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Infant Industries Accessing Global Markets: Strategic Risks and Potential Trade Barriers in Bioplastics

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Abstract

Bioplastics is an industry that is seen to have considerable potential to decrease dependence on petroleum and contribute to environmental enhancement. Bioplastics markets, however, are likely to be niche markets and, hence, firms from countries with limited domestic markets will need to expand their sales to foreign markets. As an infant industry, however, international supply chains in bioplastics are poorly developed and trade barriers to new products may exist. As a result, bioplastic firms from small markets face strategic risks when attempting to gain access to foreign markets. Overcoming these risks has implications for the structure of international supply chains. A transaction cost economics framework is used to illustrate the difficulties associated with accessing foreign markets in the case of the Canadian bioplastics industry. A case study is provided of the strategy used by a multinational firm to establish an international supply chain in bioplastics. Implications for the future development of the bioplastics industry are discussed.

Key words: Bioplastics, infant industry, international supply chains, strategic risks, transaction costs.

The JEL classifications: F13, F14.

Introduction¹

The increasing demand for environmental stewardship and the focus on reducing greenhouse gas emissions to slow global warming has raised to prominence an old, and new, idea – to increase the importance of non-food industries whose output is biologically based. This new interest in alternatives to petroleum-based products has led to significant resources flowing into research and development pertaining to potential bioproducts that could help attain society's environmental goals. Far less discussed, however, are the constraints faced by infant industries that lack an established supply chain. Research and development is important, but it will not bring these products to market. It is important to recognize some of the supply chain challenges that may be faced by bioproducts industries. This paper focuses on bioplastics and the challenge presented by the establishment of international supply chains. A transaction costs framework is used to provide insights into questions pertaining to the establishment of international supply chains for bioplastics. The case of an already commercialized bioplastic sheds light on the type of vertical coordination that needs to take place for the industry to mature.

Bioproducts

Approximately a century and a half ago, there was an established bio-based industry whose main input was biomass. This industry produced a wide array of products including: inks, dyes, textiles, lubricants, cosmetics, medicines and car parts. Technological improvements in the ability to find, extract and transport fossil fuels led to the development of a petrochemical industry that competed effectively against existing the bio-based industry on the basis of cost and product quality. However, given that petroleum-based industries have significant externalities associated with them, in the future there is the potential for bio-based industries to again become competitive with industries that have fossil fuels as their primary input. The ability of bioproducts to compete effectively depends on three crucial assumptions. First, that government policies are used to correct the market failures associated with the petroleum-based industries. Second, that there will be

¹ Funding support from the Social Sciences and Humanities Research Council of Canada and BIOCAP Canada is gratefully acknowledged.

significant cost-reducing scientific advances and technological improvements. Third, that firms basing their production on biologically-based inputs can access sufficiently large markets to reap the cost reducing benefits of economies of scale in their production. It is the third assumption that provides the focus of this paper.

Bioproducts can be defined broadly as commercial or industrial products that are generated from biomass but are not intended for human consumption or animal feed. Thus far, however, the technological advances appear modest and there are few bioproducts that are able to compete directly with existing petroleum-based products. However, public policy makers in some countries are beginning to take action against the externalities associated with fossil fuels and, in particular, against greenhouse gas emissions. The United States, the European Union (EU) and Canada are all actively pursuing the development and acceptance of bioproducts. Biomass currently accounts for three percent of the US energy needs and represents more than 300 billion pounds of products annually, primarily derived from forest products¹. There are about 250 companies in the US that produce bio-based products ranging from plastics to lubricants, inks, enzymes, adhesives, solvents, paints, cosmetics, landscaping products and pharmaceuticals. Likewise, the EU has invested heavily in bioproducts research over the past 10-15 years. The EU experience suggests a noticeable lack of market demand at current prices but despite this there is a widespread and growing interest to the industry's development. In Canada, as of April 2002, Industry Canada reported approximately 75 to 100 domestic firms either actively engaged in bioproducts research and development (R and D) or already engaged in manufacturing products on a commercial basis (Innovation Canada, 2002). It is important to note that the majority of these firms and the current investments are focussed on bio-based pharmaceuticals and other high value products judged to have the best probability of high returns. Outside the US, the Kyoto agreement focused a great deal of attention on bioproducts, as countries search for ways to meet their commitments through the reduction of greenhouse gas emissions (GHG).

Bioplastics

One class of bioproducts that might prove to have considerable potential is bioplastics (also referred to as biopolymers). Some bioplastics have already reached the stage of commercialisation and they are a major focus of the bioproducts effort in the US and the EU. Canada has seen several small start-up companies that are targeting their technologies and products to small niche markets. There is a broad range of biopolymers that can come from many different sources such as crops, forests, marine life, insects, livestock, bacteria and fungi. The focus of this study is an industrial-scale application of a bioproduct using agricultural feedstocks; bioplastics represents one of the largest potential products in this category.

Bioplastics, unlike their petroleum-based counterparts, can be biodegradable and as a result of this environmentally friendly attribute, are capturing the interest of both governments and firms. This is particularly true in the EU where regulations promoting the composting of biodegradable materials has boosted demand. The EU market for bioplastics in 2000 was 10,000 tonnes (40% of the world market) and it's expected to grow to 60,000 tonnes by 2005. This is, however, very small when compared to the conventional plastics market in the EU that was approximately 37 million tonnes in 2001². The main product markets are food packaging, compost bags, paper coatings, dishes and cutlery (Warmington, 2002). Other potential uses of bioplastics that are being explored include loose fill packaging, packaging for electronics, injection mouldings, films and fillers, and children's toys. The long-term market opportunities for bioplastics in the EU are estimated to be about 300,000 tonnes by 2010 (Canadian Agri-Food Research Council, 2003).

¹ Fostering the Economic Revolution in Bio-based Products and Bioenergy: An Environmental Approach. January 2001. An interagency strategic plan prepared in response to the US Biomass Research and Development Act of 2000 and the Executive Order 13134: Developing and Promoting Bio-based Products and Bioenergy by the US Biomass Research and Development Board.

² The figures quoted include EU 25 plus Norway and Switzerland. Association of Plastic Manufacturers in Europe (2003). http://www.apme.org/dashboard/business_layer/template.asp?url=http://www.apme.org/media/Public_documents/20030617_120738/AnnualReport_2003.pdf

Markets in the US are also expanding, but unlike those in the EU, the incentive is not government policy and consumer concern for the environment but, rather, traditional economic ones such as price and performance. The US plastics industry has approximately sales of US\$ 50 billion per year. If the potential market for biodegradable polymers is similar to that in Europe, about 20 percent of sales, then ultimately the North American market is approximately 10 billion dollars per year (Agriculture and Agri-food Canada, 2002). However, if new fibres can earn acceptance in the apparel and textile industries, then the markets could be even larger. Numerous traditionally petroleum-based chemical companies have been involved in the research, development and commercialisation of bioplastics. Most notable are advances by Cargill Dow Polymers and DuPont, firms that have made investments in new production facilities for bioplastics. In general, there are two main sources of commercially available biodegradable plastics: starch-based materials (either unmodified, or modified and complexed with other polymers) and polylactic acid (PLA), where starch is first fermented to lactic acid and then polymerised into PLA.

Potential Environmental Impacts

The rule of thumb for starch-based plastics is that they can save between 0.8-3.2 tonnes of CO₂ per tonne of plastic produced relative to fossil fuel-derived plastics (Agriculture and Agrifood Canada, 2002). Even with this advantage, however, bioplastics may not have a significant impact on GHG emissions in this decade, as the current markets are small. If there is to be meaningful GHG reduction the current small niche markets for bioplastics must expand. The current focus of research and development reflects this concern and concentrates on price and performance advantages over petroleum based substitutes. There may be even more downstream CO₂ saving realised through the composting and recycling of bioplastics. The advantage of bioplastics may, in fact, lie in the ability to compost the material and use it as a soil input in the future. However, this would require product labelling to differentiate these plastics and for a waste separation system to be in place¹.

Challenges and Barriers to Industry Development

The biggest challenge currently facing the bioplastics sector is the inability to scale up to commercial production and expand beyond small niche markets. Thus far, the bioplastics industry has been focused on the niche market of consumers looking for the attributes that bioplastics provide. Some of the hurdles that a new industry like bioplastics faces are: current small volumes, obtaining a consistent input supply, uncertainty, imperfect market information, capital limitations, and export constraints.

The low volumes that are currently produced are not sufficient to ensure a long-term bioplastics industry. The inability to capture the benefits of economies of scale has been identified as one of the biggest problems that the bioplastics industry is facing. To succeed it is vital that the bioproducts industry expands beyond small volumes to become a competitive substitute for petroleum-based plastics. While the "scale problem" is evidenced even in large markets like the US and the EU, it is doubly difficult in economies with small markets. If Canada, for example, is to have a long-term bioplastics industry the market must grow both by focusing on being competitive with petroleum-based substitutes in the domestic market and accessing niche market in other countries.

Low volumes are linked to problems associated with insufficient investments in world-scale production facilities. In Canada, for example, there has been no major investment in the industrial-scale production of bioplastics. The US has recently seen two major plants built for this purpose and firms have begun to produce products on a commercial scale. The development of a new industry is often compared to "the chicken and the egg" problem. To be precise, it is difficult to say which comes first; should industrial-scale facilities to produce bioplastics be set up regardless of uncertain supplies of inputs or should producers invest in crops that can ensure a competitive bioplastics industry without facilities being in place to use their crops? This is an example of a

¹ It is important to note that the energy saving of bioplastics is still up for debate and there are some scientists who claim bioplastics maybe more energy intensive than petroleum-based plastics (Gerngross and Slater, 2000).

hold-up problem where asset specific investments need to be made and, due to the risk of opportunism, neither party wishes to be the first mover.

The need for a consistent supply (both quantity and quality) of inputs is necessary for a viable bioplastics industry. Canada has the potential to supply the starch required by the bioplastics industry but there is doubt whether it can compete with the already developed and highly subsidized corn-based starch industry in the US as well as other cheaper starch producers worldwide. This constraint may be overcome by strategically targeting the location of investments, perhaps in southern Ontario, where it will be feasible to use only Canadian starch sources but would allow the import of corn-based starch from the US. The Canadian government's desire to develop this industry has been a major driving force. Beyond the desire to reduce GHGs, a secondary basis of the government's interest is to find better markets for Canada's agricultural commodities; imports of US corn as inputs would diminish the expected benefits. Whether a consistent quality will exist depends on how farmers view this industry. Is it a place to send substandard food crops or can it compete against current market outlets for grain? Farmers will need to be willing to invest in crops that provide processors with a steady supply of grains that contain the quality attributes required to ensure the consistency of their bioplastic products. As suggested above, this is an asset specific investment and producers will need to be provided with incentives if they are to change – a premium price compared to current markets. Due to the nature of bioplastics, however, and the goal to make them competitive with petroleum-based substitutes leaves little room for premiums. To date, little research has been done to determine if consumers are willing to pay for the attributes of bioplastics and, as a result, it is difficult for firms to develop strategic expansion strategies.

Canadian farmers have been successful in providing consistent grain with desirable attributes for flour. This has been the consequence of many years of breeding that has resulted in varieties designed for the needs of Canada's customers. Up until the present, most Canadian wheat has been bred for protein attributes, which are important for high quality flours. In the Canadian Grain grading system for wheat, by contrast, there has been little room for feed varieties of wheat that are bred for extremely high yields and starch content. Further, to protect the high quality reputation of wheat grown for bread and pasta, the government has put up significant regulatory barriers to the licensing of high starch wheat varieties for commercial production. If the future does lie in a bio-based economy, Canada will need to redirect the current regulatory focus to include crop with large starch potential. There is likely a role for institutional development to help reduce transaction costs and develop the market. This is central to Canada being able to compete with the US corn industry, which currently has the ability to produce high volumes of consistent and low cost starch.

The ability to quickly develop the crops required of bio-based industries may be greatly enhanced by genetically modified technology. The use of this technology is, however, controversial – particularly in some potential export markets. As the current markets for bioplastics lie in the EU, it is risky to pursue the development of bioplastics based on biotechnology due to strong consumer resistance in the EU to genetically modified organisms (GMOs) (Gaisford et al., 2001). On the other hand, Canada's major trading partner, the US, has licensed a number of GMOs and there has been little consumer resistance to commercialisation. Thus, whether to fully adopt this technology in Canada is a subject of intense debate.

The bioplastics industry, as with many new industries, is viewed as breaking new ground, introducing completely new products on the market and creating the need for new supply chains. Importantly, this industry has a high degree of uncertainty associated with it. Firstly, it is uncertain whether there are environmental benefits from adopting this technology. This has led governments to be careful about fostering these industries through regulations that would ensure their adoption. As well, there is uncertainty surrounding the market for bioplastics in the EU, as there appears to be an information asymmetry problem that consumers cannot identify the biodegradable plastics from the traditional ones. This information-based market failure could provide a role for labelling so that consumers could be better informed. The introduction of a product in a new market place is always uncertain. Amplifying the uncertainty is the fact that bioplastics will need to secure export markets as the Canadian market is small. As with many Canadian products, the opportunity lies in the export markets and exporting always increases risk and uncertainty.

This leads to the challenge of acquiring adequate market information with respect to consumer preferences, prices sensitivities and optimal product format. The challenge among export markets may vary. For example, in the EU it is the environmental attributes of the bioplastics that are important but in the US it is the ability to compete on price and performance. If the desired target market is the US, then there is a high degree of price sensitivity. Targeting the EU, product characteristics and consumer preferences will be important.

Another barrier is the access to financial capital. In the absence of supply chains and well-developed markets, such endeavours are regarded as high risk and the cost of capital reflects this risk. It is very difficult to establish new markets and supply chains without access to capital. In the US, however, the development of this industry has been dominated by multinationals that have no difficulties accessing capital. Conversely, in Canada, it has been small start up companies that face significantly higher capital costs. The difference between Canada and the US can, in part, be attributed to access to cheaper inputs as the US industry enjoys a higher level of subsidization that reduces inputs costs and makes the industry more attractive to the large multinationals.

Lastly, there may be export constraints that are complicating the development of markets of sufficient size and the ability to organise efficient international supply chains. Many potential exports are subject to tariffs or non-tariff barriers to accessing foreign markets. When a new product is developed, it may be assigned to existing tariff classifications that are inappropriate. For example, agricultural products that have traditionally been used for food may have high protectionist tariffs which reduces the ability of crops grown for bioplastics from competing with plastics based on petroleum that typically enjoy low tariff levels. Hobbs *et al.* (2000) noted this exact problem in the bison industry, as bison is exported to the EU under the beef tariff line that carries a 50 percent tariff when there is no EU-based bison industry to protect. The delays and costs associated with obtaining a separate tariff line for bison have been perceived as sufficiently onerous to deter what is an infant industry in North America from pursuing it even if bison has shown to have considerable market acceptance in the EU. A favourable tariff classification, on the other hand, may assist in the process of developing foreign markets for new products. For example, the US Federal Trade Commissions voted to designate PLA as a generic fibre category similar to cotton, wool, silk, nylon and polyester that carry a low tariff level¹. This resulted in advantageous market opportunities and the potential for growth is considered very significant (Cargill Dow, 2002). Since the EU seems to have the greatest market potential for bioplastics produced in Canada, it is important that trade barriers do not hamper market access and the ability to develop that market.

Comprehending the Challenges

Some of the key issues facing the nascent bioplastics industry in small markets are the need to invest in products or facilities that are vulnerable to the actions of others (asset specificity), not being protected against self-serving activities of other actors in the supply chain (opportunism), unanticipated future events (bounded rationality) and unequal access to information (information asymmetry). These are all problems where insights can be gained from using a Transaction Cost Economics (TCE) approach.

Transaction Cost Economics is a theory of industrial organisation that finds explanations for how economic activity is co-ordinated and how the costs of those activities can shape or inhibit the development of an industry. Williamson (1986) identified three critical dimensions that characterized transactions: uncertainty, frequency, and asset specific investments. These characterizations play a key role in the dynamics of the new bioplastics industry. It is these characteristics that will determine the level of vertical coordination and how an industry will develop. When markets are used for vertical coordination, it is prices that provide firms with incentives to buy and sell. When prices change it forces firms to re-evaluate using the market mechanisms. Firms using the market will employ resources to acquire information on prices, to negotiate transactions, and ensure the agreed provisions of the transaction are adhered to. These activities come under the general title of information, negotiation and monitoring costs.

¹ Depending on the exact tariff classification, tariff levels for imports into the EU in this category are low, most at 0 percent and the US tariff level for the same category ranges between 5 and 9 percent.

Information costs are incurred *ex ante* to a transaction and can include everything from the time allocated to finding trading partners, identifying product qualities, and gathering price and currency information. Negotiation costs are the costs incurred while the transaction is being arranged and are often linked to contracting costs. These include the resources used to specify contractual terms, the paying of any middlemen or agents and legal services. There are also the costs incurred after a transaction is agreed; these are termed monitoring and enforcement costs. This involves ensuring that all the pre-agreed provisions are fulfilled. High levels of asset specificity and existence of bounded rationality and chance of opportunism will increase transaction costs and lead to closer levels of vertical coordination.

Establishing a supply chain infrastructure for new products is inhibited, first and foremost, by its high levels of asset specificity. For example, investment in a bioplastics manufacturing facility is asset specific. One may argue the building could be used for an alternative use but most likely there would be a significant investment made for production equipment to produce a specific bioplastic. To adapt current plants for plastics production may not be suitable as the chemistry involved is different and one would need new and specific equipment for such a task. This can be illustrated by the fact that there will need to be holding facilities for the biomass or starch which will differ from the current holding facilities used for petroleum. As well, there may be a push for a specific variety of grain to use as an input. However, a grain company may not be willing to acquire the amount needed of this grain as they may incur a loss due to its specific nature if they cannot find an alternative buyer. Hobbs et al. (2000) observed that new industries often face the classic hold up problem of who moves first, as assets are specific and open to opportunism.

TCE assumes that agents are subject to bounded rationality, where behaviour is intendedly rational, but only limited so and opportunism arises, which is a condition of self-interest seeking with guile (Williamson, 1986). The risk of opportunisms in the case of bioplastics is compounded by several factors. Firstly, in a new industry there is uncertainty about the reputation of the buyers and sellers as there has not been time to establish reputations. This may not be a significant constraint in the case of bioplastics as it seems that many of the players are well-established chemical companies with worldwide reputations. It may be, however, that only these firms have had sufficient reputations to overcome this constraint. In Canada, thus far, small start up companies are the norm in the bioplastics industry, and opportunism may be a factor as credible reputations have not yet been established.

The international nature of this industry increases the risk of opportunism. It is easy to see that it is virtually impossible to write fully contingent contracts. The parties involved with the contracts can never foresee all possible situations that may arise. Acting opportunistically may be easier to get away with in an international environment. The best protection one has against opportunisms is repeat business (Kerr and Perdakis, 1995). A firm is much less likely to act opportunistically if they wish to continue doing business with the other firm in the future. What complicates international transactions is the lack of an efficient system of private international law system to govern the contracts (Wasylyniuk et al., 2003). For example, one must decide whether to pursue action in the importing or exporting country and yet the courts in one country do not have jurisdiction over an action in another country. Due to this gap in governance systems, international disputes are often settled by arbitration. Arbitration is not necessarily binding and one party could still decide to ignore the results of arbitration. Firms that are incurring the information, monitoring and enforcement costs to protect themselves against opportunism may find this lack of transparency sufficiently risky to deter investment based on loose contractual agreements, and form more official relationships such as joint ventures or vertical integration. With common interest involved in joint venture and vertical integration there is less incentive to act opportunistically.

It is important to recognize that international business will increase information costs because of currency differences. It is expected that information costs will rise in the international setting as firm must not only gather price information but currency information as well. Floating currencies increase the risk of business. Currency hedging can mitigate this risk and most large company commonly engage in this practice but contract lumpiness and lack of experienced staff often limit the abilities of smaller firms to engage in currency hedging (Gillis et al., 1992).

Hobbs et al. (2000, p. 593) noted, "Information asymmetry is pervasive in the development of supply chains for infant industries." Unlike traditional grain markets, prices of grain and starch for bioplastics may not be as readily available. As well, processor may be subject to information asymmetry as there are no well-developed standards for the industry. This lack of transparency may increase the information costs of both the suppliers and the processors. Where little or no information on the desired quality is available, it may be in the best interest of the processor to move to higher levels of vertical coordination to reduce quality uncertainty.

Potential International Bioplastics Supply Chains

Understanding the current challenges faced by the new bioplastics industry provides insight into the possible level of vertical coordination that will facilitate the growth of this industry. It is obvious there is a high degree of assets specificity involved with this new technology. As well, the risk of opportunisms is present and exacerbated by the need to access international markets. Transaction costs involved with this market are high due to its infant stage and its need to develop as an internationally traded product. This leads to the hypothesis that this industry will need to see close levels of vertical coordination in order to strengthen and flourish.

Perhaps this is best illustrated by examining a specific bioplastics that has reached the commercial stage of development and has an established supply chain. This product is a good example of how other bioplastics will need to develop their international supply chains to bring products to sufficient markets to make them commercially viable. DuPont has developed the bioplastic Sorona™ which is a copolymer based on 1,3 propanediol (made from corn starch) and the petroleum-derived terephthalate. Sorona™ can be spun into apparel-grade textile fibres. Fabrics made from Sorona™ are "soft to the touch, exhibit excellent stretch and recovery characteristics, can be dyed readily and feature the easy care characteristics of polyester"¹. DuPont has built a state-of-the-art plant in Kinston, North Carolina to produce Sorona™.

This supply chain begins with formation of a very strong science and technology base. DuPont has developed an R and D alliance with the Massachusetts Institute of Technology (MIT); this entails a US\$35 million, five-year alliance. This includes the formation of inter-disciplinary teams working on projects that focus on bio-based materials and technologies². Likewise, DuPont has a partnership with Genencor, the world's second largest developer and manufacturer of industrial enzymes. It is interesting to note that Genencor is the result of a joint venture between Eastman Chemical Company (Kingsport, Tennessee) and Cultor Ltd. (Helsinki, Finland). Together DuPont and Genencor filed a worldwide patent on microorganisms and processes that produce 1,3 propanediol (3G) in a single step from virtually any carbon source³. DuPont announced a wheat research alliance with the John Innes Centre. This alliance provides the John Innes Centre and its Sainsbury Laboratory access to genomics research tools developed by DuPont and a clear commercialization path for developed technologies. DuPont gains access to a world centre of excellence in molecular biology that will help it use biotechnology to improve wheat yields and quality.

These types of research alliances that designed to accelerate scientific discovery are the norm in DuPont's case. Other alliances include: 3-Dimensional Pharmaceuticals (Yardly, Pennsylvania), Lynx Therapeutics (Hayward, California), CombiChem Inc (San Diego, California) and Affymax Technologies (Santa Clara, California).

The alliances that exist to provide inputs within the supply chain are now examined. These alliances include the purchase and merger with Pioneer Hi-Bred. Pioneer Hi-Bred is the world's leading developer and supplier of advanced genetics to farmers worldwide. Pioneer operates in seventy countries around the world and develops hybrids of all types of crops. In the area of starch, sugar and protein production DuPont has a partnership with Tate and Lyle. This is a joint development agreement to produce bio-based polymers. Tate and Lyle is a global leader in carbo-

¹ Sorona™ Website site. <http://www.dupont.com/sorona/home2.html>

² DuPont web site www.dupont.com

³ DuPont press release, April 11, 2000.

http://www1.dupont.com/NASApp/dupontglobal/corp/index.jsp?page=/content/US/en_US/news/releases_today.html

hydrate processing and produces sugar, cereal sweeteners, starches and citric acids. Similarly, DuPont purchased Protein Technologies International (PTI) from Ralston Purina. PTI is the leading global supplier of soy proteins for the food and paper processing industries. PTI has since been renamed DuPont Soy Polymers. Soy protein can be used as a direct substitute for casein in various industrial applications. The company claims their soy protein offers cost savings, more stable pricing, reliable product availability, and consistent quality.

To understand the manufacturing ability of this supply chain, one must first examine DuPont itself. DuPont is the largest chemical company in the US and operates in seventy countries throughout the world. DuPont has numerous business units, including: agriculture and nutrition, nylon, performance coatings and polymers, pigments and chemicals, polyester, special fibres, and specialty polymers and electronics. DuPont has 135 manufacturing and processing facilities throughout the world. As mentioned previously, DuPont has built a continuous polymerization plant for the production of SoronaTM in North Carolina.

Further strengthening the manufacturing potential of DuPont is the acquisition of 1,3 propanediol (PDO) technology from Degussa. Degussa also agreed to construct and operate a 9,000 metric tonne PDO plant in Wesseling, Germany. PDO is an important component of DuPont's SoronaTM. The German plant, which produces PDO based on petroleum feedstocks, is intended to give DuPont a head start in developing products from PDO and provide a "bridge to market" for DuPont's bio-PDO. The bio-based technology is expected to dramatically lower the cost of PDO production, as well as downstream products.

This leads to the final stage in the supply chain, the manufacturers that will use SoronaTM as an input. DuPont has released licences worldwide for the use of the technology. Some of the current licenses include Far Eastern Textile Ltd. that is based in Taiwan and is one of the biggest polyester producers in Asia. Correspondingly, DuPont has provided a license for Teijin based in Japan that is quickly becoming one of the largest polyester producers in the world with plants located in Japan, Thailand, Indonesia, Mexico, China and Italy. Other licenses with Asia companies include Toray also based in Japan and Saehan based in Korea. Lastly, a joint venture between DuPont and Haci Omer Sabanci Holding A.S. gave rise to a new company called DuPontSA that will develop, make and sell polyester filament, resins, and related products throughout Europe, the Middle East and Africa.

Applying this example and examining some of the key feature such as multinationals, joint ventures and licences illustrates how this supply chain has emerged to reduce transaction costs. Multinational companies arise because, as they engage in international business, the size of transaction costs involved increases and the most efficient way to reduce costs is to operate as single coordinating business unit (Kerr and Perdakis, 1995). DuPont is a multinational company and has successfully reduced their transaction costs by operating as an integrated firm. However, when specific and complex technology is involved, it isn't enough to be a multinational company. To benefit from the limited global technical expertise, Dupont has aligned itself with many other firms by utilizing joint ventures. International joint ventures are very common and the shared profits lead to benefits for both parties involved in the joint venture. It is common, however, that international joint ventures will arise to combine capital and expertise of firms in different countries for the mutual advantage of the firms involved. When drawing on two sets of expertise, the reduction in transaction costs can be significant. It is often that case that different cultures can have different methods of practising business. The costs involved with learning these business cultures can be expensive and time consuming. A joint venture with a local firm can eliminate these costly learning periods. Joint ventures are set up with a specific task in mind and when the task is accomplished the venture ceases to exist. Both parties share in the profits, which helps to reduce the motivation to act opportunistically. Due to the nature of a joint venture, they are easy to dissolve, which can reduce the transaction costs involved with abandoning international business (Kerr and Perdakis, 1995). All these advantages of joint ventures make them. Hence, international joint ventures are an ideal mechanism for DuPont to align itself with those that own the intellectual property and have technical knowledge in important aspects of bioplastics.

DuPont has chosen to take the licensing approach for the upstream delivery of SoronaTM. Again, reducing transaction costs is the motive. One may question why joint ventures were the

preferred method of downstream coordination for technology and research and licenses for upstream coordination. As previously stated, joint ventures are conceived to accomplish specific tasks and once it is complete the venture no longer exist. DuPont wishes to form lasting relationships with processors to utilize their technology on a continuing basis and this does not lend itself to a joint venture. A firm's reputation regarding the quality of the good they produce provides a level of trustworthiness with which it conducts business. The trademark of a reputable firm can be licensed out for the benefit of the licenses.

This example of a current bioplastic that has both been commercialised and where a complete supply chain has been formed is instructive for other nascent bioplastics industries. It is a comprehensive web of highly dynamic and large multinational companies that form an extremely integrated global supply chain. This form of industrial organization is what would be predicted by TCE, in that due to asset specificity, uncertainty, risk of opportunism and bounded rationality, a supply chain with closer vertical coordination has emerged. These multinational firms have aligned themselves to reduce transaction costs so that they can take full advantage of this high quality and cost saving technology.

Conclusion

Considerable public investment is being made in fostering the development of bioplastics in a number of countries – some of which have limited domestic markets. To be commercially competitive with traditional petroleum-based plastics, economies of scale in production will have to be achieved. This will require access to international markets and, in particular, the development of new international supply chains. It will also require new tariff classification systems so that what have traditionally been agricultural products can compete with typically low tariff petroleum-based products.

Accessing international markets is, however, very risky. Simple supply chains based on market transactions are particularly risky and alternatives organisational forms may be better suited to opening international markets. This paper has examined the risks associated with establishing international supply chains for bioplastics and the transaction costs that must be incurred to overcome those risks. It appears that transaction costs will be high and that competitiveness will to a large part be determined by the ability to reduce those costs. If the transaction costs cannot be reduced, bioplastics may be non-viable in small market countries.

One commercialised bioplastic's international supply chain was examined. Close vertical coordination through a multilateral enterprise, joint ventures and licensing arrangements characterise this supply chain. While the model of a large multinational may not be desirable in all cases, the evidence suggests that supply chains based on close vertical coordination among supply chain participants may be necessary to gain international competitiveness. Governments in small market countries such as Canada have been quick to expend resources to overcome the perceived market failure in R&D but a similar effort has not been forthcoming in ensuring that a market failure does not arise from the inability to access foreign markets and, hence, to realise competitive scales of production. Research into both barriers to market access and internationally competitive organisational forms for supply chains is required. A market failure in this area will be just as detrimental to the development of a viable bioplastics industry as an absence of R&D.

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