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Public and private goods in the development of additive manufacturing capacity

Abstract: The promotion of additive manufacturing (AM) as a set of enabling technologies has been a prominent feature of new policies seeking to revitalize manufacturing in developed economies. Because of its differences from traditional manufacturing technologies, small businesses, in particular, face high costs in adopting AM methods. How can governments assist small firms and their innovation ecosystems to make significant leaps in enabling technologies? This paper conceptualizes the challenges faced by groups of small enterprises adopting new technologies and a decentralized policy effort to systematically increase the use of advanced manufacturing technologies. In Canada, funding used by community colleges to create applied research centers has been intended to establish anchors for local "industrial commons" around advanced manufacturing methods. By providing both information and working capital to private sector partners, these community college programs should ideally mitigate challenges to the adoption of AM technologies—the so-called "valley of death"—in local ecosystems. There are many successful individual cases of partnership (i.e., private goods); however, this bottom-up approach seems to fail both as a means of promoting vibrant industrial commons (i.e., public goods) and as a coherent national strategy. We trace the challenges of this approach to principal-agent problems associated with layering new programs upon existing organizations, the density of program participants, and the presence of appropriate technologies.

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Recent years have seen a re-emergence of interest in manufacturing in high-income countries following decades of displacement of manufacturing to low-cost countries.[1] Policy makers are actively seeking both effective policies to help reverse the hollowing out of their manufacturing sectors and pursuing the advancement of technologies that might also help to do the same.[2] In particular, the imagination of policymakers in these developed countries has been captured by the potential of additive manufacturing (AM) to help transform and revitalize domestic manufacturing, particularly among small businesses. Additive manufacturing— colloquially called "3D printing"—has the potential to improve design, speed prototyping, and produce increasingly complex parts that cannot be made with traditional manufacturing methods. The popular expectation in developed countries is that because of these efficiencies, enterprises with AM capacities will be able to both help stem the flow of design and manufacturing abroad to low-cost countries and to "reshore" the supply of parts and inputs to domestic original equipment manufacturers (OEMs). Undoing what Breznitz and Zysman call the "decomposition" of localized manufacturing supply chains is potentially a manner in which wealthy countries can redevelop and retain manufacturing capacity.[3]

Because AM requires a distinct set of human and capital resources, small enterprises frequently face difficulties in developing and adopting these enabling technologies. While wealthy countries seem to share an interest in AM as a means of industrial revitalization, their strategies for developing and diffusing its use differ significantly. Both the United States and Germany have sought to establish dedicated institutional capacity to research and develop AM technologies. Germany, for example, relies on a well-known network of publicly-supported Fraunhofer Institutes. Similarly, and as part of the National Network for Manufacturing Innovation (NNMI), the United States has pursued a focused strategy of funding a range of enabling technologies, among which is AM; the AmericaMakes program in Ohio is a dedicated center for the development and diffusion of AM. The Canadian government, by significant contrast, has adopted a much less focused or coherent approach, intending to couple the adoption of AM with existing local industrial strengths. What is the logic of this less centralized approach? How might it facilitate the absorption of AM as an enabling technology across local economies?

We examine one piece of the decentralized Canadian strategy: the Community and College Innovation Program (CCIP), a federal program that provides funding

1 Livesey (2012); Fuchs and Kirchain (2010); Pisano and Shih (2012).

2 O'Sullivan et al. (2013).

3 Breznitz and Zysman (2013); see also Cattaneo et al. (2010).

for applied research to community colleges that already have some manufacturing capability and contact with surrounding industrial ecosystems.[4] In this paper we undertake three tasks: 1) outline one of the key elements of this comparatively unfocused approach to diffusing AM technologies through community colleges and polytechnics, 2) interrogate the logic of this program, which is built upon the notion of local industrial commons/public goods,[5] and 3) suggest that for a variety of reasons the program may not achieve the kinds of localized public goods and acceleration of AM absorption that it seeks.

To briefly preview the argument, we argue that while advanced manufacturing technologies *may* help revitalize Canadian manufacturing, small firms (SMEs) often face very high barriers to their adoption. Canada's decentralized efforts to helping SMEs adopt these kinds of technologies appear to have fundamental shortcomings. For roughly the last decade, Canada's National Science and Engineering Research Council (NSERC) has funded the establishment of collaborative centers within the community colleges and polytechnics through the College and Community Innovation Program (CCIP). The program facilitates the colleges' provision of direct assistance to SMEs for the use and adoption of new technologies.[6] The CCIP is intended to not only facilitate the uptake of advanced technologies and provide services in a manner that benefits individual firms but that also aggregates into broader public goods or an industrial commons around AM, a strategy that resonates with systems-based understandings of innovation.[7] However, we identify a number of potential problems with the implementation of the program that undermine this goal. Always intended to promote local strengths, the CCIP has, however, allowed for the pursuit of local organizational goals that may contrast with national goals. As a consequence, there has been a principle/agent problem between the federal government and the colleges whereby the colleges' use of CCIP funding may not be conducive to a national strategy for advancing AM. Namely, the approach to layering new programs onto existing organizations has resulted in a system with fragmented interests. It has allowed colleges to train in technologies in which the faculty has existing expertise (e.g., polymer additive manufacturing) rather than pushing technologies that are arguably more appropriate given the national manufacturing sector (i.e., metal sintering).

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4 The decentralized approach to technology development could also be said to include the Industrial Research Assistance Program (IRAP), the most significant source of direct assistance for Canadian business across sectors (Breznitz and Samford (2017)).

5 Pisano and Shih (2009).

6 NSERC (2013). These funds are not intended only for the promotion of advanced technologies or AM in particular, but they have been commonly used for centers with that goal.

7 Freeman (1987); Nelson (1993); Cimoli et al. (2009); Lundvall (2010).

Furthermore, insufficient funding to community colleges means that assistance to firms provides individual private goods to participating firms but seems unlikely to aggregate into the kind of public goods, or vibrant industrial commons, imagined. This has also led community colleges to seek out funding from other government agencies, such as the Canadian Foundation for Innovation, which further adds to the disjointed nature of existing programs. We argue these factors are a consequence of this less-focused, more bottom-up approach to developing AM, which stands in contrast to the U.S. and German approaches, where new institutional capacity is being built to strengthen advanced manufacturing.

In the sections that follow, we (i) very briefly review AM technology, along with the reasons it is seen as potentially transformative. We then (ii) elaborate the ideas of the innovation ecosystem and the "valley of death"—concepts which policymakers and small businesspeople frequently reference. We (iii) outline the contours of Canadian efforts to harness community colleges for explicit use as developers of advanced and AM capacity and how those efforts are intended reshape challenges of adopting AM technology faced by SMEs. This is based on site visits and semi-structured interviews with bureaucrats, college administrators, and enterprises in Ontario. Next, (iv) we discuss the relationship between private benefits and an industrial commons, and suggest that these partnerships fail to produce nation-wide technology adoption and manufacturing revitalization. There are important broader implications of this examination—chiefly related to the decentralization of industrial development programs and the manner in which private benefits aggregate into more public goods—which we draw out in the conclusion (iv).

Additive Manufacturing: Potential and Challenges

Government support for the development and diffusion of AM technologies is predicated on the notion that they have the potential to alter production in a wide array of industries. AM refers broadly to the production of an object with the layer-by-layer deposition of material. It is distinct from "subtractive" manufacturing—in which material is cut away from an original piece—as well as from casting and molding, cutting and bending, and other "traditional" forms of production. It couples digitized computer-aided design (CAD) with machines that can produce a layer-by-layer "print" of the designed object in a relatively short time. Beyond these general similarities, there are multiple differences in AM technology. The primary distinction—and the relevant one in the context of this paper—is between the technologies used in polymer or resin printers and those that produce metallic objects. AM of metallic components typically involves laser sintering, in which lasers trace shapes in successively applied beds of metallic powder, fusing layer upon layer into a solid shape. Polymer technologies typically involve the extrusion of liquid materials through a moving nozzle or print head, where they harden in contact with previously deposited layers.[8] In general, polymer printing is more widely available and mature than metal sintering; indeed, it is relatively mature forms of these technologies that the firms discussed below are seeking to incorporate into production.

AM methods offer advantages stemming from speed and flexibility. Particularly, they are useful when the components to be produced are complex, customizable, and low volume. Prototyping and verification, which inherently involve low volumes that may need repeated adjustment, are procedures that particularly benefit companies. The ability to make prototypes quickly and avoid the production of test molds, easily alter digital designs, do preliminary testing digitally, and produce prototypes in a variety of materials lowers the time, expense, and risk associated with commercialization.[9] There are also benefits for industries that: produce customizable goods or those that find holding inventory is costly; seek to produce complex or lightweight parts that traditional methods cannot manage (e.g., lightweight brackets for airplanes); and want to decentralize production. Whether this impression is accurate or not, many policymakers have seen the potential—particularly the politically popular notion in wealthy economies of repatriating manufacturing jobs—and have begun to make efforts to increase absorption of AM across their economies.

The reality that these expectations encounter is that small businesses often face very high barriers to the adoption of AM, given the upfront costs and technical requirements. AM is highly complex, combining elements from information and communications technologies (ICT) and computer-aided design with materials engineering. Indeed, the U.S. Small Business Administration recently identified eleven endemic problems to SME adoption of AM, most of which generally fall into areas such as lack of access to capital, lack of technical information and expertise, and difficulty with adoption and commercialization of AM.[10] These barriers speak to the need for active policy to promote adoption of AM if SMEs are to be key in revitalizing domestic manufacturing. Canada has seen a chronic erosion

8 Wohlers (2014). Although many forms of AM are relatively mature—leaving adoption as the primary issue—other technologies are developing very rapidly. For example, recent advancements have seen the blurring of the two methods: light beams that are directed at pools of resin, hardening the resin in desired forms. However, the basic distinction between metal and polymer/resin production remains important, as discussed below.

9 Ibid.

10 Harrison (2015).

of the competitiveness of its manufacturing in medium-high tech goods (such as automobiles) and has struggled to replace that with higher-tech manufacturing.[11] Although it shares some of the same targets, Canada's approach to revitalizing manufacturing through AM has been distinct from the United States and Germany, both of which are more centralized. If industrial development policies can be firm-, sector-, or region-specific, the Canadian approach may be thought of as a trans-industry, technology-specific policy that is both decentralized and focused on existing or incipient industry clusters.[12] As we suggest in the following sections, this strategy is built upon the development of locally-appropriate industrial commons around advanced manufacturing to promote absorption into existing industrial areas.

Innovation Ecosystems and Valleys of Death

Given the differences in human and capital resources they require, AM methods are often difficult for SMEs to adopt. The College and Community Innovation Program (CCIP) has been used to establish centers that are, in part, geared toward expanding the absorption of AM technology (and other advanced manufacturing methods). The underlying logic of the advanced manufacturing CCIP-sponsored centers is that raising the levels of expertise, experience, and training around AM will increase uptake in local ecosystems that specialize in particular industries. Jackson offers a useful heuristic for depicting the manner in which innovation ecosystems function.[13] She conceptualizes the innovation ecosystem as two related economies: 1) the "research economy" in which investment in research generates new technologies, which provides the basic technology and ideas for 2) the applied "commercial economy" which adapts, implements, and commercializes those technologies and introduces new technology needs. Jackson represents the ecosystem as two curves—cost of investment in the

11 Carriére (2014); STIC (2014).

12 Porter (2007); see also O' Sullivan (2013), which is discussed on greater detail below.

13 Jackson (~~2013~~). We use this framework not to insist that there is a tidy linear progression from idea to commercialized product, or that research and commercialization are so neatly separated. In fact, there is much evidence to demonstrate the iterative, contingent process of innovation, rather than linear. Instead we use this heuristic to illustrate the notion that there is often a gap in applied research, where SMEs in particular face constant challenges to obtaining, understanding, and adopting new processes or beginning to manufacture new products. This is a general gap that manufacturing extensions services such as IRAP in Canada, MAS in the United Kingdom, and MEP in the United States have long sought to address (Shapira et al. (2015); Breznitz and Samford (2017)).

research economy and return from commercialization in the commercial economy—as reproduced in Figure 1. Along the bottom axis is the stage of development: discovery (dominated by academia and research laboratories), technology demonstration and development (dominated by small enterprises), and commercialization (involving investors and broader industry).

This heuristic draws attention to several features of innovation ecosystems. First, the public funds invested in discovering new technologies are typically greatest at the outset, at the point of so-called "basic science" or primary research, and then decline as the technology becomes mature, if not widely adopted. Second, the returns accruing over the process of adoption and commercialization are not immediate, instead requiring a period during which firms develop the practical means to use the technologies and gather the capital necessary to commercialize on the required scale. Third, in many jurisdictions there is a gap in the life of technology development between the largely public investment in primary research and the full commercialization of the products that incorporate them (or the complete integration of process innovations). This gap, where funding for primary research has dwindled but before commercialization is complete, has been referred to as the "valley of death": the point at which public funding has run its course and private returns and investment are not yet sufficient, frequently leading efforts to commercialize new technologies to fail. Some ecosystems and some

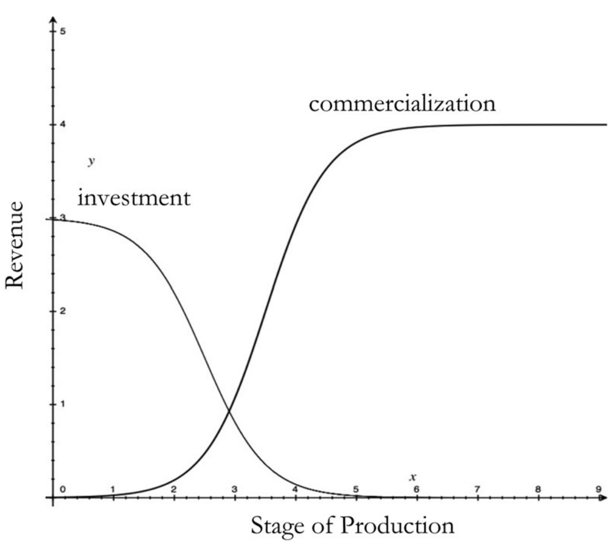

Fig. 1 - B/W online, B/W in print

Figure 1: Valley of Death in Innovation Ecosystem

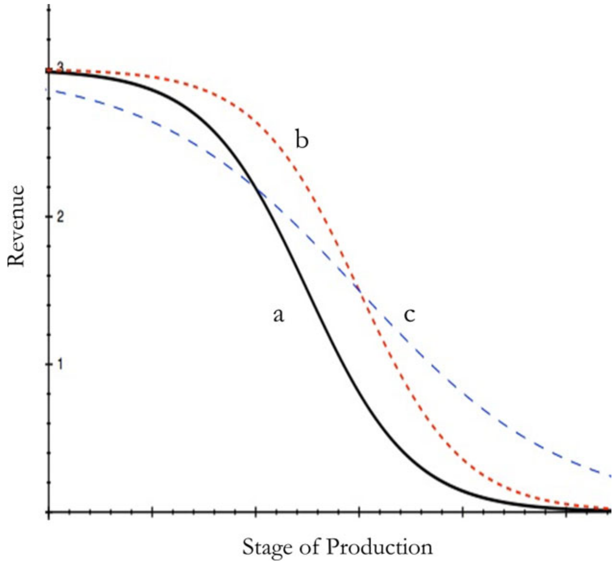

Fig. 2 - Colour online, B/W in print

Figure 2: Shifting Investment Curve

sectors may have wider and deeper gaps than others. When much of the investment in the generation of new technologies is publicly sponsored and the burden of commercialization rests on private industry, this metaphorical valley is a transition from investment to return, from greater public responsibility to greater private responsibility, from discovery to application.

On an *ecosystem* level, smoothing the transitions between these steps is critical, particularly for SMEs that may lack the resources to take those steps on their own.[14] The tendency of an ecosystem to facilitate successful commercialization of technologies is critical to its dynamism. We contend that the shape of these imagined research and commercialization curves—and hence the capacity of an ecosystem to generate and effectively commercialize innovations at a given rate—is frequently a question of public policy. Jackson suggests that the research curve can be shifted to the right by government "championship" of industry through the provision of funding and resources for basic and applied research.[15] On the commercialization side, she suggests that any activities that lower the perceived

14 Firms tend to think of the "valley of death" in terms of their own activities—bringing a particular product to market; we understand it as a dynamic that may be manifest at a broader, systemic level, where firms in the same ecosystem face similar conditions.

15 Jackson (2013).

risks of investing in firms that are trying to commercialize individual technologies will shift the commercialization curve to the left. The consequence of these two shifts is a shrinking of the "valley" that makes adoption or effective commercialization of a technology difficult. We argue that the development of a so-called "industrial commons" around a particular technology or industry has the effect of shifting costs and returns such that the gap between basic science research and commercialization is minimized. Pisano and Shih define the industrial commons as "know-how, advanced product development and engineering skill, and manufacturing competencies related to a specific technology" that are embedded across firms and institutions in a geographically constrained area.[16] The general presence of these capacities in the community theoretically has the effect not only of generating more innovative ideas but also of allowing them to be successfully absorbed and commercialized. We argue in the following section that that the CCIP and allied programs in Canada have ostensibly been geared toward closing this gap for SMEs across industries by promoting the formation of locally specific industrial commons around additive manufacturing methods. The NNMI in the United Sates has had a very different approach, developing a single federally controlled organization devoted to additive manufacturing technology. Similarly, the German federal and state governments have funded a network of Fraunhofer Institutes dedicated to the advancement of AM.

Community Colleges as Industrial Public Goods Providers

The skills and competencies inherent to industrial commons make absorption of a new technology more likely.[17] The intention of CCIP is to use community colleges to construct this kind of industrial commons around technologies that are germane to local economies; many have included additive and advanced manufacturing methods and know-how as enabling technologies that have applications across manufacturing sectors. Community colleges—whose faculty already possess technical expertise and knowledge of the local productive ecosystem—can train the future manufacturing workforce in AM methods and can also act as technical interlocutors with the private sector. The following sections describe how this model fits within the broader scope of Canadian industrial policy and identify the manner in

16 Pisano and Shih (2009), 3.

17 Pisano and Shih (2009). By "new" we simply mean one that has not been widely adopted in an industry. Many forms of AM are relatively mature, but the fact that they are not broadly used by SMEs in, say, the aerospace sector would made them new.

which the CCIP program is intended to provide local public goods that mitigate the threat that SMEs face regarding the adoption of AM technologies.

The Canadian approach to promoting industrial innovation has for decades drawn upon two primary tools. The first is the Scientific Research and Experimental Development (SR&ED) tax credits, which give breaks for the costs that Canadian businesses incur for research and development. The over-reliance on tax incentives has been heavily criticized as being inadequate to spur the adoption of rapidly changing technologies; tax credits have historically accounted for roughly 70 percent of the government expenditure on R&D support.[18] The second is through a manufacturing extension program, the Industrial Research Assistance Program (NRC-IRAP), which was established in the early 1960s. Through this program's regionally-based agents— effectively extension agents—advise companies seeking assistance and providing either direct aid or connecting them to a network of research labs and universities that can assist them. The IRAP program has been deemed highly effective by, among others, the government of Canada, OECD, and the Inter-American Development Bank, benefitting the firms at a cost to benefit ratio of 1:11.[19] While there are possibly positive economic externalities—such as knowledge spillovers —associated with a firm's receiving of assistance from IRAP, the program effectively provides them private goods in the form of research assistance and knowledge.

In the early 2000s, faced with the fact that compared to its peer countries Canada was a relatively generous provider of funding for primary research (largely indirectly through the tax system) but that its SMEs performed poorly in the areas of new product development and technology absorption, NSERC established the Community and College Innovation Program.[20] Much like IRAP, this program was intended to provide direct technical assistance and applied research to SMEs, with the colleges' manufacturing centers acting as consultants rather than IRAP representatives or their network of research partners. Also like IRAP, it was intended to not be geographically delimited in the sense that work was not concentrated in one research organization or cluster that specialized in AM, in contrast to the NNMI. However, beyond manufacturing extension service alone—which benefits individual firms—community colleges were intended to develop into hubs for the local ecosystems. The logic behind drawing upon community colleges was that

18 CCA (2013); Jenkins et al. (2011). The use of tax credits is especially problematic for small firms, which tend to have less capacity to conduct R&D, making tax-based incentives poor remedies for them.

19 Breznitz and Samford (2017); Shapira et al. (2015); see also NSERC (2013).

20 Under the conservative Harper government, although the CCI program grew, the overall public investment in R&D fell significantly relative to peer countries in the OECD.

they were already deeply embedded in their communities: aware of the kinds of industry operating there and the likely technical needs of enterprises and able to train students who generally remain to work in local enterprises.[21] As well-placed potential partners, the federal CCIP funding would permit them to develop regularized forms of interaction between the private sector and the colleges, with the notion that these partnerships would 1) draw upon expertise and available labor in the college, 2) provide small firms assistance and opportunity to upgrade, and 3) give students practical training in advanced manufacturing problem solving. In the years following the 2008 economic downturn, like many other "new industrial policies" in peer countries, the federal NSERC program was expanded to a budget of roughly $50 million CAD annually, and from six original pilot colleges to roughly 100 institutions that are eligible for grants.[22]

In order to understand the functioning of the CCIP's efforts, we undertook semistructured interviews with a range of program stakeholders in the greater Toronto area, which has both a high concentration of community colleges and varied sectoral clusters, from heavy manufacturing to ICT. Interviews included program administrators at the Advanced Prototyping Technology Center at George Brown College, the Center for Advanced Manufacturing and Design at Seneca College, the Center for Advanced Technologies at Sheridan College, Center for Smart Manufacturing at Conestoga College, and the Additive Manufacturing Resource Center at Mohawk College. Further interviews included federal administrators of the CCIP program as well as those in related programs, such as IRAP and the Ontario Centers for Excellence. We interviewed eighteen firms that had been assisted by these college centers. Finally, we interviewed five nonparticipating firms considering incorporating AM methods into their production methods.[23]

These centers function by sponsoring applied working partnerships between college faculty and students and private enterprises that face particular barriers to adopting advanced manufacturing methods. Small enterprises that encounter gaps in their practical capacity to develop an idea or adopt a production or design method apply to a funded community college for assistance. The firm

21 NSERC (2013).

22 The most rapid growth of program funding was in the granting cycles between 2008 and 2011 (NSERC (2013)): 2008–09: nine grants, 2.05 million CAD; 2009–10: twenty-five grants, 14.55 million CAD; 2010–11: twenty-one grants, 28.03 million CAD; 2011–12: twelve grants, 32.16 million CAD28.03. See O'Sullivan et al. (2103) for new industrial policies in the United States, the United Kingdom, Germany, and Japan.

23 Differing confidentiality agreements between the colleges and the firms with whom they work disallowed selecting a sample from the population of firms. The firms are not balanced across the colleges with whom they collaborated.

presents a short-term problem to the college, and the faculty and students use their equipment and know-how to address the applied research question at hand, consulting with the businesses regarding their progress. The gaps faced by the firms may fit anywhere between developing a concept and commercialization. On the former end, an administrator at one of these centers remarked that,

> [t]he smaller companies, all they have is an idea in their heads. A lot of work has to be done ahead of time using our faculty and our students to design the part, and many iterations of that design, and maybe making parts out of plastic first to say, 'Is this what you really wanted or not?' before we even attempt to make a metal part.[24]

For other companies, the gaps are the consequences of production problems that emerge after attempted use or failed experiences with a production method or commercialization of a product that require remediation. For most of the participating firms, the gaps fall somewhere between establishing proof of concept with a particular technology and the verification of an AM prototype in its operational environment. While there is a broad range of projects they will commit to, the college administrators are quick to point out that they do not engage in primary research and that ultimately "who exploits this value [of innovation] is still the job of private industry."[25] The colleges are not interested in acquiring intellectual property or in commercializing the products for their own gain, but rather see themselves as applied research centers and as providers of human and physical resources to address specific business failings. In the words of one college administrator:

> Here is where we are: we have a technological hub facility, with expertise of our faculty. We have the manpower of the students who are willing to work on these projects, spending more time on these projects, and hopefully we can solve them [for the firms]."[26]

What the college centers do, then, is to provide physical and informational resources that fit where small firms might experience problems with the adoption or use of an advanced technology in their process.

On the level of individual firms, these partnerships with the colleges clearly provide two distinct kinds of assistance. In one respect, the aid they receive is *informational* and addresses technological incapacity. SMEs are well known to face more significant constraints on their informational access to new technologies and do not have the same levels of R&D as their larger counterparts due to a lack of personnel and capital for funding these activities. Moreover, AM and other

24 Author interview; Mohawk College, February 4, 2015. Names of interviewees are withheld here in order to comply with research ethics review.

25 Author interview, Seneca College, January 30, 2015.

26 Author interview, Sheridan College, December 2, 2014.

advanced methods are, in particular, what one administrator referred to as "closed areas," blocked by very high barriers to entry and a lack of experience with technologies that are fundamentally different from traditional manufacturing. This college administrator posited that, "For them [SMEs], it's a strange area because it's closed, they don't have any experience, and they cannot go back to the data and say, 'Oh if I just do this, it will be correct.'"[27] So the contact with a community college center that promotes advanced manufacturing allows the enterprise to gain access to information about and have a direct experience with new technology; without that exposure the field of AM would remain far less accessible to them.

On the other hand, the partnerships may be understood as satisfying the needs of SMEs by providing *working capital* to the enterprises through the colleges. One of the key features of SMEs is that their size severely limits the number of employees, the amount of space, and uncommitted physical capital that they can dedicate to their own research and development. Under these partnerships, the colleges' facilities and efforts on behalf of the enterprise are subsidized by funds from the federal and provincial governments. The colleges provide physical space, machinery, expertise, and even labor for the enterprises that they would otherwise be without or that they would have to raise and spend additional funds to acquire. While the exposure to the technology itself is important, the access to this working capital is also a critical benefit for the participating SMEs.

By most indications, SMEs who have been engaged in projects with a community college center through the CCIP have been generally positive about the outcomes of their participation with the colleges. Some 66 percent reported concrete changes in their capacity to introduce improved products, processes, or services.[28] Almost half reported that their participation had lowered the amount of time that they ordinarily need to bring a product or service to market. These indicators are suggestive that—beyond one-time improvements in a particular product or process development—working with the college raised their abilities to continually do R&D themselves, presumably by providing information about "closed" technology areas in the case of advanced manufacturing. The colleges themselves reported an increased ability (in some cases from nothing) to address the needs of local SMEs as well as adjusting their course designs to better fit with their increased role assisting private sector actors.

27 Author interview, Sheridan College, December 2, 2014; see also Harrison, (2015).

28 NSERC (2013); these are based on a survey of eighty-eight participating firms.

Public Goods

The goals of these college-based centers go beyond providing private goods to individual firms. The provision of information, training, and working capital to firms, as described above, is a private benefit to those individual enterprises engaged in partnerships with the colleges; we argue, however, that beyond the private goods that accrue to the individual firms, in the best of cases this partnership program may provide public goods at the level of the local innovation ecosystem. Specifically, the aggregation of increased workforce training in enabling technologies like AM, broader outreach by the colleges into the private sector, more technically capable graduates, and more knowledgeable companies should provide the foundation for an industrial commons around additive manufacturing. As suggested previously, this commons might be imagined as helping narrow the gap between the research and commercialization economies.[29] This section specifies the relationship between individual (i.e., private) and ecosystemic (i.e., public) benefits and the manner in which the public goods may raise the absorption of advanced technologies (see Table 1).

Public goods are typically defined as information, commodities, or services that are available to all members of a group (i.e., "non-excludable") and are not exhausted by use (i.e., "non-rivalrous").[30] Pisano and Shih's concept of an ecosystemic industrial commons—locally shared knowledge, skills, and competencies—is framed as such a good.[31] Debates about the management of traditional commons have centered on how governance can control consumption of an existing good though government or private coordination.[32] By contrast, in an industrial commons, the goods themselves may need to be developed by coordination to promote the development of technologies, broad training, and prevention of exit by key organizations. One of Pisano and Shih's key recommendations for the

29 A factor that complicates the assessment of this program is that the ecosystems that the community colleges are intended to strengthen are not specifically defined. They are roughly geographic, roughly sectoral, but there are no bright lines that would facilitate the collection of aggregate quantitative data inside/outside the cluster, before/after the program, and so forth. We therefore rely on accounts from the primary stakeholders (college center administrators, participating firms, and program officials from the CCIP and similar programs) of where the failings of the program might lie.

30 Samuelson (1954).

31 The industrial commons is rhetorically linked to the traditional notion of a commons, which is not a public good but a common pool resource (i.e., "non-excludable" but "rival"). The spillovers of knowledge and capacity that Pisano and Shih (2009) imagine are not exhausted by use, however, and are thus public goods rather than club goods.

32 Hardin (1968); Ostrom (1990).

Table 1: Public and Private Benefits from Colleges-Enterprise Partnerships

Individual Benefit (Private Good)	Systemic Benefit (Public Good / Industrial Commons)
Applied information about particular application of "closed" technology like AM; increased capacity for R&D long-term (Firm)	Broadly raised capacity and levels of practical/adaptive research across ecosystem
Subsidized working capital for a project (Firm)	Systemically lower costs of adopting AM technologies and conducting R&D
Individual human capital (Students/Workers)	More highly trained workforce in AM; greater systemic understanding of potential use of AM; decreased risk of adoption of AM methods and use in commercialization
Program Example: Industrial Research Assistance Program (IRAP)	Program Example: Community and College Innovation Program (CCIP) (in intention)

revitalization of a failing industrial commons is increased investment in applied research and practical application, which is precisely where the CCIP program is targeted.[33]

As Canadian community colleges operate in the area of applied rather than primary research—adoption and commercialization of technologies—the large increase in federal funding for the colleges moves funding toward later stages of product development. In other words, resources are added to activities such as practical or applied research rather than to the primary research that the federal and provincial governments have traditionally subsidized, largely though the university system and through tax credits. Clearly, this shift—which maintains funding for basic science research in the universities and research institutes—implies a greater total amount of funding going toward investment in the adaptation and diffusion of difficult to adopt, high-tech manufacturing methods, such as AM, to the benefit of SMEs that have typically little to do with primary research on these manufacturing technologies.

Heuristically, this can be illustrated by a rightward shift of the research/investment line, demonstrating the extension of funding for investment further into the cycle of product development. In Figure 3, if (a) is the baseline, line (b) illustrates the extension in greater degree to adoption and practical research, without diminishing the investment in pure science R&D. Alternatively, as in line (c), the extension of funding to applied research and commercialization may be accomplished

33 Pisano and Shih (2009), 9.

Fig. 3 - Colour online, B/W in print

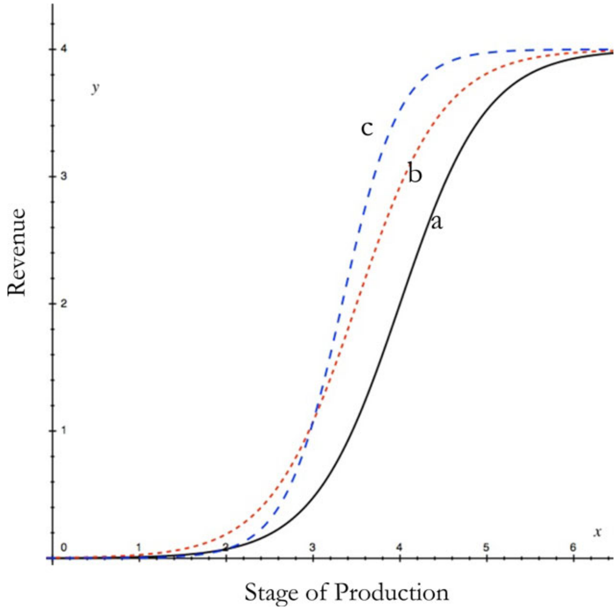

Figure 3: Shifting Commercialization Curve

by a rebalancing of investment, reducing government investment into primary research activity. In either case, the point is that investment is increasingly devoted to applied research, adaptation of new technologies, and cycles of commercialization, rather than discovery. The expectation is that funding of these later stages of product development and technology adoption will reduce the gap between the research and commercialization economies, making the valley of death narrower or shallower. One critical note is that this shift has not been limited to a single industry, but should instead allow for more successful adoption of AM technologies across industries, from medical devices to aerospace.

While these community college partnerships may be interpreted as shifting the research investment line rightward to reduce the challenges of commercialization of particular technologies in a given ecosystem, they are also clearly aimed at shifting the commercialization curve leftward (i.e., so returns accrue more quickly). At an aggregate level, we interpret these programs as ideally shifting the commercialization curve in two ways. First, by providing the human and physical resources necessary for technology adoption or adaptation, the college programs have the effect of reducing the private time and effort necessary to adopt new process or product technologies. The leftward shift of the baseline (a)—seen here in line (b)—as well as the increased inclination of the curve (c) in

Figure 4 depict this insight. Practically speaking, the reduction of risk, the provision of working capital for commercialization, and so forth, decrease the time and private effort necessary for the commercialization and return. As an example, the president of one firm described its work with Mohawk College as speeding its efforts to overcome a design barrier:

> Because of the design of our particular first product that we have… we wanted it to be as close to the design parameters as we could get. There was a sticky point with us that we were having to redo our design to be able to fit the machines, which is quite common in engineering to do. We were hoping that there was another method to do it. This is where Mohawk [College] came up. They showed us that, yes, they can do the thing that we need to be done. That was the bottleneck…[34]

Moreover, the partnerships can also speed adoption and commercialization, shifting the commercialization curve, by reducing the need to either save or raise additional capital. For example, the working capital provided by these industrial commons may stand in for financing that would otherwise need to be raised or borrowed, facilitating the speed at which SMEs may move forward with product development.

Finally, for SMEs the programs clearly reduce the amount of risk they face in their efforts to successfully bring new technologies to market. This reduced risk is in part a consequence of the added efforts of experts and the additional labor committed to the project in question. Where firms might otherwise conclude that the monetary risks associated with the failure to effectively adopt a new technology are too great, the promise of a subsidized project team to work on developing a solution lowers the potential costs, even if the technology is never successfully commercialized.

The effect of broadly increased training of students—in additive and advanced manufacturing methods in this case—is also consequential. Clearly, human capital accrues to individual students, who are then better situated to find employment in higher value-added tasks. For individual firms, the opportunity to employ highly trained workers who already have experience with applied research has obvious benefits. In aggregate, however, the benefits should accrue to the ecosystem as a whole. That is, a dense population of workers trained in the use of AM methods should reduce both the time and the risk associated with bringing new products and processes to markets.

Those studying innovation from a management perspective tend to emphasize factors that shift the commercialization curve, such as finance; those focusing on the technical generation of innovations or invention tend to focus on policies and conditions that might shape the research investment curve. It is our contention

34 Author interview, small medical device firm, February 16, 2015.

that policies that help provide an industrial commons and simultaneously and systematically shift the two lines toward one another—or "bridge between basic research and commercial R&D" in Pisano and Shih's terms—are likely to be the most successful at improving the rates of technology adoption.[35] Because primary research is so often the role of the public sector and commercialization best accomplished by the private, policies that shape both inhabit the area of public-private arrangements and are likely to be geared toward applied research. As the breadth of private firm beneficiaries and trained graduates increases, the systemic gap between discovery and commercialization should become less daunting. That is, ostensible private goods provided to individual firms aggregated into broader public goods in, say, the form of broad AM knowledge and capacity which affect even those enterprises that are not participants in the CCI programs.

Challenges to the national strategy of local public goods provision

The community colleges have been imagined as technology and training hubs at the center of their ecosystems, providing the information, training, and services necessary to create industrial commons around AM and other advanced manufacturing technologies. There is much appeal in the Federal sponsorship of community college partnerships: it values local capacities; draws on existing organizations; individual firms are pleased with their contacts with colleges; the elements of these public-private cooperative programs are politically appealing, touching a wide swath of potential beneficiaries; and they should result in broad social benefits, raising the levels of human capital, providing public goods to promote more innovative and globally competitive SMEs, and spurring economic growth and reinvigorating traditional manufacturing.[36] Whether this partnership model does deliver all of those benefits—and not simply *private* gain for those firms lucky enough to participate—is less clear. An open question is how effectively these programs 1) translate or aggregate private assistance into public benefits for the broader innovation ecosystems in which they operate and 2) amount to a coherent national strategy. We identify three features of the existing CCIP that represent challenges to these two outcomes: principal-agent problems between the federal government and colleges, program density, and the technical limits and appropriateness of community colleges' capacities.

35 Pisano and Shih (2009), 9.

36 NSERC (2013).

Principal-agent problems

One of the central problems with the federal approach to promoting multiple, local industrial commons is the very decentralization of decision-making that makes local targeting possible. The use of community colleges is rationalized by federal and provincial governments based on their presence in the local community and ecosystems: They understand the production methods of local firms, what kinds of skill requirements employers have, how to anticipate what skills they will need, and typically incorporate local business leaders into their directory boards. However effective this may be on a local level, it remains unclear whether this constitutes a viable national strategy. Scholars and policymakers have argued that decentralization allows national programs to draw upon the knowledge and proximity of local officials to the affected populations.[37] This seems appropriate for a program seeking to diffuse a set of advanced manufacturing technologies into a variety of industrially distinct local ecosystems. However, there remain questions about how well the local community college programs function together as key players in a national policy around AM use.

First, there are concerns with whether the decisions made at a local level by individual community colleges aggregate into a coherent national strategy. If, as suggested elsewhere, there are more firms seeking access to public resources than can be provided access, the question of the criteria by which private-sector interlocutors are chosen becomes salient. College program administrators suggested that the decisions about which firms to engage were based on perceived fit with their colleges and students: "Largely, faculty in community colleges are engaged in applied research because they want to improve their students' learning. That's the primary motivation for the community college faculty."[38] The decisions, thus, rely at least in part on what faculty interests are and what capabilities they currently possess in their centers (more on that below), rather than which project would provide the most benefit to the broader ecosystem. These criteria may be appropriate for the local students, but insofar as the program is aimed at national industrial development and the diffusion of technologies like advanced manufacturing methods, they are a potentially sub-optimal basis for selection of business partners. There is a clear discrepancy between the role of the community colleges as envisioned by the federal granting agency, which has a federal focus, and what is envisioned by the colleges. For example, a federal administrator of the CCI grants reported,

37 Oates (1972); DeGroot (1988).

38 Author interview, Sheridan College, December 2, 2014.

> They focus on these local companies because this is mainly the objective of the [Community College Innovation] program to help SMEs to be more innovative, to help them to commercialize better stuff or develop new products and adapt new technology. The colleges are really there to help the SMEs.[39]

This focus on the capacity of SMEs differs starkly from the focus on training their particular students and choosing private sector partners based on existing faculty interests. The fact that there is such a discrepancy between the colleges (deciding on firm partners) and the federal and provincial governments (deciding on funding) suggests that the relevant decision makers are not necessarily working toward the same overall goals due to a principal-agent problem not uncommon to decentralized policy initiatives.[40]

A related salient issue is the question of the coordination or arrangement of the means by which firms come to the partnerships with the community colleges. Interviews with college administrators, policymakers concerned with the partnership programs, and firms all indicated that loose organizational structure and reliance upon network contacts was inefficient. College administrators identified multiple, un-coordinated means by which businesses might make contact with them. Most saw the arrival of their private sector partners as ad hoc: They might be referred by provincial or federal agencies such as the Industrial Research Assistance Program (IRAP); might be informed about programs by a business organization; or might just know of the college and its programs from everyday experiences. This betrays a sense that there is little overall coordination of the efforts to ease the absorption of advanced manufacturing methods in SMEs. A federal IRAP official was less generous when asked about coordination:

> No, the answer is no [there is no effort to coordinate]. We tried a few times, but these funding agencies work the same way as the dairy industry across Canada…: this is mine, and you can't touch it; I'm not going to let you get mixed into my decision-making process. In other words, this is my particular empire.[41]

This inefficiency is borne out in the experiences of enterprises as well. For example, one firm that ultimately ended up working with one of the community colleges indicated that they had initially sought help from a university in the United States because the IRAP administrators were unaware of the community college center within their own municipality that was working on the very same technology. Similarly, elsewhere we document the efforts necessary for a single business to uncover the services necessary to prototype and begin production of an industrial fastener. The broader point, then, is if the partnerships are dependent upon which

39 Author interview, NSERC Official, Febraury 12, 2015.
40 DeGroot (1988); Tommasi and Weinschelbaum (2007).
41 Author interview, IRAP Official, January 21, 2015.

firms approach the colleges, which is in turn a function of informal and ad hoc networks or fortuitous accident, this provides a poor basis for a consistent and coherent national policy that functions effectively across industrial areas.

Program density

The second concern is with the density of partnerships and whether the provision of these public-private partnerships is sufficient to truly constitute a public good or a broader industrial commons around AM or other technologies. As many have pointed out, there are relatively few examples of pure public goods, and most goods land somewhere on the spectrum between pure private and pure public. As suggested above, we can reasonably conclude that industrial commons and funding, such as the community college partnerships outlined here, when effective, are clear public goods: They can develop and spread training and knowledge that reduce the aggregate economic losses associated with failure to adopt new technologies and raise the level of human capital appropriate for advanced manufacturing. The problem arises if the provision of public-private partnerships is too sparse. With low program density, the benefits provided by the assistance program tend toward private goods that accrue primarily to the participating enterprise alone and away from a broader program that has an effect at the level of the ecosystem. In other words, if there are too few partnerships, the aggregate effect on the broader ecosystem becomes negligible, even though participating firms still benefit individually.[42]

Although the federal and provincial governments have been expanding these programs, year over year, there is some evidence that levels of provision fall below private sector demand, across the 100 or so eligible colleges. One clear indicator of this is the capacity of the colleges to engage in partnerships with firms seeking assistance. One administrator reported being approached by firms five or six firms a week, when ultimately his college has the space, expertise, and labor to work with between forty and fifty firms per year. Asked about outreach, the administrator responded,

> We want people to approach us, and we do not approach people, the industry directly… But, really imagine if I advertise what I am doing, now suddenly, 100 are coming. How can I respond to that need?[43]

42 In such a situation, the program would effectively become a manufacturing or business extension service, much like IRAP, a long-standing and better funded program, but whose goal is not cluster development.

43 Author interview, Sheridan College, December 2, 2014.

If, as suggested, only 20 percent of firms seeking assistance are able to receive it, and that making the services more widely known will only lower that proportion, the obvious question is whether that is sufficient. If technical assistance is only provided to a small proportion, the system-wide benefits of that assistance are less certain and aid begins to look less like an public industrial commons than a private good issued to a select few: trained students for the broader community are undersupplied, fewer firms receive assistance with the barriers they currently face, and, critically, they do not experience the long term improvement of their research capacities that participants identified as a benefit. However, the colleges themselves are not overly concerned with such under-provision because they perceive their top priority to be the development of human capital through student training.[44] Administrators of the advanced manufacturing centers very frequently offered some version of the sentiment that the training of students was their top priority and that the participation of the private sector in partnerships was geared toward that end.[45] As such, for the colleges the sufficient number of partnerships is related to the training of students rather than the number or proportion of enterprises served.

Appropriateness of technology

The final problem relates to the limits and appropriateness of expertise in the community colleges themselves, and, thus, for their partnerships to be able to ease adaptation and commercialization of AM methods across sectors of the economy. One official involved in the program identified the broader industrial aim of their cooperation with SMEs as: "Keep those parts [produced] here at home for the manufacturing sector, bring parts back home, and a make parts that nobody else can make and export those parts."[46] However, while in most of manufacturing that is relevant for industry in Canada (particularly the auto and aerospace industries) where final products are metal, the vast majority of additive manufacturing capacity in the colleges is on polymer printers. While these polymer machines may be useful for rapid prototyping and design applications, they use a dedicated technology and the know-how is unlikely to bleed over into metal

44 One possibility that needs further exploration is that while enough public-private partnerships may be formed to provide the necessary human capital development and training for students, that this number of partnership falls short of closing enough of the gaps faced by firms seeking to adopt AM or other advanced methods.

45 Author interview, Seneca College, January 20, 2015; Author interview, Sheridan College, December 2, 2014.

46 Author interview, Mohawk College, February 4, 2015.

sintering.[47] Moreover, polymer prototypes are unable to be verified in simulated or real environments where a metal component will ultimately be used; “functional” metal prototypes rapidly produced with additive methods may potentially be verified in their working environments. However, the colleges typically lack the capacity to use metal sintering to do diagnostic testing or functional prototyping on many parts that they are able to produce. If the colleges are limited technically, then they may only be capable of helping bridge the systemic gaps in certain kinds of manufacturing, or assist some kinds of manufacturers up to particular levels of development, without actually spanning the valley of death. The danger, then, is either providing public goods that assist firms only to certain technology stages and not all the way to commercialization or extending a great deal of effort to develop industrial commons that neither effectively combine AM with existing local strengths nor address local needs.

In short, there are indications that because of the limitations in the amount or type of assistance offered through these college-private-sector partnerships, the goods provided behave more like private goods that are chosen with competing or inconsistent criteria and provided to a select group of participating firms, than like public goods that reshape the broader innovation ecosystem by providing elements of a vibrant industrial commons around the AM technologies that can reduce risk, cost, and time to market.

Conclusions and future considerations

Canada’s College and Community Innovation Program does parallel the trend of recognizing the “systems-nature” of manufacturing in the so-called new industrial policy in the developed world.[48] We have argued that the College and Community Innovation Program is based on the idea of creating local ecosystem hubs from existing community colleges or greatly enhancing their roles in local innovation ecosystems. This theoretically moves a step beyond predominantly manufacturing extension type programs—such as IRAP—by providing applied research services in such a manner that the benefits to the businesses, students, and colleges themselves also aggregate into local public goods. These public goods or local industrial commons would ideally increase the adoption of AM and other advanced manufacturing methods by broadly raising the level of knowledge, capacity, and

47 See Wohlers (2014). The technologies for polymer printing and metal sintering are significantly different. There are some elements, such as digital design, that are transferrable, but from both an equipment and materials perspective, there is little correspondence between the two.
48 O’Sullivan et al. (2013).

experience with these methods, and reduce the risk of adaptation of these methods into their production. That said, we have argued that—given available evidence—principal/agent problems, poor coordination, technical limitations, and underprovision are likely to undermine the ability of the CCIP to effectively achieve these goals. This is not to claim that the program is of no value, simply that the tensions that we have identified are likely to reduce its capacity to generate local industrial commons, leaving the colleges operating, effectively, as a manufacturing extension service, like IRAP.

Parallel efforts aimed at the diffusion of advanced manufacturing generally and AM specifically in the United States and Germany underline the challenges presented by the nature of Canadian efforts to promote advanced manufacturing in part through the community college system. The CCIP is clearly a program that targets "cross-sectoral manufacturing-based activities," as do American and German policy; similarly, the "factor inputs" that it intends to improve are "labor" and "knowledge."[49] But the manner in which the programs are structured is significantly different, and these differences underline some of the weaknesses of the CCIP that we have described. The U.S. federal government has begun to provide public goods to help the adoption of AM and digital fabrications through the NNMI program (AmericaMakes) in Ohio. NNMI is a cluster-based program that seeks to promote both the generation and diffusion of advanced manufacturing methods by providing access to manufacturing technology and facilitating contact between private sector actors and educational institutions and the research infrastructure.[50] As a single cluster dedicated to the development of AM manufacturing, this approach is clearly more focused than the program operating through the Canadian community colleges, whose interests are divided by pedagogical interests and localized capacities. Although it seeks to take advantage of particular existing manufacturing capacities in Youngstown, OH, the program is not layered on top of existing organizations (i.e., community colleges). While community colleges have to fulfil both a teaching and now a research role on a limited budget, the center in the United States adds to institutional capacity strictly dedicated to building up an AM industrial commons. That unity of purpose notwithstanding, it might face similar challenges to those in

49 O'Sullivan et al. (2013) plot "level" of policy intervention against the targeted "national manufacturing system 'factor inputs'" in order to demonstrate how national policies depart from one another. Cross sectoral policies targeting knowledge and labor are common to Germany, the United States, the United Kingdom, and Japan. Other Canadian programs are clearly sectoral: Auto21 and the Automotive Supplier Innovation Program (ASIP) do in the automotive sector, for example.

50 Livesey (2012); O'Sullivan et al. (2013).

Canada in terms of program density considering there is only one center dedicated to AM as part of the NNMI. Germany, on the other hand, has a more robust technological infrastructure and relies largely on the system of Fraunhofer Institutes that was established in the early post-war years to assist small businesses. Each of the roughly sixty-seven institutes is dedicated to a particular industry or set of technologies and has comparatively greater expertise and focus than the typical community college. Similarly, as they are dedicated to business assistance and applied research, the decisions of the institutes about how to operate are not divided by pedagogical concerns. AM expertise is undertaken by thirteen institutes that are coordinated in one alliance and the partner institutes focus on related competencies, such as advanced materials and digital design.[51]

Because of this lack of centralized focus, the CCIP embodies several tensions that seem to be absent from the NMMI and Fraunhofer Institutes. First, there is a clear tension between the federal government's aims in promoting AM and other forms of advanced manufacturing across industrially distinct clusters and the decentralized nature of using community colleges as the linchpins of local industrial commons. On the one hand, because the community college programs are geared toward the adoption of advanced manufacturing methods and not toward a particular industrial sector, the flexibility to choose the most relevant private sector partners for the local ecosystem is important. After all, the existing strengths or capacities differ by region, so the ability to focus on a given sector should allow for federal funding to be targeted most appropriately. Assistance may be able to focus on, for example, autos and auto parts in heavy industrial areas like Hamilton, ON, or printable IT devices in the more tech-oriented Waterloo, ON area, where existing networks of firms may further promote technology diffusion.[52] While decentralization in this respect is likely positive, the differing aims of organizations and agents at different levels of decision-making appears problematic. If the limited number of firm partners are chosen on the basis of college faculty interest and pedagogical opportunity, this is likely to produce different partnerships than if the interest of the most strategic local firms is the top criterion for selection, as implied by federal officials. Firms seeking assistance are unlikely to be considering the broader benefits to the local ecosystem. These differences of intention—indigenous to decentralized control—may undermine the effective diffusion and adoption of advanced manufacturing technologies. More focused and dedicated approaches to developing and diffusing AM methods, such as the ones being undertaken at AmericaMakes and numerous

51 http://www.generativ.frauhttp://www.generativ.fraunhofer.de/en/profile.

52 Samford (2017).

Fraunhofer Institutes, may be more effective by virtue of the concentration of decision-making.

A second tension that emerges from our analysis is that between individual and systemic views of the challenges to commercialization. In interviews, SME operators often spoke of a valley of death that their firms individually face in adopting new technologies or using them for commercialization. From their perspective—operating in the *systematic* gap where adoption of new technologies is risky and costly—they face and talk about this phenomenon in individual or micro terms. From this perspective, this valley is a permanent feature of their operations and any technology, product, or process changes will be associated with the risk of failure. As such, they perceive the need for policies and funds that mitigate risk as a *permanent* necessity. This raises the question of how policymakers—who see these phenomena at a systemic or macro level—perceive the need for on-going active funding of these projects. Our intuition is that they do not see the need for programs such as the CCIP to go on without end at the same (or higher) funding levels. The participating colleges themselves have raised doubts about the self-sustainability of the centers, suggesting that any broader systematic benefit may be lost with the cessation of federal funding. In short, there may well be a political conflict baked into these distinct micro and macro views of the valley of death.

A final point returns to the distinction between polymer printing and metal sintering, and raises the question of whether more aggressive policies are necessary to push many local ecosystems to move beyond their existing capacities. As of this writing, only one of the interviewed centers was working with metal sintering machines. Located in a historical metallurgical cluster, it is precisely the kind of college that proponents of the decentralized approach would have expected. That said, the greater Toronto area and Southern Ontario more broadly have a history in the production of metal goods (auto and aerospace parts among them) that extends well beyond the heart of the steel industry. The future need for metal sintering knowledge is fairly obvious. However, if the inclination of colleges is to focus primarily on their existing capacities and most small firms themselves do not use the technology yet, it is not apparent where the impetus to jump from polymer printing to metal sintering will come from. That is, it is not clear that the decentralized approach to building up college centers will provide the scale of sintering capacity that will be necessary in the region in coming years. In the broadest sense, this is a question about the lengths to which governments must go to facilitate and encourage innovation and growth among agglomerations of firms, particularly in areas beyond their historical strengths.

Like several of its peer countries, Canada's profile as a producer of manufactured goods has declined over recent decades, with manufacturing job losses in the most traditionally industrialized areas of Southern Ontario and Quebec.[53] Policymakers and academics have framed AM as a broadly applicable technology that has the capacity to transform and revitalize manufacturing across a number of particular industries. Time will tell whether Canada's approach to promoting the broad adaption and application of AM technology through the CCIP and local industrial commons is successful and whether broader use of AM helps reverse declines in domestic manufacturing. What is clear at this point is that the nature of decentralization in the program, the expectation of aggregation of private goods into multiple industrial commons, and the apparent expectation of local sustainability in the ecosystems are all characteristics of the CCIP's efforts to advance additive manufacturing that may ultimately render it akin to a manufacturing extension service rather than an effective developer of local ecosystems.

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