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The Internet of Things and Printed Electronics: Case Studies of Innovation by SME Manufacturers

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This paper examines the firm and industry-level innovation dynamics enabling Canadian manufacturing SMEs to harness printed electronics (PE) in order to enhance the value chain positioning of their traditional product offerings via Internet of Things connectivity. Case studies of intelligent packaging, intelligent clothing, and medical wearable SMEs highlight how firm-level IoT innovation capabilities are enhanced by partnering with supply chain actors at the industry-level, as well as through participation in government research consortia. As integrators of PE technology into traditional products, these firms are able to successfully shift their positions and value propositions in their respective value chains. The findings of this research illustrate the potential role of both government and industry consortiums in enabling SME manufacturers to capitalize on the emerging opportunity of IoT through integration into Global Production Networks (GPNs) and Global Innovation Networks (GINs).

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I. Introduction

This paper employs semi-structured qualitative interviews to analyze three case studies of Internet of Things (IoT) product innovation by Canadian Small-Medium Enterprises (SMEs). Part I will contextualize this paper's case studies with reference to the literature on the unique challenges faced by SMEs engaging in collaborative open innovation (OI) partnerships, which are increasingly seen as necessary to carry out IoT product innovation. This literature informs the research questions of this paper: What partnering strategies do SMEs employ to overcome knowledge gaps to innovate in IoT products? What is the role of innovation intermediaries (government and industry associations) to facilitate this flow of knowledge? Part II will lay out the case studies of intelligent packaging, intelligent clothing, and medical wearable SMEs who have successfully harnessed printed electronics (PE) in order to enhance the value chain positioning of their traditional product offerings via Internet of Things connectivity. Part III analyzes the firm-to-firm OI partnering strategies employed by the three case study firms to facilitate knowledge flows. The IoT case studies exhibited an orientation towards upstream partnerships with suppliers, contrary to the expectation of downstream partnerships with clients in the literature on OI in SMEs. Part IV will then analyze the network-enhancing role of printed electronics innovation intermediaries, specifically an industry association and a government lab. The engagement dynamics reported by the IoT case studies corroborate many aspects of the literature on OI in SMEs, including the network-enhancing potential for different types of innovation intermediaries to enable SMEs to bridge knowledge gaps. In sum, this paper's findings contribute to the literature on OI in SMEs in two ways: 1) extending the OI in SME literature into the context of IoT product innovation yields observations of distinct upstream firm-to-firm partnership orientations; 2) the case studies reinforce the literature's emphasis on the network-enhancing role of intermediaries by providing a more granular, detailed treatment of the role of innovation intermediaries than is typically garnered by survey-based analysis.

II. Literature on Barriers to SME Internet of Things Product Innovation

This section contextualizes this paper's case studies with reference to the literature on the unique challenges faced by SMEs engaging in IoT product innovation. This literature informs the research questions of this paper: What partnering strategies do SMEs employ to overcome knowledge gaps to innovate in IoT products? What is the role of innovation intermediaries (government and industry associations) to facilitate this flow of knowledge? Innovating new products that are IoT enabled has been shown to require deeper collaboration and partnership strategies than traditional product innovation(Leminen, Rajahonka, & Westerlund, 2015). This stems from the underlying nature of IoT technology as compared to non-connected manufactured products. Specifically, embedding sensors and connectivity into products that previously were not connected to the internet requires differentiated skill sets and knowledge bases than those possessed

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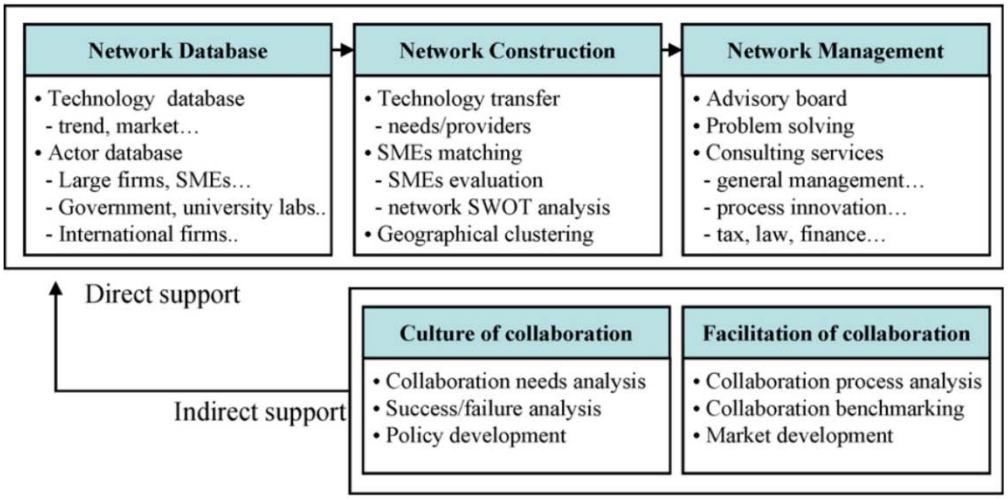
by non-IoT manufacturers (Kim, Lee, & Kim, 2016). This leads to the necessity for firms to adopt a more collaborative orientation when pursuing product innovation within the IoT ecosystem(Kim et al., 2016). Research on IoT business models indicate that "software & app developers, launching customers, hardware partners and data analysis partners are the most important partnerships types", as firms typically do not have these competencies in house (Leminen et al., 2015, p. 677). From a business model perspective, Leminen et al.'s survey results found that "incorporating IoT products in the product portfolio is a specialization that is (partly) acquired by outsourcing" and that often times "it is not possible to build your solution alone and IoT companies will have to outsource also crucial activities to partners" (Leminen et al., 2015, p. 677).

This imperative to collaborate speaks to a broader trend outside of the IoT sector, where the dynamics of firms engaging in collaborative innovation strategies have increasingly been studied within the Open Innovation (OI) literature. Open innovation has been characterized as follows:

"Valuable ideas can come from inside or out of the company and can go to market from inside or outside the company as well. This approach places external ideas and external paths to market on the same level of importance as that reserved for internal ideas and paths to market during the Closed Innovation era"(Chesbrough, 2003, p. 43).

The literature on OI is primarily focused on large firms in high-tech industries (Hossain & Kauranen, 2016). Therefore, this study's focus on SMEs who leverage OI to innovate in traditionally low value sectors such as manufacturing and garments serves to fill a gap in the literature on OI in SMEs. The literature on SME participation in Open Innovation has identified barriers which function to impede SME adoption of OI (Bigliardi & Galati, 2016; Hossain & Kauranen, 2016). Bigliardi & Galati's survey of 157 Italian SMEs identified these barriers to SME adoption of OI to include 'knowledge', 'financial and strategic', and 'collaboration' and 'organisational' barriers (2016). SMEs possess limitations, such as resource scarcity, unstructured innovation processes, and unstructured internal capabilities (Hossain & Kauranen, 2016; Lichtenthaler, 2008). On the other hand, SMEs have unique traits that enable OI, such as specialized knowledge and more flexibility in their decision making (Christensen, Olesen, & Kjær, 2005). These SME-specific barriers and traits speak to the fact that "building absorptive capacity – firms' ability to sense, value, assimilate, and apply new knowledge – is a prerequisite for sourcing innovation from external sources" (Hossain & Kauranen, 2016, p. 63). Furthermore, comparisons between OI in large firms and SMEs have found SMEs to be more dependent on OI than large firms (Spithoven, Vanhaverbeke, & Roijakkers, 2013). The literature has shown that SMEs prefer to collaborate more with customers than with suppliers (Hossain & Kauranen, 2016; Theyel, 2012). Hossain and Kauranen's literature review on OI in SMEs has identified a gap in the literature relating to understanding partnership strategies of SMEs vis-à-vis the pros and cons of collaboration with customers and suppliers (Hossain & Kauranen, 2016, p. 69). Therefore, this paper's first research question addresses this gap in the literature by analyzing what partnering strategies SMEs employ to overcome knowledge gaps to innovate in IoT products.

Another gap identified by Hossain and Kauranen's literature review on OI in SMEs relates to understanding the role of intermediaries in enabling OI in SMEs:"although intermediaries play pivotal roles in removing hurdles for SMEs' efforts to adopt OI, they have received limited attention in the current literature (Hossain & Kauranen, 2016, p. 69). Lee et al. examine open innovation in the context of SME by suggesting a network model that emphasizes the role of intermediaries in linking SMEs to knowledge networks (2010). Their research results "support the notion of open innovation in SMEs, by proposing intermediation as one way of facilitating this strategy, and by suggesting an intermediated network as an effective model to enable their collaboration and specialization" (Lee, Park, Yoon, & Park, 2010, p. 291). The intermediated network model is a conceptualization of the role of innovation intermediaries as consisting of three direct activities (see figure 1).



Source: Lee et al. 2010, p. 293

Figure 1: Conceptual Framework of an Intermediary's Role in the Intermediated Network Model

First, intermediaries create a network database to "identify appropriate collaborative partners" (Lee et al., 2010, p. 294). This is achieved by the intermediary assisting its SME members in their partnership search processes through the maintaining of a database of relevant technology and partners. Secondly, intermediaries can assist in the network construction stage by constructing a network structure that enables appropriate firm matching support for the purpose of effective technology transfer. Finally, intermediaries engage in network management in supporting the ongoing process of collaboration(Lee et al., 2010, p. 294). Lee et al.'s intermediated network model augments these three direct activities with two indirect supports to SMEs' networking efforts, one designed to develop the culture of collaboration and the other to facilitate collaboration.

These activities of an intermediary can shift the conventional collaboration model (based normally on reliance on larger firms or outsourcing to other SMEs) towards a more open structure. As SMEs often focus on specific niches, "involvement in a network may be an effective way to successfully enter wider markets and acquire complementary resources, and of increasing core competencies to improve their chances of competing against their large competitors" (Lee et al., 2010, p. 293). Echoing Lee et al's intermediated network model, Breznitz and Cowhey identify a "networked solution" systems role for intermediaries in assisting SMEs to participate in networks for innovation. Intermediaries perform this role when they "bridge traditional segments within an industry…" and when they "bridge traditional industries and the new technologies and skills needed to operate them, thereby infusing these industries with new knowledge, ideas, and the skills to act on them" (Breznitz & Cowhey, 2012, p. 147). This brokering role enables new partnership formation between firms from previously unrelated industry sectors. Finally, these 'networked solution' intermediaries focus on "solving problems and creating technical capabilities (such as lab testing for quality) for the network by engaging members of many organizations in the network" (Breznitz & Cowhey, 2012, p. 147).

Industry associations are another type of intermediary that has been shown to enable SME innovation (Dalziel, 2006). Industry associations help small and medium firms build cooperative ties and compensate for limited trust between network members (Lee et al., 2010).

Survey-based research of over 2000 Canadian firms indicates that "industry associations are valuable contributors to the ability of firms to innovate, and that "industry associations appear to outperform governments and universities as innovation enablers" (Dalziel, 2006, p. 297). Dalziel uses this survey research to construct a theoretical perspective on the innovation enabler role often performed by industry associations. Dalziel describes how industry associations enable innovation as follows:

> "Organizations that perform innovation enabler roles (enablers hereafter) impact a focal firm's ability to innovate by shaping the networks and markets in which the firm engages in four ways: (1) they identify and legitimize agents; (2) they facilitate the creation of ties between agents; (3) they increase access to resources through network brokerage; and (4) they facilitate joint action through network closure" (Dalziel, 2006, p. 299)

In relation to other intermediaries, "the contributions to innovation of industry associations are strong because their activities are driven by the needs of their clients and because they have specialized knowledge of the context in which technology is applied

and new products developed" and because "their heterogeneity mirrors the heterogeneity in the population of firms that are their clients" (Dalziel, 2006, p. 299). In sum, the literature on innovation intermediaries (both government and industry associations) informs the second research question of this paper: What is the role of innovation intermediaries (government and industry associations) to facilitate this flow of knowledge?

III. Three Case Studies Internet of Things Product Innovation by SMEs

Part II will lay out the case studies of intelligent packaging, intelligent clothing, and medical wearable SMEs who have successfully harnessed printed electronics (PE) in order to enhance the value chain positioning of their traditional product offerings via Internet of Things connectivity.

	Packaging	Wearables	Medical Wearables
Product Innovation	– Intelligent Packaging for Pharmaceuticals (conductive inks on cartons and NFC chips on pill compliance blisters)	– Uses conductive yarns to measure biometric data (heartrate) in athletic wear – Uses printed electronics to create Electro Luminescent athletic wear	– Uses printed electronic pressure sensor to measure pressure at the bottom of the foot, preventing diabetic foot ulcers

Figure 2: Three Case Studies of IoT Product Innovation

a) Packaging

This Ontario-based packaging firm is a family-owned SME primarily producing pharmaceutical and food packaging. The firm employs around 250 employees, with annual revenue of approximately $90 million. They have developed pharmacy packages and compliance cards that use printed electronics to connect to smart phone apps (internet of things). One partnership with a federal research lab has yielded smart compliance card packaging that could log when medications are taken and provide notifications to a patient reminding them of their next dosage. Embedding IoT connectivity into packaging adds value to the firm's offerings to their clients: "the marketing teams can do [a lot] with some of the digital technology, the amount of data collection they can get for consumer profiling and behaviour profiling, they pay a lot more money to do that with other outside services where we can potentially build some of this functionality into the packaging" (interview A). Avoiding commoditization of their core product has been the main driver behind this business model reorientation towards OI partnerships: "there's been a real paradigm shift in our industry where…we were driving each other down in price to the point of really hurting ourselves… as we look at these partnerships, it's one of our key strategies moving forward is partnerships to get us out of that area" (interview A). The firm noted that the commoditization pressure "really pushed us and we've actually dedicated staff, time, resources to this and have a whole department that focuses our energy on trying to figure out the next generation of packaging, what are the next things we have to do" (interview A). The essence of this firm's use of PE is a strategy to blend an industrial commodity (packaging) with IoT technology to create a service environment layer. This functions to blur the distinction between manufacturing and services, in line with the John Zysman's description of the 'services with everything' trend in creating value through digitization of traditional products (Breznitz & Zysman, 2013).

b) Wearables

This is an80 employee company based in Ontario that creates garments with both active technology (transmit and receive signals) and passive technology (embedded technology that does not transmit and receive). The active technology they are researching is "a shirt that has sensors or electrodes knitted in using conductive silver or any kind of conductive element and then you can pick up the heartbeat and it goes into your device that you clip on and then sends a remote...wirelessly to your phone for example" (interview B). Their staff is very technical because they do most of their own R&D: "we're not your typical manufacturer. Manufacturers usually have a very small team and production is bigger. But because we do R&D we do are development. It's probably we have less on the production floor and we have much more in the engineers, designer side of things" (interview B). They have 60 patents, in technologies such as printed sensors and lights and weaved functional electric textiles. Their typical customer is licensing and white label R&D partnerships with US garment companies. They also have their own brands, such as printed electronic electro luminescent lights on active wear. A main challenge reported is the lack of a sufficient supply chain, causing them to have to vertically integrate their

operations. The essence of this firm's use of PE and related IoT products (conductive yarn sensors) is to use the sensor technology to produce data streams and other novel functionalities to garments. This adds value compared to non-IoT competitors in the garment/textile sector.

c) Medical Wearables

This 10 employee, Alberta-based firm was originally founded in 2010 out of research conducted in the founder's medical school residency. The first-of-its-kind product uses printed electronic pressure sensors to measure pressure at the bottom of the foot. The goal of this product is preventing the development of diabetic foot ulcers for people who are neuropathic. Over the course the disease, about 50% of Diabetics will develop neuropathy. Consequences of diabetic foot ulcers can be amputation of limbs, and it is the number one cause of hospitalization of Diabetics. The product utilizes PE in order to create a pressure sensor that is thin enough to work in conjunction with patient's existing orthotics. Once the sensor detects a build-up of pressure, the user gets a notification to a paired device which alerts them to relieve the pressure on their feet in order to prevent the formation of an ulcer. The product has successfully entered health systems in Canada and the US.

IV. Firm-to-firm Partnership Dynamics in IOT Product Innovation

Part III analyzes the firm-to-firm OI partnering strategies employed by the three case study firms to facilitate knowledge flows. The OI in SME literature holds that SMEs tend to build networks with customers over suppliers (Theyel, 2012). In contrast, the IoT case studies exhibited an orientation towards upstream partnerships with suppliers, contrary to the expectation of downstream partnerships in the literature on OI in SMEs (see figure 3). As the descriptions below illustrate, these partnerships are mutually beneficial. The supplier firm gains a demonstrator of a tangible use case for their printed electronics while the case study firm gains the ability to leverage the IoT connectivity in extracting more value from their downstream clients than their non-IoT product category would allow. Also, common themes emerge regarding firm-level challenges in searching out appropriate partners (searching) as well as integrating PE into their product and production (absorptive capacity).

	Packaging	Wearables	Medical Wearables
Firm-to-Firm Upstream Vs. Downstream Partnership Orientation	More Upstream Upstream: partnerships with conductive inks suppliers and printed NFC suppliers. Downstream: offering customizable 'a-la-carte' menu of connected packaging options	Both Upstream and Downstream Upstream: pressuring yarn suppliers to innovate. Downstream: white label solutions to suppliers	More Upstream Upstream: integrator of PE tech, works with suppliers of conductive inks to develop proprietary solutions

Figure 3: Upstream vs. Downstream Orientation of Firm-to-Firm Partnerships

a) Packaging

This firm has engaged in multiple upstream partnerships with suppliers of printed electronics in order to add digital functionality to their line of packaging products. The first firm-to-firm partnership was with a US supplier of conductive inks. The resulting product was a cardboard package with an invisible code that can convey information to a smartphone. The use case for the technology in this instance is to convey that the package is authentic, as well as to convey product information to the consumer. This has the potential to add value to downstream clients whose products are often counterfeited (such as pharmaceuticals). In terms of absorptive capacity challenges, the main issue was reported as "learning and modifying our own manufacturing processes to deal with electronic conductive ink, which we didn't know a lot about before but now we've got a pretty good idea about it" (interview A). The knowledge brought by the upstream partner is described as follows: "where [the ink supplier] came in was app development and things along those lines, not our core competency, we don't want to get into that" (interview A). This upstream partnership enables the firm to add value to downstream clients: "we want to be able to provide that conduit and you know I can get the SDKs for this stuff to provide to our customers to build it into their own apps; many of our customers already have apps" (interview A). In terms of the search process in finding this collaboration partner, the connection as made through mutual membership in a global packaging industry association: "our CEO and the Chief Marketing Officer for [ink company] at that meeting, meeting together, they knew we were playing with [their conductive inks]; they

accelerated the partnership to make it happen even faster. So it was having some in's at the high levels that really pushed this along" (interview A).

The second partnership was with an upstream supplier of printed Nearfield Communications (NFC) tags from Europe. This partnership yielded a more technically advanced product in terms of IoT connectivity. NFC chip and antenna inside "actually knows and has two different states as to whether it's been opened or closed" (interview A). This 'factory sealed and authenticated' information can be communicated via a consumer facing smartphone app, along with other product information and coupon offers. On the business facing side, the same chip offers enhanced logistics traceability, as it "can do things like serialization where you can track items down to the item level because each one has a unique serial number" (interview A). In store and after point of purchase, "we can gain some consumer profile data from that; if we can convince you and incentivize you somehow to keep scanning at home then the brand owner can learn what your behavior patterns are with the particular product and so we're really doing a lot of things with one piece of technology" (interview A). These business facing benefits of the technology are what position the firm to avoid commoditization of their product vis-à-vis downstream clients. In terms of the search process in finding this collaboration partner, both were speakers on a smart packaging panel for a global packaging trade show.

For this firm, partnerships are identified as a central to strategy going forward in order to access competencies that are not present in-house: "we know that we can't do it all ourselves, we are simply too small a company to try and achieve that and I think that more importantly it's more of a strategic decision; we don't want to go too far off our core competency. That's the reason for it, so we think partnership makes a lot of sense" (interview A). Increased partnerships required a reorientation in the business model of the firm: "we realized that if we really want to add new functionalities, specifically digital mobile functionality, we knew we would have to move into the world of actually working with partners and going outside. So it's been an interesting challenge because generally speaking we haven't worked that way in the past" (interview A). In dealing with upstream partnerships, the firm's expertise in the use case of packaging is valuable to their PE supplier because it makes the PE technology more tangible, providing a pathway to the market:

"So when you look at our partnerships, what do we bring to the table versus what do they bring to the table? Well, they bring us technologies and knowledge and know how that we simply don't have. We don't have programmers on staff, we don't have engineers on staff, we have specialists in certain areas but really we're focused on manufacturing something. They bring all that good tech; what do we bring? We bring the fact that we actually have products we manufacture that sell and we have channel partnerships…we basically bring them commercial opportunity and in a way we can make their products more palatable. When you start talking about NFC, if you don't really show a use case, it doesn't make a lot of sense, so that's kind of what we kind of bring to the table is that piece of know how" (interview A).

Downstream, their customers began asking for innovative solutions in their RFPs. This, plus the commoditization pressure caused them to take a more innovative approach to adding value to their packaging. As a result of their various upstream technology partnerships, the firm is able to offer their clients an 'a-la-carte' menu of intelligent packaging options: "we really do approach it kind of like when we go out to customers an a la carte style menu of you want these functions, then you go to [conductive ink]; you want these functions, then you go with [NFC]." Preliminary feedback indicates that their printed electronics intelligent packaging is being recognized as more innovative by customers than the offerings of larger global competitors. One of their customers who is a top five drug company recently commented to them that although they represent ten percent of their spend in this category and (ninety-percent is going to giant multi-national conglomerates), "the funny thing is that all the innovation and good ideas on technology are coming from the little tiny Canadian company and not the giant companies that have offices all around the world" (Interview A).

b) Wearables

In terms of upstream partnerships, this firm collaborates with suppliers in a manner that pushes them to offer more innovative solutions: "in terms of changing relationships with providers is we push people to think outside the box and we push them to put money in R&D and invest in new development because we have a need" (Interview B). An example of this dynamic is in working with yarn suppliers to enable their knitted sensors into garments:

"There is conductive yarns but primarily they are for antimicrobial. There's not a lot of people - lucky for us - that are doing knitted sensors into garments. So yes it's still silver but it's the wrong combination or the wrong yarn for the function that we need it to be. So we will work with those yarn suppliers who develop something that would work better for our product, thus improving them, because we're not the only ones looking at this kind of technology. We believe it is the future. But at the same time we're not going to start buying yarn companies and expand our lab that way, it doesn't make sense. We also look for strategic partners in that kind of situation where we can have a joint effort in product development. It benefits both people if we can find new innovations that help optimize products" (Interview B).

In terms of downstream partnerships, most of this firm's collaborative partnerships are limited to white label licencing of their solutions to brand name garment firms: "it's appealing to companies that want to create products under their brands with our technology" (interview B). However, the firm notes that "it's still early because these companies are not ready for wearable tech but they know that it's the next big thing so they're actively testing" (interview B).

c) Medical Wearables

This firm integrates printed electronic technology into their product through upstream partnerships: "ultimately we're technology integrators and we're consumers of printed electronics in terms of the solution we're offering…it's kind of fundamental to our product right now and so without it you couldn't actually create the product" (interview C). This upstream collaboration with PE suppliers involves a back and forth process of tailoring available technology to meet their specific needs: "we work with printed electronics firms to evaluate the technologies and to develop solutions that meet our particular needs. The development of proprietary inks. And the application of those inks and design" (interview C). Reflecting the literature on OI in SMEs, this firm has dedicated a lot of effort into the search stage of identifying appropriate collaboration partners:

"A big part of our business has been finding suppliers capable of producing those products that meet our specifications and to work with to develop those proprietary solutions…We buy technology from companies that are all over the world and that includes Canada...Those partnerships, they come about through attending trade shows in Canada and talking to the consortium of Printed Electronics and doing things like Internet searches. It's kind of a mixed bag of how you make these connections and meeting with people" (Interview C).

This firm does not currently engage in many downstream OI partnerships: "in terms of partners, if you're saying white-labelling of technology, that's not something we've done yet" (interview C). Nonetheless, the firm notes that it is something they are open to in the future: "we're always looking at potentially licensing or white-labelling our technology for other companies who feel what we have may be of value to them or something they want to incorporate into their product of their offering" (interview C).

V. The Role of Intermediaries

This section analyzes the network-enhancing role of printed electronics innovation intermediaries, specifically an industry association and a government lab. The engagement dynamics reported by the IoT case studies corroborate many aspects of the literature on OI by SMEs, including the network-enhancing potential for different types of innovation intermediaries to enable SMEs to bridge knowledge gaps.

a) Role of Government Intermediary

The main government printed electronics research lab is the National Research Council's Printed Electronics Consortium. Established in 2013 with a 5 year $40 million federal commitment ($16 million from industry), the Ottawa-based NRC PEC allows members to "collaborate with leading members of the Canadian Printable Electronics industry to conduct product-driven applied research. They gain access to comprehensive PE solutions, both from NRC and through other consortium members, securing a significant competitive advantage." PEC's fee-for-service offerings also enable non-members to access their expertise and equipment. NRC PEC has over 16 members including PE suppliers as well as end use firms such as packaging companies.

b) Packaging

This firm's project was to develop an intelligent packaging compliance card that harnesses printed electronic sensors for tracking compliance to pill regimens in conjunction with smartphones. This collaboration began after the NRC approached them:

> "So that's you know it just happened to be from a timing perspective the NRC approached us at that point in time about getting involved in intelligent and smart packaging and that's something we were already looking at and we had some thoughts behind it, so we entered into the consortium to try and develop and push smart packaging in the Canadian market space…the NRC approached us – they had the print electronics profile and they realized that smart packaging was an area that really probably made the most sense in terms of pushing printable electronics to the consumer level and so they approached us with the idea that – hey, you're in the healthcare space, you want to do more with your packaging, why don't you join up and they have different tiers of membership level" (Interview A).

This intermediary functioned in line with Lee et al.'s description of network database (identifying appropriate partners) and network construction (actively matching SMEs with appropriate technology) (2010). This intermediary also reflected the literature's focus on intermediaries bridging traditional industries with new technology industries (Breznitz & Cowhey, 2012, p. 147). Also significant is the networking within the members of the consortium. Since the company opted for tier one status, they could direct their own team of researchers, as well as access the research projects of other tier one members:

Tier one being a management committee member, which we are; tier two and three members have to be invited into projects, so being a tier one member allowed us a few different key advantages. One is we got to set our own project; we got to look at what we actually wanted to achieve and said that, tier two members don't have that capability, they just get invited in. The other thing as a tier one members we have different types of licensing options in terms of the intellectual property…that aren't necessarily related to packaging but some of the components I may be able to take and implement in packaging and at a better, more favourable licensing option" (interview A).

Finally, the firm's reasoning behind the decision to join reflects the literature's emphasis on intermediaries serving to augment SME product knowledge with access to advanced technological knowledge and facilities that were not available in house nor through firm-to-firm collaborations:

"we manufacture boxes, we're a carton manufacturer, we're a label manufacturer, getting into print electronics was a very new space for us and very difficult in the sense that it's not something where everybody just knows how to do it and it's not even something where you know you can find kinds coming out of school who actually know anything about it. So, you know, that were the NRC scientists really made a big difference because they obviously had the capability of doing that…" (interview A).

c) Wearables

Their project is to have NRC researchers assist them in characterization of their IP, which makes the patenting process easier:"we have a project with them where they characterize some of our IPs. So we can build our own intellectual property a little bit better and stronger without having to take the time to analyze everything we do. We can outsource that" (Interview A). Similar to the packaging case study, this firm's experience reflects the literature's focus on the network-enhancing role of intermediaries. Specifically, intermediaries network SMEs into knowledge networks, help facilitate firm-to-firm collaboration, and provide physical resources and research expertise:

"why we get involved [in NRC] is that we believe that they can help us facilitate and they have resources - they facilitate companies working together. They also have resources that we don't have like people, expertise, for example NRC has equipment and scientists and a lot of expertise that we can't hire full-time. It doesn't make sense of us to. So we can give them a project, they can handle it themselves, and then other people can share those same resources without the heavy investment in capital" (Interview B).

d) Medical Wearables

While this firm is not a member of NRC Consortium, they were reached out to by the NRC and are currently assessing whether to join. They view the consortium as useful for precisely the network enhancing reasons identified in the literature:

"The good thing about what that specific consortium was doing I think is the idea of bringing together companies that potentially have complimentary needs, so the printed electronics manufacturers with people who are consumers of printed electronics. And that's part of the reason they reached out to us, was I think they were very heavy on the ...heavier on the manufacturing side and not didn't have enough people on the application side. And so kind of getting that balance of people who consume it from people who just make it" (interview C).

In deciding to get involved in NRC or academic partnerships, this firm discussed concerns over IP leakage that is core to the product:

"In terms of what makes our decision to engage with different people…The issue for companies like us in dealing with whether it's the NRC or it's universities is...because there's always a question of IP and IP ownership and IP leakage, and what is core to your business and what is not core to your business. And so those are all things that we have to weigh out depending on who we're dealing with and what's going on. So the hard part for us is we really need to as a company we need to decide is this our core IP or isn't it" (interview C). This firm also has also engaged in a provincial program functioning as an innovation intermediary connecting SMEs with European firms for R&D partnerships. The partnership has yielded a 'smart bandage' for the prevention of bedsores. The program was described as follows:

"That program was designed to connect small SMEs in Alberta and Germany. The way the program works is you would define a joint project with your German partner that you found and the Alberta Government would share up to a maximum amount, but basically 50% of your costs on the project on the Alberta side. And then your German partner would get funded from their German equivalent" (interview C).

The firm's description of the government's intermediary role reflects the findings of the literature's emphasis on SMEs engaging with intermediaries to facilitate access to the benefits of OI collaborations. Specifically, the government intermediary's support assisted in brokering an introduction, which reduced the risks of investing in OI R&D collaboration:

"The big benefit of that was in many ways sharing the risk and sharing the cost of development of products…it gives you more of a willingness to take some additional risk in terms of project or maybe push that technology envelope a little bit further. That again is something that having some people share the

technology risk with you definitely increases the appetite to assume risk, especially when you're a small startup like we are" (interview C).

e) Role of Industry Association

The Canadian Printable Electronics Industry Association (CPEIA) is Canada's main PE industry association. Established in 2014, CPEIA has grown to 63 members as of Aug. 1, 2015. CPEIA "brings together key Canadian and international players in industry, academia and government…to facilitate growth through networking, stimulate R&D and investment, build a strong supply chain and drive the broad adoption of Printable and Organic Electronics by end customers in a range of Canadian industries, including Intelligent Packaging" (Canadian Printable Electronics Industry Association, 2017). The association makes efforts to have a heterogeneous membership base that spans both producers of PE as well as end users. For example, CPEIA and PAC Packaging Consortium have jointly formed IntelliPACK in September 2015, to "unite leading organizations across the packaging value chain, to collaboratively explore, evaluate and mobilize innovative SMART PACKAGING solutions" (IntelliPACK, 2017). A similar organization was created for intelligent buildings.

f) Wearables

This firm hopes to gain exposure and enhance their network though the association. They also won an award for product innovation at the association's annual conference. Reflecting the OI literature, this firm noted that the association is helpful as a platform for networking, helping partnerships to form:

"like I said there's a lot of product out there or there's a lot of tech but they don't actually put them in a product that can be commercialized to the end-user…I believe the role of these industry associations to facilitate conversations amongst like minds and to create exposure for companies, because there is a lot of talent in Canada, but unless you look for it or unless somebody tells you, you're not going to know they exist, so these industry associations help with that. They create a good platform for networking and opportunities for strategic partnerships to form. Like the NRC provide a lot of tools and resources so that we can develop successful and innovative product" (interview C).

This firm's perspective reflects the literature's findings on the unique effectiveness of industry associations in facilitating innovation for SMEs due to their facilitation of networking and OI collaborations within its heterogeneous membership base (Dalziel, 2006).

g) Medical Wearables

This firm's perspective also reflects the literature's conception of industry associations as an OI intermediary for SMEs. This firm described the value of the industry association as laying in linking users and producers of PE and giving a united voice to the industry:

"Part of the value of having a consortium - would it be a matchmaker – I kind of view them as champions - having some group that represents...sort of championing or bringing to the forefront about why an industry is important and working with municipal, provincial and federal governments, whatever it is to create tax incentives or programs that help foster innovation in those areas, I think it's something that's incredibly valuable…being that sort of champion and point of contact and matchmaker across borders would be something I think would be incredibly valuable that small companies or startup companies don't have the time or the resources to do" (interview C).

Finally, this firm viewed the network enhancing role of the association as particularly needed due to the geographic size of Canada: "I think given the number of companies and companies in Canada you almost have to put them together in sort of this consortium to get a critical mass of technology companies" (interview C).

VI. Conclusion

This paper has examined three case studies of SMEs who have introduced IoT innovations: a packaging firm, a wearables firm, and a medical wearables firm. Analysis of the these examples suggests possible differences in firm-level innovation in IoT as compared to OI product innovation in other technologies.Specifically, IoT product innovation demands OI collaboration by SMEs who want to innovate, but in a different way than OI in other technological contexts. In terms of firm-to-firm partnerships, the case studies in this paper demonstrated more upstream collaboration as compared to the literature's characterization of other sectors, where OI in SMEs tends towards a focus on downstream partnerships. In terms of intermediaries, the case studies illustrated the network-enhancing role of printed electronics innovation intermediaries, specifically an industry association and a government lab. The engagement dynamics reported by the IoT case studies reflected the literature's emphasis on intermediaries functioning in a network-enhancing role to enable SME partnerships that bridge knowledge gaps. These findings contribute to the literature on OI in SMEs in two ways: 1) extending the OI in SME literature into the context of IoT product innovation yields observations of distinct upstream firm-to-firm partnership orientations; 2) the case studies reinforce the literature's emphasis on the network-enhancing role of intermediaries by providing a more granular, detailed treatment of the role of innovation intermediaries than is typically garnered by survey-based analysis. Future research should expand upon the limited sample of

cases to interrogate whether other firms engaging in IoT product innovation exhibit similar firm-to-firm and intermediary partnership dynamics.

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