance, a tier-2/3 executive remarked on their company's hesitancy to implement new supply chain management and tracing solutions: "we're required to follow what the tier-1s need us to do, and they don't need us to be there right now. Their only concern with us is that we are ISO registered and that we keep up our annual surveillance audits" (Tier 2/3 plastic parts executive). Similarly, through interviews, we observed that the tier-1s were reluctant to push their tier-2/3 suppliers to adopt more advanced aspects of I4.0, such as enhancements in product traceability. For example, a tier-1 interviewee noted their company's lack of concern for how their suppliers met their production requirements, stating: "they are really just contractors. We don't require them to have performance monitoring systems or tracing solutions." (Tier-1 stamping and casting executive).

The third barrier to I4.0 adoption that our research identified was related to workforce development issues. Figure 5 shows that 70% of tier-1 and 64% of tier-2/3 manufacturers recognised new training and hiring demands as obstacles to their adoption of I4.0. Here again, our interviews provided additional insight into the numerous dynamics at play. For example, one tier 2/3 executive described the series of training-related challenges their firm encountered while introducing I4.0 tools (including sensors, edge computing, and ERP solutions) into their existing operations. They explained that many of those challenges arose because of simple data entry errors, stating:

> "They constantly make mistakes and sometimes forget to enter the data, so there is definitely a bit of a learning curve to get over there. There is also a bit of a reluctance to change amongst some of our older workers, so managing that has proven to be a challenge" (Tier-2/3 stamping and casting executive).

Executives also reported impediments finding and hiring workers with relevant technical skills. For example, a tier-1 executive identified:

> "Attracting the talent is tough. Let's be honest, we're at record-high employment levels in Southwestern Ontario (where the majority of Canada's automotive manufacturing industry is located) and largely the Western hemisphere, so trying to find good technical people is just challenging. Beyond that, trying to go and find good technical people that you can afford is even more of a challenge because we're an automotive company, we're not pharmaceutical, we're not banking. We just don't have those kinds of budgets". Tier-1 stamping and casting executive

Interviews also revealed that the labour force-related challenges of implementing I4.0 were more complex than the blanket 'lack of skilled personnel' problem cited by 70% and 64% of tier-1 and tier-2/3 survey respondents, respectively. Those interviews revealed, for example, considerable disparities and asymmetries in technological competence within individual suppliers and facilities. To illustrate, an executive at a tier-1 manufacturer described that while their company employed knowledgeable and skilled staff, their facility's data sources had not advanced to the point that they could effectively deploy machine learning capabilities:

> "We have a young engineer who is specialised in AI working on a small application right now, and while we are looking for opportunities to deploy it, we are finding that we have problems that require artificial intelligence, and there are problems that don't. The major difficulty for us is that the problems where we have good datasets, we don't need artificial intelligence" (Tier-1 stamping and casting executive).

The labour force issues identified in Figure 5 and clarified via our interviews draw attention to several well-established workforce development issues that limit I4.0

advancement in the Canadian automotive industry. These include matters relating to its semi-peripheral status and locality-level factors that arise from the nature of the sector's recent development. In the case of the former, while Canada is home to a well-educated and skilled labour force, the ability of its automotive industry to suitably employ that talent is constrained by its relative lack of managerial and R&D capacity compared with the US, a core automotive jurisdiction (Lobo et al., 2013; Center for Automotive Research, 2015; Goldman et al., 2016). Indeed, recent evidence suggests that as many as one in four Canadian STEM graduates are leaving the country for the higher wages and better job prospects found elsewhere (Spicer et al., 2015). In the latter case, compounding the country's workforce development issues are its ageing manufacturing workforce (25% of which is currently over the age of 55), and the relative inability of Canadian auto manufacturers to attract younger workers to the industry, which tends to be more strenuous, male-dominated, and lower-paying than other Canadian sectors (see Prism Economics, 2020; Yates and Holmes, 2019; CME, 2020).

In conclusion, we observed that the following factors constrain I4.0 implementation in the Canadian automotive sector:

1 Canadian suppliers continue to view cost as their primary source of competitiveness and are reluctant to consider more innovative and transformative strategies that the advanced I4.0-oriented tools tend to support.

2 I4.0 adoption patterns within the sector are highly uneven and marked by higher levels of experimentation by the tier-1s and hesitancy at the tier-2/3 level to engage with new manufacturing technologies.

3 The high cost of I4.0 technologies, including limitations in existing government programs that are designed to help companies defray their initial investment into new manufacturing solutions.

4 Lead automotive firms not requiring their suppliers to have more advanced I4.0 capabilities.

5 Skill and talent gaps within the sector that are exacerbated by structural weaknesses in the Canadian automotive labour market.

The broader implications of these results for economic development in the automotive semi- periphery are addressed in the next section.

6 Discussion

Throughout this paper, we have demonstrated that numerous industry stakeholders and international organisations have identified I4.0 as a viable means to secure industrial upgrading and development in the automotive industry and, in so doing, engender economic resilience. Our emphasis has been on automotive semi-peripheral jurisdictions with Canada serving as the case study. Through this, we have examined how key actors therein, including its policymakers and manufacturers, have responded. Notwithstanding the considerable attention that I4.0 has generated, we have observed that Canadian automotive companies are engaging with new technologies and tools in a piecemeal and limited fashion. This section further discusses our results, examining whether I4.0 can effectively spur industrial upgrading and resilience in semi-peripheral automotive countries and regions. As will be described, this research is also of significant consequence for other jurisdictions, including those in the automotive integrated periphery.

To begin, our results suggest that I4.0 has so far not spurred elevated levels of industrial upgrading and has, therefore, not triggered a pattern of resiliency within Canada's automotive industry. We observed that Canadian automotive suppliers are only just beginning to experiment with I4.0 in their operations. Furthermore, while most Canadian automotive companies are employing basic I4.0 instruments (such as sensors), few are experimenting with I4.0s more advanced tools and technologies (illustrated in Figure 2). Beyond that, we found that I4.0 implementation is occurring unevenly within the automotive supply chain as larger, typically upper-tier automotive suppliers, experiment with new technologies and techniques, and lower- tier companies make limited investments (illustrated in Figure 4).

Given the moderate levels of I4.0 adoption that we observed, our research suggests that resilience in the automotive semi-periphery is unlikely to take hold. Instead, we suggest that the patterns and levels of I4.0 adoption in the Canadian automotive industry are more likely to entrench what Sweeney et al. (2020) define as economic resistance. Like economic resilience, resistance denotes an industry's or broader economy's actions to resist outright collapse in the face of exogenous economic shocks. However, unlike resilience, economic resistance entails more limited levels of economic development (i.e., an absence of growth) and more locked-in firm behaviours (e.g., more limited levels of diversification into other sectors and R&D). Following a more resistant model of economic development, our research indicates that the Canadian automotive semi-periphery's minimal I4.0 experimentation allows companies to retain their current practices and conventional sources of competitiveness. However, the Canadian sector's avoidance of I4.0s more advanced features is inconsistent with the notion of resilience, and the year-over-year growth the concept implies (see Hassink, 2010; Gong and Hassink, 2017; Evenhuis, 2017; Sweeney et al., 2020).

The resistance-inducing character of I4.0 in the Canadian automotive industry case study is an outcome of several structural and competitive dynamics endemic to automotive GVCs. As the GVC/GPN literature illustrates, innovation-led economic development within automotive GVCs is defined by unequal power dynamics between companies and individual countries and regions (see MacDuffie and Helper, 2007; Sturgeon et al., 2009; Pavlinek, 2012; Goldman et al., 2015; Mordue and Sweeney, 2020b; Helper et al., 2019). For example, considerable evidence indicates that automotive OEMs and tier-1s hold power over countries and other firms within global value chains, determining the direction of both production and R&D mandates and capturing the economic rents associated with those activities (Rutherford and Holmes, 2008, 2014; Carey, 2019). By contrast, the GVC/GPN literature indicates that tier-2/3 firms lack comparable power resources, a by-product of their deficiency of financial and staffing resources and the nature of contractual relationships within the automotive sector (Helper, 1991; MacDuffie and Helper, 2007; Rutherford and Holmes, 2007, 2014; Kuan et al., 2014; Helper and Kuan, 2016; Holmes et al., 2017).

As we witnessed, the Canadian automotive sector's limited adoption of I4.0 is influenced by similar unequal power relationships to those identified in the GVC/GPN literature. I4.0 adoption in the Canadian industry is limited by the inability of smaller tier-2/3 manufacturers to invest in even basic I4.0-oriented technologies. This is an outcome of two dynamics. First, their access to financial and staffing resources is limited, particularly in comparison to larger automotive manufacturers (i.e., the OEMs and tier-1 suppliers) which have begun experimenting with more advanced I4.0-related tools, such as big data analytics and machine learning. Second, through interviews, we observed that the larger tier-1 suppliers were reluctant to engage their (typically) smaller tier-2/3 suppliers in the development of new I4.0-oriented technologies. Accordingly, even though power dynamics in the automotive industry provide upper-tier suppliers and OEMs with the ability to require competencies that I4.0-related instruments support, those same upper- tier and more powerful members of the industry, do not sufficiently value those capabilities or are not prepared to provide the funds adequate for lower-tier members to participate. Thus, large portions of the industry remain locked into the maintenance of a traditional cost-based source of competitiveness, an arrangement inconsistent with the demand and deployment of I4.0s more advanced features. That means that unless and until GVC power dynamics change, it is unlikely that the mere availability of I4.0 tools will engender their widespread deployment in the automotive semi-periphery.

By triangulating previous research and data accumulated about Canada, a prototypical semi-peripheral automotive country, and the contents of interviews and survey results gathered for this project, we form a series of policy-oriented suggestions. The purpose in doing so is to reinforce strategies and actions to reorient the Canadian automotive manufacturing industry away from mere resistance pathway (to going away) toward an orientation more in keeping with the concept of resilience. Through that, we suggest that policymakers in automotive semi-peripheries consider:

1 Programs to incent experimentation and implementation of I4.0 instruments and tools. Moreover, in recognition of the limited potential that some I4.0 technologies and tools offer to elevate source(s) of competitive advantage for automotive firms located in semi-periphery jurisdictions, policymakers there should prioritise I4.0 proposals that support firms seeking to reconstruct or re-define their source(s) of competitive advantage. As such, support should concentrate on deployment of I4.0 instruments designed to differentiate firms in non-productivity/cost-oriented manners (e.g., via customisation, increasing traceability, improved supply chain management, etc.)

2 Establishing mechanisms designed to draw in smaller, typically lower tier members of the automotive supply chain, a consequence of their limited financial and human resource capabilities (vis-a-vis larger, typically higher tier members of automotive GVCs which this research has shown are more likely to be engaged)

3 Building on item #2 above, design programs to provoke multi-tier collaboration. While it is likely that a program premised on inter-tier cooperation will cause larger, typically upper tier members of the automotive GVC to extend knowledge and practices to smaller, lower tier members, it is also probable that smaller, technology-based firms will bring new capabilities to established firms.

7 Conclusions

Our case study of Canada, a semi-peripheral automotive jurisdiction and its (limited) application of the instruments of I4.0, is instructive in so far as understanding the applicability of the concept to other segments of the global automotive industry. Indeed, we suggest that our analysis of the implementation of I4.0 in the automotive semi-periphery also has relevance for less developed, lower-cost countries with significant automotive manufacturing footprints: the automotive integrated periphery. Because Canada, an economically advanced nation with a knowledge-intensive profile, has not witnessed wide scale adoption of I4.0, it is unlikely that automotive integrated periphery countries will have different motivations or results. Moreover, if I4.0-oriented tools are not valued or not required by the customers of firms located in the automotive semi-periphery, it is unlikely that firms located in the automotive integrated periphery will be granted different, more knowledge-intensive mandates; mandates that demand firms located there to consider wide scale adoption of I4.0 tools.

Throughout the 21st century, policymakers within the automotive semi-periphery have sought to find a compelling tool to bolster their industry and find an unequivocal source of competitive advantage. In this sense, I4.0 represents only the most recent of a long list of industrial policy instruments and issues designed to retain manufacturing or gain mandates for R&D (see Pavlinek et al., 2009; Lampon et al., 2015; Jacobs, 2016; Mordue, 2019; Pavlínek and Žížalová, 2016; Sweeney et al., 2020). However, notwithstanding its prominence, our results indicate that much like those other measures, I4.0 will not provide the remedy for economic development that some of its most vocal advocates proclaim. Instead, our research has shown that within established industries such as the automotive sector, pre-existing GVC power dynamics limit the degree to which I4.0 can spur resiliency in the automotive semi-periphery and other jurisdictions. Even so, deft and targeted policy design may provoke consequential effects.

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Notes

1 See Hassink (2010), Gong and Hassink (2017), Evenhuis (2017), and Sweeney et al. (2020) for more in-depth

2 GM announced the closure of its Oshawa Ontario assembly plant in 2018 and it made its last vehicle in 2019. That decision was reversed in November 2020 and the plant will re-open in 2022.

3 The Canadian Automotive Partnership Council examines competitive issues facing the Canadian automotive industry. Membership consists of the CEOs of Canada's five assemblers and leading parts suppliers, as well as representatives of Unifor, industry associations, auto research-focused academia, and the federal and provincial (Ontario and Quebec) Ministers of Industry.

4 The initial mailing list was drawn from the APRC supplier database developed by Dr. Brendan Sweeney from secondary sources.

5 We interpreted our survey results within the statistical package for the social sciences (SPSS). Utilizing cross tabulations and chi-squared analyses in SPSS, we compared the survey responses of Canadian and foreign-owned companies. Additionally, we compared the response of larger tier-1 manufacturers to smaller and more domestically embedded tier-2/3 suppliers.

6 For example, to support improved traceability, supply chain management practices and data-driven decision making.

7 Significance-levels were calculated by chi-squared analysis in SPSS.