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Working Paper:

Regional systems of innovation as modern r&d entrepots: the case of the Saskatoon biotechnology cluster

Peter W.B. Phillips
NSERC/SSHRC Chair in Managing Knowledge-based Agri-food Development,
Department of Agricultural Economics

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Preface:

The knowledge revolution is transforming the basis for Western Canadian agriculture. Professor Peter Drucker has argued that "the basic economic resource – 'the means of production,' to use the economist's term – is no longer capital, or natural resources (the economist's 'land'), nor 'labour.' *It is and will be knowledge."*

This series of research and policy papers is designed to contribute to a greater understanding of the extent, speed and implications of this transformation in the agri-food sector and to provide for a broader public policy debate about the resulting opportunities and challenges both within and around the agri-food industry.

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The author:

Dr. Peter W.B. Phillips is a Professor of Agricultural Economics in the NSERC/SSHRC Chair in the College of Agricultrue. Dr. Phillips is also an Associate in the College of Commerce, a Professional Associate in the Department of Political Studies and an Adjunct Professor of Administration at the University of Regina. He is Saskatchewan Director of the Canadian Agri-food Trade Research Network, an active member of InnoCom (a SSHRC funded network), a Senior Associate in the Estey Centre and a member of the Canadian Biotechnology Advisory Committee.

The author can be contacted at: Department of Agricultural Economics, University of Saskatchewan, 51 Campus Drive, Saskatoon, Canada S7N 5A8. Tel: (306) 966-4021, fax: (306) 966-8413, email: phillips@duke.usask.ca.

Regional systems of innovation as modern r&d entrepots: the case of the Saskatoon biotechnology cluster

Peter W.B. Phillips[1]

Contents

Abstract

Economics examines innovation from the perspective of the incentives for and impacts of research at the microeconomic or firm level while the national systems of innovation (NSI) literature examines clusters of innovation within states or regions. This paper offers a synthesis of the two approaches to studying innovation, proposing a unified theory that posits that systemic modern innovation occurs within and among firms and agencies at the local or regional level but integrated into the global production system. As such, modern innovation systems reflect many of the characteristics of the classical trade entrepot, where most the inputs are imported tax free, value is added locally and then semi-finished outputs are exported for further processing and distribution to final consumers. The Saskatoon-centred, canola-based biotechnology cluster exhibits many of these attributes, with the majority of the basic research and many of the proprietary technologies being imported, assembled into new crop varieties for commercial release first in Western Canada, and then exported on a largely tax-free basis as intermediate product to global markets. This alternative model for innovation poses significant implications for researchers, markets and public policies.

Key words
Regional systems of innovation, entrepot, biotechnology

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[1] *Peter W.B. Phillips, Professor, NSERC/ SSHRC Chair in Managing Knowledge-based Agri-food Development, University of Saskatchewan, 51 Campus Drive, Saskatoon, Canada S7N 5A8. Contact: phillips@duke.usask.ca..*

1. Introduction

Innovation, the driver for growth and development, is increasingly being discussed and examined. There are two main competing views of innovation. The economic theory of technological change has for many years focused on the firm as the primary research unit (e.g. Arrow, Solow) and, in the footsteps of Schumpeter, has examined the microeconomic incentives and impacts of private research for commercialisation. Some economists (e.g. Romer, Grossman and Helpman, Krugman) recently have examined the impact innovative activity at the firm level has on the larger economy, focusing especially on the implications of "endogenously" generated innovation on macroeconomic growth, trade and industrial location. Even so, they tend to assume that innovation is a discrete event that occurs within firms. Recently a few of these economists have begun to notice that firms are not complete and often must reach beyond their boundaries to satisfy their needs. Nevertheless, the focus remains steadfastly on innovation that is primarily directed by a single corporate leader. Alternatively, a group of political economists with more of an interest in the influence of institutions has developed a theoretical "systems" approach to innovation, often called the "national systems of innovation" or NSI. Harking back to Marshall (1890), these researchers (e.g. Freeman, Nelson, Lundvall, Porter) have looked at the role of economies of scale and scope in the local, regional or national innovation systems themselves. Once again, however, this approach tends to consider innovation as an activity that is or should be limited to a region. While the NSI literature posits that innovation is embedded in networks which at times span international borders, the resulting policy prescriptions tend to focus on how national governments can encourage greater self-sufficiency in innovation. Those that have looked at the international effects have examined how multinational national enterprises (MNEs) contributed to domestic capacity through direct investment (Chesnais) and at innovation's effects on international trade (Dalum, Andersen and Broendgaard, and Fagerberg).

In practice, standing back from either the firm or the region and looking instead at the sources and uses of knowledge in the innovation system gives a significantly different perspective. This paper, drawing on evidence in the agricultural research world, presents a synthesis approach that starts from the assumption that innovation is actually a global activity that transcends any firm or region. No one firm or region drives the innovative activity—multiple actors jointly lead it. Parts of the innovative effort, however, have the potential to become linked to firms or regions. In essence, modern innovation systems reflect many of the characteristics of the classical trade entrepot, where most of the inputs are imported, value is added locally and then semi-finished outputs are exported for further processing and distribution to final consumers.

The Saskatoon-centred, canola-based biotechnology cluster exhibits many of these attributes, with the majority of the basic research and many of the proprietary technologies developed elsewhere being imported, assembled into new crop varieties for commercial release first in Western Canada, and then exported on a largely tax-free basis as germplasm or intermediate product to global markets. Consistent with both the economic and NSI theories, canola research is agglomerating in and around Saskatoon, which poses significant implications for researchers, markets and public policies.

This chapter examines the theory, practice and implications of regional systems of innovation as entrepots. Section 2 offers a short outline of the background to the regional innovation system operating in Saskatoon. Section 3 provides a summary of the theory and literature on clusters and innovation systems. Section 4 briefly outlines the data sources used to examine the Saskatoon cluster. Section 5 examines the Saskatoon cluster, highlighting the entrepot aspects of the innovation system. Section 6 concludes with a discussion of some of the policy implications of this alternate approach to innovation research.

2. Background and circumstances

'Location, location, location,' the battle cry for property realtors everywhere, is increasingly becoming the focal point for discussion of the dynamics and benefits of knowledge-based growth. This examination of the Saskatoon-centred, canola-based research cluster can help to illustrate the dimensions and structures that underlie a successful knowledge-based research system.

The original transformation of rapeseed into canola and more recently the privately-directed, research-intensive activity around canola is largely a Canadian story (Gray, Malla and Phillips, NRC, McLeod). For thousands of years rapeseed has been used in various markets as a cooking oil, industrial lubricant, animal feed or green manure. Focused research after 1943 in universities, at Agriculture Canada (now Agriculture and Agri-Food Canada, AAFC) and in the National Research Council (NRC) labs in Canada sought to improve the agronomic and food attributes of rapeseed. That effort culminated in 1978 with the development of new variety of rape that had lower amounts of erucic acid (which is linked in some studies to heart problems) and glucosinolates (which impair the feed value of the meal). The new low erucic acid, low glucosinolate standard was trademarked by an industry association as 'canola' and became the forerunner of most varieties used around the world today. Beginning in the 1980s with the adoption of genetic engineering technologies, canola was targeted for further development by private companies. In 1995 canola became the first genetically-modified food crop in the world to be extensively commercialised and now has one of the highest adoption rates. R&D into new novel traits continues unabated.

A survey of most of the companies and public sector research and development efforts in the canola industry (undertaken in 1997-8) revealed that since the advent of private capital in the sector in the mid-1980s, the canola research effort has been slowly but steadily concentrating in Canada and, specifically, Saskatoon. Table 1 shows that Canada's share of the global total research effort, which was approximately 75% in the 1945-66 period, dropped to about 40% in the late 1980s as the research effort disseminated from the public to the private sector, but has since rebounded to approximately half of the global effort. This concentration has been almost exclusively due to the relocation or development of private research and development programs in Canada. The public share of the Canadian effort has dropped from almost 100% in the 1944-75 period to only about 44% in the late 1990s. Meanwhile, the effort in Canada has been concentrating in Saskatoon. Although companies like Zeneca, Pioneer Hi-Bred and Cargill/Intermountain Canola have located in other provinces, extensive private research has located to Saskatoon, supplemented by an increasing concentration of public research in

Agricultural and Agri-food Canada and the National Research Council in the city since the late 1980s.

Table 1: Canada's and Saskatchewan's share of the total canola research effort globally, and proportion of share produced by public sector

	Global employment		Saskatchewan		Canada	
	Annual average	Public effort as % total	Share of global total	Public effort as % share	Share of global total	Public effort as % share
80-84	191	68.3%	32.2%	96.8%	48.1%	94.6%
85-89	287	56.1%	25.8%	96.8%	42.1%	85.3%
90-94	499	44.1%	25.3%	81.3%	41.3%	65.9%
95-98	702	36.4%	29.5%	59.5%	48.3%	44.5%

Source: Canola industry survey, 1997-8; based on person years of employment devoted to research and development

Preliminary evidence suggests that the vast majority of the applied research to develop varieties is based in Canada. Canada has registered 180 varieties of rapeseed/canola since the 1940s, more than two-thirds developed domestically. Although some other countries (esp. China, Sweden and Germany) developed many varieties, all of the new traits introduced in the past 40 years—e.g. low erucic acid, low glucosinolates, hybrids, novel oils, blackleg disease resistance, key yield gains—were at least partly developed and were all introduced first in Canada. At least partly as a result, in 1999 Western Canadian farmers produced more than 20% of the world's output of canola/rapeseed, exporting approximately 80% of it to global markets, accounting for more than 60% of the world trade (Phillips and Khachatourians).

From a superficial perspective, this level of agglomeration suggests Saskatoon and Canada may have reached a critical, self-sustaining mass of capacity. In practice, however, this agglomeration has limited scope. Saskatoon and Canada have a much higher share of some parts of the research, development and commercialisation of new innovations that other parts. Saskatoon imports much of the basic research, patented technologies and skilled workers, combines them with locally-owned and developed elite germplasm, commercialises the new varieties in Western Canada and then markets the raw or semi-finished product to the global agri-food industry. By conservative estimates, however, less than half of the end-market value of canola produced in Canada is added in Canada; the rest is either imported and added during the R&D or production phases or added as the seed, oil and meal moves downstream towards the consumer (Phillips and Khachatourians). In short, Saskatoon is a centre for innovation, but cannot be viewed as self-sustaining. Rather, it exhibits traits that hark back to the "entrepot" model of development.

3. The model

There is significant confusion in the literature about the definition, sources and uses of innovation. For the purposes of this paper, it is assumed that innovation involves planned systematic effort to add value through research and development. In that sense, it differs from much of the invention that occurs in small and medium-sized companies, where individual entrepreneurs or scientists have “light bulb” insights that lead to valuable science or technologies. If the development is solely based on inspiration, neither the economic nor the systems literature has much to add. These developments are often better understood as the result of serendipity rather than planning and effort. Modelling this type of activity is pointless, as inspiration seldom arrives in the same place twice. In contrast, planned and systematic innovation can and should be modelled and examined. This section offers the historical “entrepot” framework as a new approach for evaluating the incentives and impacts of innovation on firms and regions.

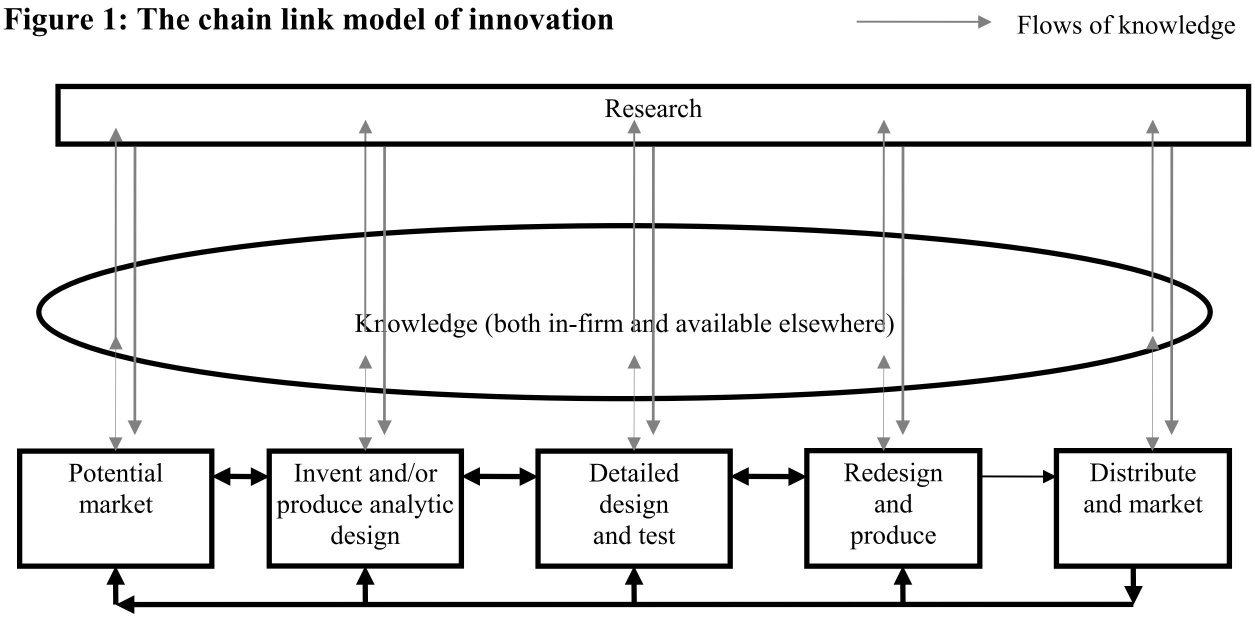
The concept of entrepot trade has been largely expunged from current economic literature and can only be found in dated references. A quick review of the leading intermediate and advanced textbooks and reference books on international trade and development failed to find any reference to entrepot trade. It is necessary to go back more than a quarter century, to a time when the focus in trade studies was exclusively on goods, to find any reference to entrepots. At that time an entrepot was defined as “a centre at which goods are received for subsequent distribution. An entrepot port has facilities for the transhipment of imported goods or their storage prior to their re-export, without the need to pass through customs control” (Bannock, Baxter and Rees). Endacott’s examination of Hong Kong, the classical example of a traditional entrepot, illustrates some of the key features of entrepots.

> The essential feature of the entrepot trade of Hong Kong was the existence of entrepot services, which tended automatically to attract trade…. [I]n addition to its natural harbour, Hong Kong possesses assets that were almost equally potent in making it a successful commercial centre. It possessed among its people, business acumen, managerial ability, commercial experience, professional skill, financial resources, control of shipping and a good supply of industrious and inexpensive artisans and workers. It would be an exaggeration to say that the entrepot trade was a product of these entrepot services … but … the rise of Hong Kong rested on the twin pillars of shipping and commercial skill … functioning under the security of a British administration.

One can see that even with this early model of entrepot trade, value added services were a critical part of the success of these centres. If one changed the name from Hong Kong to Saskatchewan, replaced harbour and shipping with agricultural land, the description would equally fit the history of innovative agriculture in Western Canada.

The challenge is to add the innovation dimension. If new developments were the result of inspiration, then the traditional linear view of R&D would be appropriate. On the other hand, if one looks at systemic innovation processes, particularly at the many inputs and outputs they usually involve, it becomes clearer that no single firm or region can truly be viewed as self-sufficient or self-sustaining. Klein & Rosenberg (1986) provide a non-linear approach that explicitly identifies the role of both market and research knowledge and the potential for open research systems. Their ‘chain-link model of innovation’ (Figure 1) begins with a basically linear process moving from potential market to invention, design, adaptation and adoption but adds feedback loops from each stage to previous stages and the potential for the innovator to seek out existing knowledge or to undertake or commission research to solve problems in the innovation process. This dynamic model raises a number of questions about the types and roles of knowledge in the process. Some of the knowledge will be available or could be developed within or outside the firm.

Figure 1: The chain link model of innovation



Malecki provides a way of categorising types of knowledge that helps to identify which route a firm or institution might go to acquire or develop knowledge needed to innovate. He identifies four distinct types of knowledge: know-why, know-what, know-how and know-who (table 2).

Each type of knowledge has specific features (OECD 1996). ‘Know-why’ refers to scientific knowledge of the principles and laws of nature, which for the most part is undertaken globally in publicly-funded universities and not-for-profit research institutes and is subsequently codified and published in academic or professional journals, making it fully accessible to all whom would want it. This knowledge would be in the knowledge block in the chain-link model, having been created almost exclusively in the research block. ‘Know-what’ refers to knowledge about facts and techniques, which can usually be codified and transferred through the commercial marketplace. The stock of know-what is in the knowledge block in the chain-link model, having been created in the research, invention, design and adoption blocks. “Know-how’ refers to the combination of intellectual, educational and physical dexterity, skills and analytical capacity to design a hypothesis-driven protocol with a set of expected outcomes, which involves the ability of scientists to effectively combine the know-why and know-what to innovate. This capacity is often learned through education and technical training and perfected by doing, which in part generates a degree of difficulty for the uninitiated and makes it more difficult to transfer to others and, hence, more difficult to codify. Know-how would be represented in the research block and also in the invention, design and adaptation stages. Finally, 'know-who', which "involves information about who knows what and who knows how to do what" (OECD 1996), is becoming increasingly important in the biotechnology-based agri-food industry. As the breadth of knowledge required innovate expands, it has become absolutely necessary to collaborate. In today's context, know-who also requires knowledge of and access to private sector knowledge generators who at times may hold back the flow of crucial and enabling information, expertise and knowledge. Know-who knowledge is seldom codified but accumulates often within an organisation or, at times, in communities where there is a cluster of public and private entities that are all engaged in the same type of research and development, often exchange technologies, biological materials and resources and pursue common staff training or cross-training opportunities. The arrows in the chain-link model would represent this type of knowledge, as building relationships that lead to trusting networks of know-who is the basis for those flows.

Table 2: Classification of types of knowledge

	Degree of Codification	Produced by	Extent of disclosure
Know-why	Completely codified	Universities and public labs	Fully disclosed and published in scientific journals
Know-what	Completely codified	Universities, public labs and private companies	Fully disclosed in patents
Know-how	Not codified	Hands-on in labs	Tacit; limited dispersion
Know-who	Not codified	Exists within firms or research communities	Tacit; limited to community

Source: Adapted by author from Malecki, 1997, p. 58.

This chapter uses a modified chain-link model to investigate the Saskatoon-centred biotechnology cluster, in order to test the hypothesis that knowledge-based innovation clusters operate in ways similar to classical trade entrepots. Applying the conceptual structure of knowledge offered by Malecki and the chain link innovation system proposed by Klein and Rosenberg to the innovation systems model developed by Lundvall allows an examination of the degree of self-sufficiency of either innovating firms or innovating regions. This framework is used to illustrate that innovation "systems" function to varying degrees as entrepots, depending on their stage of knowledge development and innovation.

4. The data sources

No definitive set of measures for knowledge and innovation has yet been developed. Nevertheless, there has been significant work undertaken in a number of areas using proxies for knowledge and the transmission of knowledge. Taking the four types of knowledge, and the resulting products, one can construct a package of empirical measures that approximate the flow of innovations through the research system and into the marketplace.

First, starting with know-why knowledge, it is clear that while it is quite difficult to identify the inputs to the research effort, one can look at 'bibliometric' estimates to measure the flow of knowledge from creators, generally in universities, research institutes and private firms. There is general acceptance of the view that publications such as academic journals are the primary vehicle for communication of personal and institutional findings that become the vehicle for evaluation and recognition (Moed, et al, 1985). Hence, in general in the past, and to some extent even in current practices, most if not all of the effort put into research ultimately will be presented for publication. The common catch phrase, 'publish or perish' captures the essence of the past practice, while, the more modern 'patent and then publish' pattern exemplifies practices in a large number of research universities and public labs. There have been a number of efforts (e.g. National Science Board, Industry Commission) to develop and use literature-based indicators to evaluate scientific effort. For the purposes of this study, the Institute for Scientific Investigations (ISI) was contracted to undertake an electronic search of their databanks, which then covered the period from 1981 to July 1996. They were instructed to search their database, which included approximately 8,000 journals in the sciences and social sciences, for seven key words/phrases: brassica campestris, brassica napus, brassica rapa, canola, canola meal, rapeseed, and oilseed(s). The special tabulation identified 4,908 individual articles in 650 journals meeting the criteria (hereafter called the canola papers) produced by approximately 6,900 authors in approximately 1,500 organisations in 79 countries. The ISI data also provides the capacity to look both forwards and backwards from the target articles to determine where the key knowledge inputs come from and where the resulting knowledge is being used. The database identifies 17,995 papers from 1,294 journals, produced by approximately 28,800 authors in 3,816 organisations in 107 countries which were cited a total of 28,946 times by the 4,908 papers that relate to canola research. At the other end of the system, the 4,908 canola papers were cited 26,946 times. The database can also be sorted and searched by author, institution, subject and country of the researcher, and then cross-tabulated for collaborations, allowing one to examine both the stocks and flow of knowledge. In this way, one can investigate the know-who linkages that underpin the innovation system.

Second, know-what knowledge is most commonly examined using patent information. Trajtenberg (1990) argues that "patents have long exerted a compelling attraction on economists dealing with technical change… The reason is clear: patents are the one observable manifestation of inventive activity having a well-grounded claim for universality." Trajtenberg concludes that in the context of specific, clearly demarcated innovation (in his case CT scanners), patents "play an important role in studying the very emergence of new markets, which seems to be the period when most of the innovative activity takes place." He likens patents to working papers in economics. Papers and patents are produced roughly in proportion with effort: a larger number of papers or patents indicates a larger research effort. "Patent counts can thus be regarded as a more "refined" measure of innovative activity than R&D, in the sense that they incorporate at last (sic) part of the difference in effort, and filter out the influence of luck in the first round of the innovative process." For the purposes of this study, the Canadian Intellectual Property Office (CIPO) database of Canadian patent bibliographic data was searched in late December 1999 for canola-related patents. That database contains all applications for patents made between 1920 and December 1999. During that period 634 patents for canola-related work were filed.

Know-how and know-who types of knowledge, as discussed above, are often inseparable and are tricky to track at the best of times. Nevertheless, this type of knowledge can be mapped by looking at a number of different sources. The regulatory systems in Canada and elsewhere provide one means of identifying who is converting the know-why and know-what knowledge into actual products, as they assess risks during the detailed design, testing and redesign periods. This data is available in Canada through the Canadian Food Inspection Agency (CFIA) authorisations for field trials for "plants with novel traits" and internationally through the OECD website on field trials. Moving along through the innovation system, the resulting products can be observed through the varietal registration system in Canada under the Seeds Act and in Canada and elsewhere through the registration of new canola varieties for plant breeders' protection, as provided under the UPOV Agreement. This data must be supplemented by industry data to identify public varieties that are not protected by breeders' rights.

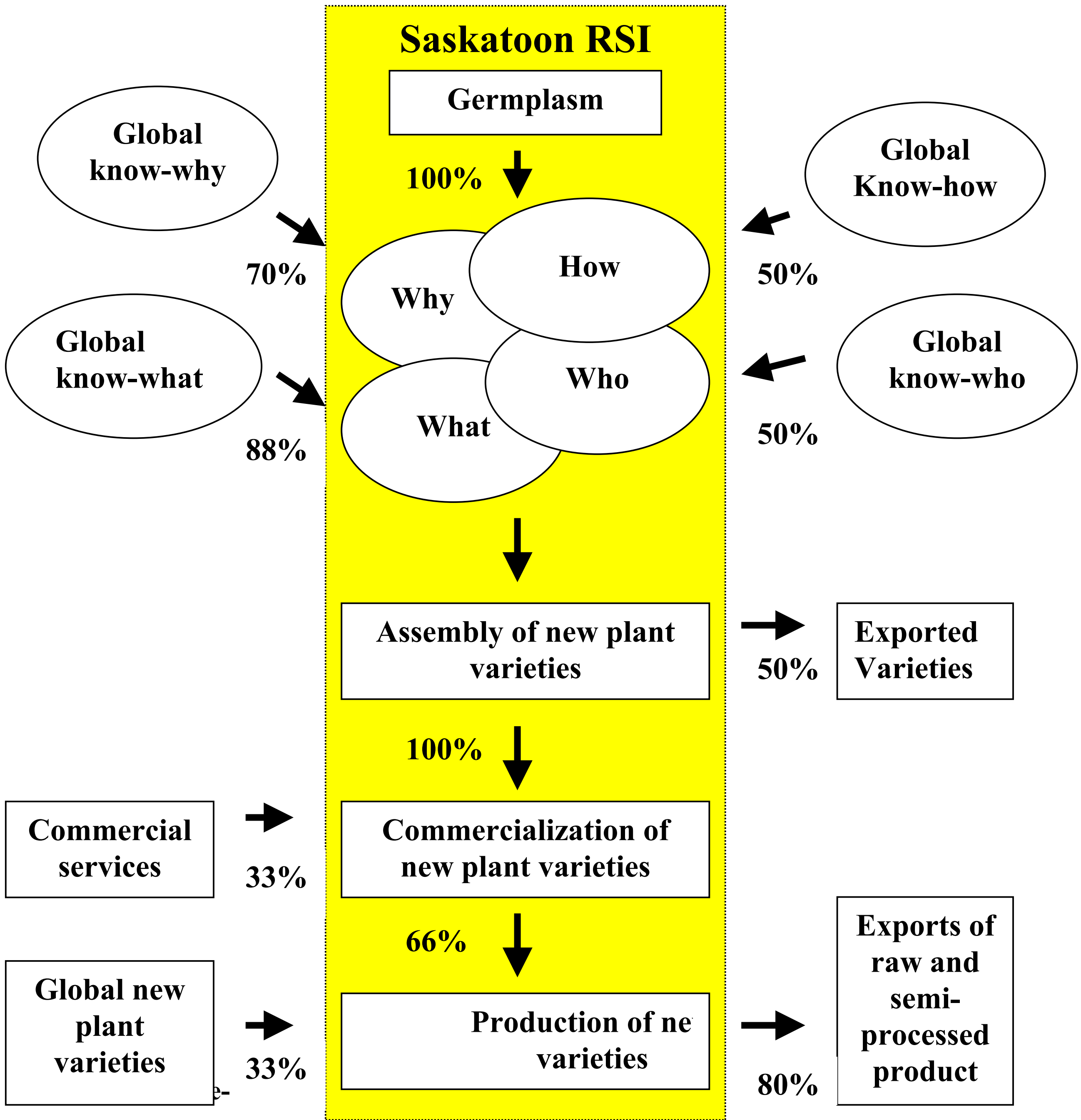
Finally, the ultimate measure of innovative success is commercialisation and market adoption. Capacity in related and supporting industries is available through industry surveys but information from the seeds market is getting more difficult to find. Aggregate data for canola acreage and yields are available nationally and through the FAO but production information on specific varieties is difficult to obtain. The canola industry in Canada is fortunate to have relatively good public sources of data (see Phillips and Khachatourians for details) to provide a base for testing market adoption rates for new varieties. Downstream of farm gate, international trade flows of canola germplasm, seed, oil and meal can be tracked through the FAO trade database, Industry Canada's Strategis export data and through the Canadian Seed Trade Association's estimates of exports of germplasm.

5. The Saskatoon-centred innovation entrepot

The dimensions of the Saskatoon innovation "entrepot" can best be analysed by looking at its relative role in creating knowledge, using knowledge and commercialising new products. One might conclude that Canada is the main canola innovator based on its record as the lead innovator and early adopter of all the new traits over the past 40 years. But a significant share of the applied research to develop the processes to develop those varieties has been done in other countries and much of the applications-based research (e.g. uses for new oils) is happening elsewhere. This suggests that Canada instead may operate in a niche in this global knowledge-based industry—as an entrepot undertaking and assembling the know-why, know-how and know-who of varietal breeding and primary production—but that the bulk of the activities up and downstream of that stage in the production system are now and may continue to be done elsewhere. Figure 2 illustrates the relationships between the global industry and the Saskatoon entrepot.

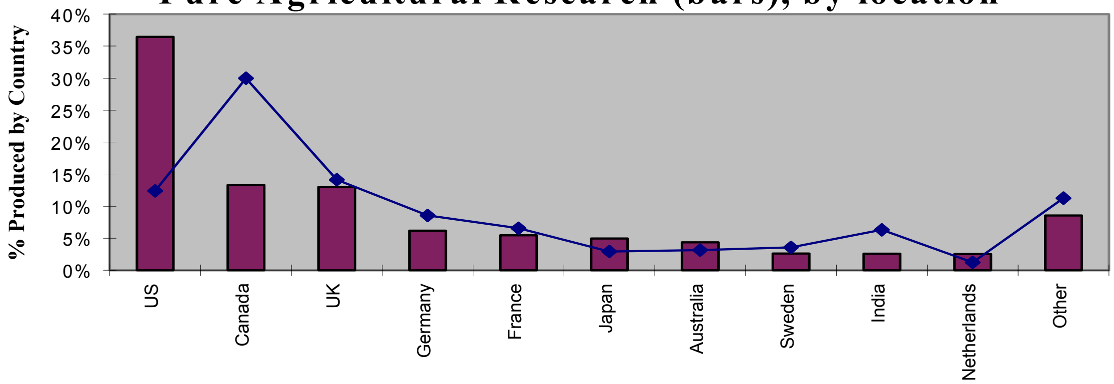
To illustrate this phenomena, the Saskatoon-centred innovation system is examined in the context of knowledge creation—which involves the four knows and the research community—and knowledge commercialisation—which involves related and supporting industries, regulators and the producers.

Figure 2: The Saskatoon biotechnology entrepot and its global connections



At the know-why level, Canada is the single largest country producing pure agricultural research into canola but the basic research that underlies that effort is disproportionately coming from the US (35%) and other countries. Canada is the only significant canola researching country that "imports" significant amounts of basic research relative to its canola research (figure 3).

Figure 3: Basic Scientific Research (line) versus Pure Agricultural Research (bars), by location



Moving forward in the research stream, Canada, and particularly the public labs in Saskatoon, held a dominant position in canola-specific research until the early 1980s, with all Canadian locations combined contributing between one third and 40% of the pure agricultural research on canola in the world to that time. More recently, however, the global research volume has expanded greatly while Canadian research efforts have been relatively steady. The result is that canola research has disseminated into a wide variety of locations and institutions. In 1981 only about 22 countries were doing any research into canola. By the mid 1990s more than 40 countries were doing research into canola on a continuing base and over the intervening period more than 70 countries did some work on canola. By the mid 1990s, Canada's share of this research dropped to only about 20%. Furthermore, as the basic scientific research has become more specialised, collaborations are playing a greater part in the global evolution of research capacity. The top nine canola research countries undertook between 5% and 22% of their research in collaboration with others in other countries (Phillips and Khachatourians). Canadian researchers undertook only 8% of their effort via international collaborations (the lowest of all countries except India), suggesting that Canada was more self-sufficient than many of the rest at this stage.

Nevertheless, Canada is far from self-sufficient. Canada is significantly more dependent on foreign actors for proprietary, know-what technologies used in the industry than for basic R&D. The Canadian patent database shows that since 1985 there have been 634 patents issued for canola related innovations (45% for process innovations), the vast majority of them to foreign (mostly US-based) research teams and companies (table 3). Canadian researchers accounted for only 75 patents, more than half of them to a few federal research scientists in AAFC and the NRC. In practical terms, virtually all of the key transformation technologies used by the canola sector are the proprietary products of non-resident companies (see Phillips 2000 for a detailed listing of owners of key proprietary know-what technologies).

Table 3: Private and Public Owners of Patents by country of residence

	Technology		Product		Total patents
	Public	Private	Public	Private	
Total Patents	66	220	37	311	634

Residence of inventor:					
- Canada	32	18	13	12	75
- Other	34	202	24	299	559
Source: Search of CIPO Canadian Patent Database, December 1999.					

Moving downstream in the product development system, field trial data provides insights into who is undertaking research, where and with whom. International field trial data shows that Canada had an early and dominant lead over any competing country. Although 12 countries had field tested at least one transgenic variety between 1988 and 1995, Canada accounted for 54% of all the field trials undertaken and did almost four times the number of trials of the nearest country (France).

One might be inclined to conclude based on the above data that the regional system of innovation centred around Saskatoon is a chimera. On the contrary the generation and transmission of the non-codified knowledge in the regional system is the key factor holding things together. People develop skills and working relationships, which together convert bits of information into operable knowledge. This tacit type of knowledge is learned almost exclusively through experience. Researchers learn how to do things and who to work with through trial and error. Most of the innovation literature assumes that this know-how and, perhaps more importantly, this know-who evolves within corporations or institutions. That may hold true in an industry or within firms that are largely self-sufficient but, as noted, there are few firms that have the internal capacity to undertake all the research and development necessary to create a marketable variety. Some companies may have that capacity within their global operations but in many cases working through the geographically-dispersed multiple layers of these multinational enterprises is more complex and less cost-effective than buying-in from a more accessible and timely local source. Hence, although Monsanto and AgrEvo, for instance, both have giant research “universities” and labs at their headquarters in St. Louis and Frankfurt, respectively, both have collaborated extensively in Saskatoon with both AAFC and the NRC. Furthermore, in knowledge-based industries training and upgrading are critical, making it essential for private researchers to interact with the broader research community. For all these reasons, most of the firms in the industry have developed an extensive “community” of networks with both collaborators and competitors, involving other private companies, universities, AAFC and the NRC.

A survey of canola firms in Canada and globally undertaken in early 1998 highlights the importance of the proximity of competitors and/or collaborators as factors in locating their research efforts. Half of all the respondents, representing the majority of private companies responding, acknowledged the importance of proximity to either collaborators or competitors. About 40% recognised the importance of being close to their collaborators, particularly the NRC and AAFC in Canada and key research universities in the US (table 4).

Table 4: How important are the following to your decisions to both undertake research and to locate the research in labs in Saskatoon or elsewhere?

	N = 28	%
Proximity to competitors or collaborators	14	50%
- Proximity to collaborators	11	39%

- Proximity to competitors	8	29%
Access to local pool of skilled labour	7	25%
Access to large and accepting farm market for seeds being produced	6	21%
Key scientists either in your company or in partner organisations	5	18%
Role of government agencies (federal, provincial, regional) related to hospitality, red tape (or lack of)	5	18%
Access to labs, greenhouses and test fields	4	14%

As with most communities, proximity matters. Formal and informal face-to-face meetings and working side-by-side on laboratory benches and in the greenhouses are critical elements of both developing the know-who and transmitting the know-how. It is highly unlikely that the community would have developed if there were only competitive firms in Saskatoon; the non-competitive environment offered by AAFC and NRC create the platform for these relationships. Both AAFC and NRC have extensive arrangements with each other, public universities and private companies. In 1995-96, the NRC had more than 31 arrangements—ranging from research agreements to collaborative work agreements and licenses—that brought more than 65 guest researchers from other institutions into the NRC labs (NRC 1997). In 1997-98, the NRC welcomed 109 guest researchers. The key feature of these arrangements is that the core research team at NRC is able to learn from all of the collaborations, thereby adding further to the know-how knowledge and provide a visible, efficient point of entry for know-who knowledge. Even firms not resident in Saskatoon have developed extensive links to gain access to the knowledge in those two institutions, which suggests that slipover benefits from the know-how and know-who located in Saskatoon may be significant and may not move far from Saskatoon.

A key element in pulling the research effort together is the specialised, skilled labour force. The gradual agglomeration of canola research in Saskatoon and Canada suggests that there should be some evidence of a speciality labour market evolving. More than one quarter of companies responding to the canola industry survey, and the clear majority of private companies, indicated that access to a deep local skilled labour pool was important. A survey of canola research employees in Saskatoon undertaken in summer 1998 received 390 responses (from 1000 surveys distributed), representing 169 person-years of canola-related employment in 1998, compared with the 248 person-years of related employment in Saskatchewan identified in the company survey. When the degree granting institutions were examined, the dynamics of the industry become pronounced (table 5). All but two of the employees with a technical diploma were trained in Canada and 82% of the employees with technical diplomas got their training from the Saskatchewan Institute of Applied Science and Technology, mostly through the two-year Biotechnology Technology Program in Saskatoon. The same trend is seen at the undergraduate level. All but 22 of 85 of the respondents with a bachelor's degree were trained in Canada. There has been a bit more intra-country mobility at this level of training, however, with only 66% of the respondents getting their training in Saskatchewan. The Saskatoon labour market draws from Ontario, Alberta and Manitoba extensively. At the graduate degree level, the labour market becomes significantly more mobile. Less than half the employees with master's degrees and only about one quarter of the employees with doctorates are trained in Saskatchewan. In short, the higher the degree, the greater the mobility and cross-national movement of employees. At the Ph.D. level, more than 35% of the workers were trained offshore, in Europe, the US and other countries. Nevertheless, it is important to note that the single largest source of both masters and doctoral level employees is the local university in Saskatoon.

Table 5: Distribution of employees in the Saskatoon agri-food research community, by degree, 1998

% total	Technical diploma	Undergraduate degrees	Masters' degrees	Ph.D. degrees
Saskatchewan	82%	66%	43%	27%
Rest of Canada	16%	25%	41%	37%
US	1%	2%	6%	10%
Europe	0%	4%	7%	18%
Other	1%	3%	3%	8%

Source: Canola industry employees survey, July 1998

The data shows that the although the local labour market is able to supply much of the labour required, some of the higher skilled employees need to be recruited from elsewhere. All employees were asked what features of the job and community affected their willingness to move to or from Saskatoon. Somewhat surprising given conventional wisdom in the industry, the "thickness" of the labour market was the key consideration mentioned by respondents. All employees with graduate degrees that responded to this question ranked proximity to other companies or agencies that could hire them was in their top five considerations and 87% of the respondents put it as the most important consideration. The second most important feature was the type of work in the job, another feature of a thick labour market. Salary and benefits came third, followed closely by career prospects. Almost all the other factors, either related to the job or related to the community, were ranked well below these four factors (see Phillips and Khachatourians for details).

Zucker et al. offer an approach to determine more explicitly how the labour market contributes to agglomeration. Their study examined the role of human capital in the birth of US biotechnology enterprises by looking for causalities between the location of research stars and the creation of new firms. They defined stars as scientists that had discovered 40 or more genetic sequences or scientists that wrote 20 or more articles on genetic sequence discoveries. They concluded that the presence of active stars in a region was strongly positively correlated with the start-up of new ventures, stating that "at least for this high-tech industry, the growth and location of intellectual human capital was the principal determinant of the growth and location of the industry itself." If we take stars to be those who publish at least 20 articles and borderline stars as those who publish 15-19 articles, we find that 69 individual scientists world-wide fit the criteria (table 6). About 45% of the stars are in Canada, 45% in Europe and 10% in Japan. Approximately 63% of the borderline stars are in Canada and the rest scattered in Europe, Japan, the US and Australia. In total, the 69 stars and near stars, which represent just less than 1% of all the scientists working on canola, produced 1,523 articles, or about 31% of all the articles produced over the period (Zucker et al. found that the stars in their study represented 0.75% of all scientists but 17% of all articles). The largest single geographic concentration of stars and near stars in the world is in Saskatoon, where 11 or 16% of the scientists live and work. If the stars and near stars are then assessed by their citations rates, Saskatoon has 6 out of 40, or 15% of the total and about one third of all the Canadian stars and near stars.

Table 6: The location of research stars by country, 1981-96

	Stars		Emerging/borderline stars	
	all scientists with 20 articles or more	at least 20 articles; >5.0 cite rate	all scientists with 15-19 articles	Scientists with 15-19 articles; >5.0 cite rate
Canada	13	5	25	13
- Saskatoon	*3*	*2*	*8*	*4*
Australia	0	0	1	1
Europe	13	8	9	6
- France	*3*	*1*	*1*	*1*
- Germany	*4*	*2*	*2*	*0*
- Poland	*1*	*0*	*0*	*0*
- Sweden	*2*	*2*	*1*	*1*
- UK	*3*	*3*	*5*	*4*
Japan	3	2	1	1
US	0	0	4	4
Total	29	15	40	25

Source: ISI special tabulations

One could conclude from this analysis that during the knowledge creation phase, Saskatoon and Canada are significantly dependent on global markets for know-why and know-what but that they are increasingly self-sufficient as research becomes more applied.

5.2 Knowledge commercialisation systems

Economic theory indicates that firms locating where there are extensive backward linkages into supporting industries and forward linkages into the market can realise economies of scope. In Saskatoon, however, apart from publicly provided infrastructure, there is limited evidence of any existing or developing critical mass of other specialised industry that strengthens the bond between the canola research industry and the location.

A number of public investments in Saskatoon support the industry, including Innovation Place research park, the Saskatchewan Research Council facilities and the POS Pilot Plant, which undertakes scale-up work on oil and meal properties for companies with new varieties and consults on oil processing technologies. This support extends to financing. Private venture financing is limited, with no access to a local stock market (Calgary is the nearest market) and with only limited venture capital lending. The public sector fills the gap. Two financial institutions—the Royal Bank in Saskatoon and the CIBC in Winnipeg, both in partnership with Western Economic Diversification—have specific knowledge-based lending facilities while there is limited public lending capacity with Western Economic Diversification, the Business Development Bank of Canada, the Saskatchewan Opportunities Corporation and the Agri-food Equity Fund all having offices in Innovation Place or Saskatoon. Nevertheless, the operation of the various federal, provincial, regional and local tax and fiscal programs has sharply reduced the cost of locally conducted research and development, to the point where in aggregate much of the private innovation enters the market tax-free (Phillips and Khachatourians). Publicly-provided infrastructure, company specific industrial incentives, federal and provincial matching research funds, research in the public labs, public financing of university research and a plethora of grants and tax incentives combine to underwrite virtually all of the out-of-pocket costs for private research in Canada. Furthermore, the privileged tax status of western Canadian farmers ensures that producers retain whatever benefits there are from early adoption. Hence, in spite of weak private capital markets, the public system has effectively made the biotechnology sector tax-free.

Although the financial, accounting and legal communities have been restructuring recently to service the growing private research effort in Saskatoon, surveys conducted in 1998 suggest that only limited accommodation had been made by then to support and service the developing biotechnology industry. All of the multinational firms undertaking canola research in Saskatoon indicated in discussions that they did their banking as part of the corporate effort, with much of the service coming from their Canadian or global headquarters which were always located in another city or province. Meanwhile, the Chartered Accountants of Saskatchewan, the Certified Management Accountants of Saskatchewan, and the Certified General Accountants of Saskatchewan, when contacted, indicated that no specific listings are available for practices that deal specifically in the area of biotechnology. A fax-back survey of biotechnology companies undertaken in August 1998 revealed once again that multinational firms used accounting services purchased through their Canadian head offices while the smaller firms responding indicated they used local accountants and auditors. None of the accounting practices were identified as having a speciality in accounting for knowledge-based enterprises.

A third key service required by knowledge-based firms is legal support for protecting intellectual property that may have commercial value. A key limiting factor in Saskatoon is that there are no resident patent agents in Saskatchewan. Most of the patent agents operating in Calgary, Edmonton, Winnipeg or Ottawa have relationships with local legal firms or have liaison offices in Saskatoon to link to the local demand for the service. Even so, a few of the legal practices in Saskatoon have capacity to support firms with protecting their intellectual property. While 9 of the more than 50 multi-partner practices operating in Saskatoon indicated they had some capacity in the area of intellectual property rights, only two firms indicated they had an ongoing practice. In addition, the focus of the local legal community is on the Canadian law, which limits their application as innovators wish to protect most of the innovations internationally. In short, firms are being serviced, but the presence of many multinationals, which buy these services internationally, combined with the absence of any registered patent agents in the province and few full-time lawyers specialising in intellectual property limits the scope benefits that could accrue to the industry.

Moving downstream from the research stage, there are vital forward linkages that increase Saskatoon's attractiveness as a research site. More than one fifth of all companies surveyed (table 5), representing most of the larger breeding operations, indicated that rapid access to a receptive seeds market was critical to their decision to locate in Canada. They confirmed that undertaking the research and commercialising the resulting varieties under the same regulatory system was a key feature in their location decisions. Heller (1995) estimates that a regulatory delay of one year decreases the rate of return for a biotechnology product by 2.8%, while a two-year delay decreases the rate of return by 5.2%.

Both the regulatory system and market responsiveness matter (Porter). In the first instance, the regulatory system determines how quickly farmers can and will adopt new varieties. The Canadian regulatory system is generally viewed as somewhat slower than the US system (although this lag may have diminished with the experience gained with early transgenic varieties), but is clearly faster than either in Europe or Australia, where no transgenic canola varieties were approved as of May 2000. The first transgenic varieties were approved for unconfined release in 1994 in both the US and Canada and began commercial production in 1995. Beyond that, farm programs partly determine the pace of adoption of new varieties. In Canada, new varieties of canola are automatically eligible for crop insurance and other stabilisation assistance, without limits on acreage seeded or location. In the EU, where the Blair House Accord and the WTO agreement limit canola acreage, incremental planting is treated less favourably than existing acreage, which limits its adoption in some countries and regions. Furthermore, canola is not yet suited agronomically to most parts of the US and Australia, which limits adoption there.

Farmers respond to varieties partly based on the regulations, partly based on the markets and partly based on their prior knowledge and experience in adopting new varieties. The evidence is compelling. Farmers rapidly adopted these new varieties, with an estimated 50% of the acreage in 1998 was planted to HT varieties and up to 72% of the acreage in 1999.

The extensive co-operative farm service networks have supported this large, receptive and relatively sophisticated farm market for new seeds in the prairies. The Prairie Pools, in particular, with an historical delivery share of about 60% and a membership including the majority of farmers in the West, have aggressively positioned their organisations as wholesalers for new varieties, partnering extensively with Svalof in earlier years and more recently collaborating with AgrEvo and Monsanto to deliver their proprietary herbicide tolerant seeds to their farmer members. In addition, the extensive network of not-for-profit producer and industry organisations such as the Canola Council of Canada and the various provincial growers associations ensure the rapid and efficient adoption of the technology.

Beyond the wholesale system, however, the market opens up to the rest of the world, with little evidence that Saskatoon, or for that respect Canada, dominates the system. The 20% of the product consumed within Canada is marketed through the Winnipeg Commodity Exchange or through a number of proprietary processing and retailing supply chains, with little backwards links to the R&D community in Saskatoon. Offshore, Canada’s influence is limited to controlling the use of the trademarked name on the 80% of the Canada’s volume that makes up almost half of the world trade in the product. Foreign-owned companies produce all of the resulting product with proprietary technologies.

On net, it would appear that while linkages in the knowledge creation system are the base for this innovation cluster, the downstream capacity to commercialise the product are quite extensive and one of the key factors contributing to the location and expansion of this activity in Saskatoon and Western Canada.

6. Conclusions and implications

This chapter has presented a modified framework for examining modern innovation and provided some compelling, if not conclusive, data from the Saskatoon-centred biotechnology-based innovation cluster that supports the view that innovation systems should be more properly examined as trade entrepot rather than self-contained, self-sustaining centres. In Saskatoon's case, the innovation cluster has found a niche as the developer and early adopter of new transgenic canola varieties. The core public labs and sophisticated producer and marketing organisations are at the heart of the cluster. It is clear from the evidence, however, that the innovation cluster is not in any way independent or self-sufficient. Rather, it draws heavily on global R&D, world-wide labour markets and speciality services from across North America, with the result that less than half of the value added to the product is added locally. In short, it operates remarkably similarly to a traditional trade entrepot.

Table 8: Global canola production and seed trade, 1961 and 1998

	share of global production		export market share	
	1961	1998	1961	1998
Australia	0%	4%	0%	8%
Canada	7%	21%	40%	47%
China	11%	23%	0%	0%
European Union (15)	15%	27%	11%	37%
France	3%	10%	10%	28%
Germany	7%	9%	1%	4%
United Kingdom	0%	4%	0%	3%
India	37%	14%	0%	0%
United States of America	0%	2%	0%	3%
World totals (thousands metric tonnes)	**3,596**	**35,869**	**310**	**8,717**

Source: FAOSTAT.

The returns of succeeding are significant. In the Saskatoon case, for example, as the research effort into canola increased, rapeseed/canola production shifted towards countries that intensively managed canola as a knowledge-product and away from countries that did not compete on the knowledge front (excluding China, which has not allowed market forces to determine production) (table 8). The EU and Canada, both leaders in the research and development of canola, together more than doubled to 45% their share of global production over the past 30 years. India, Pakistan, Poland and Japan, meanwhile, invested little in R&D for new varieties and saw their share of global production drop to about 21% in 1992-99, compared with 50% in 1961-65. In addition, a number of new producers are on the horizon with commercial quantities of canola. The UK, the US and Australia, each significant investors in canola-related research, are notable for entering and significantly expanding their market shares in the 1980s (equal to 8% of global production in 1992-99). Although none of these countries is producing enough to challenge the key producers of EU or Canada yet, their future role cannot be ignored, especially in the product end of the business. Canada sustained and solidified its commanding position in the seed export market throughout the period. As Canada's share of production rose, so did its share of trade, reaching 47% in 1998. Europe, the only other large exporter, saw its share of trade rise from 11% to 26% over the same period. Meanwhile, as research and production stagnated relatively in most of the rest of the countries in the world, their export market share dropped, to 14% in 1996 from 49% in 1961.

There are three aspects of this model that warrant further discussion.

In the first instance, the concept of knowledge based clusters operating as entrepot needs to be examined in other areas to determine whether it is a general or specific case. Other regional clusters should be examined using this (or a modified) methodology to determine whether they are self-sufficient or exhibit entrepot characteristics. A good example of a related study is the work of Feldman (1994), which examines the role of Johns Hopkins University in the Baltimore area. Other investigations need to be undertaken.

Second, the model needs further refinement. Each of the definitions and methods for evaluating the knowledge factors could be improved. Furthermore, while serendipity, the wild card in the mix, may not be amenable to modelling in the strictest sense, it may be further investigated in the context of examining the 'know who' dimension. There is evidence in the literature on creativity that communication, connections and critical mass play a significant role in the occurrence of serendipitous outcomes, and while such outcomes cannot be planned, the conditions for increasing their likelihood can be nurtured.

Third, this alternate model of innovation poses some serious challenges for development policy. Much of current development effort has a strong mercantilist orientation, with a focus on generating exports while impeding imports. Governments at all levels in many countries are actively using their tax and fiscal policy to encourage greater local R&D or to attract global firms to relocate their R&D programs into their jurisdiction, in an effort to generate higher value exports or to replace imports. This often has involved preferential support for national champions or exclusive deals to encourage an MNE to relocate their activities. Usually governments do this without any consideration of the corresponding relationships and interactions that especially knowledge based firms require to succeed. If innovation can be thought of as limited to within a firm or within a regional or national community, then such a narrow approach might have some chance of succeeding. But if innovation is truly global, as appears to be the case in many of the life sciences, then narrow, mechanistic self-sufficiency strategies may either simply fail or at times prove to be counterproductive. The evidence from the biotechnology sector suggests that innovation is truly global, which goes a long way to explaining why both firms and skilled employees are more interested in the innovation community than in fiscal incentives, public infrastructure or government supports. By extension, a mercantilist policy that discourages global links could not only fail to attract but could ultimately drive out firms or researchers as they seek access to the global community.

Table 9: Public policy options for nurturing knowledge-based innovation clusters

Knowledge factor	Policy prescription
Know-why	• Develop absorptive capacity through basic research capacity in universities and public labs • Nurture two-way international flows of information through programs that support and encourage international collaborations
Know-what	• Create effective intellectual property protection systems that facilitate two-way international flow of innovations • Encourage location of competing and collaborating multinational enterprises to encourage transfer of proprietary technologies
Know-how	• Develop and maintain a critical mass of researchers and technologists focused on advancing and using the technologies either in public labs (e.g. AAFC) or in private firms • Nurture "thick" labour markets through post-doctoral research support and liberal labour policies
Know-who	• Develop and maintain open-platform institutions to facilitate research collaborations (e.g. NRC) • Nurture collaborative, industry-led networks to facilitate communications and to assist with developing the forward and backward institutions necessary for efficient commercialisation

The entrepot innovation model, as illustrated by the Saskatoon-centred biotechnology-based innovation cluster, offers alternative options (table 9). One key to succeeding in this type of a world would be to invest in those institutions and mechanisms that encourage the development and access to the four knowledge factors, which provide the true base for the "absorptive capacity" of a research economy. From this example, it is possible to identify a number of vital elements to creating that capacity. First, there must be effective mechanism to both practically and legally transfer knowledge, which at a minimum involves a domestic research community with international collaborations, some MNEs with proprietary technologies and appropriate legal protection for intellectual property. Second, there needs to be open and accessible labour markets for skilled workers. Third, there needs to be a platform, such as the NRC, AAFC and industry-led networks, for community-based interaction and synergies to develop. These elements provide the foundation for absorbing global knowledge. Others, such as preferential financing and speciality commercial services may be important, but would appear to be second-order requirements.

In short, the innovation clusters are very attractive economic development tools, but they must be nurtured with an appreciation for their partial and incomplete nature. Fundamentally, they are part of a global innovation system, and cannot thrive if cut off from the lifeblood of the system—ideas, skilled labour and collaborative platforms.

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