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THE CANADIAN PULP AND PAPER INDUSTRY
AN ECONOMIC AND ENVIRONMENTAL ANALYSIS

A Thesis
Submitted to the Faculty of Graduate and Postdoctoral Studies of the
University of Ottawa
in partial fulfillment of the requirements for the degree of
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Economics

by

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The completion of the thesis has proved that a woman can have it all: family, work, and academic life. I hope that I could become a perfect example of hopefulness, and persistence in order to bring dreams into life. I won't stop here and I expect no one stop living their dreams while they are still alive. I will continue my challenge to the very end and I am determined to create incentive and guide for people who would like to take this road of success and achievement. May God give me the opportunity to do so.

Elham Azarafshar

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ABSTRACT

This thesis looks at the Canadian Pulp and Paper Industry at both the empirical level and the theoretical level. In the first half of the thesis, the empirical aspects of the industry are studied within the framework of the trade-off between environmental protection and efficiency of the plants. In the second half, several theoretical issues related to the market structure of the pulp and paper industry are analyzed. Chapter 1 provides an overview of the Canadian Pulp and Paper Industry and the various production processes. In Chapter 2, an empirical analysis is undertaken to study the relation between technical efficiency and pollution. This analysis has far-reaching policy implications as it allows us to study empirically the effect of pollution control regulations on the performance of the firms. Chapter 3 contains a study on the international trade in market pulp, with specific focus on the trade among Canada, US, and Europe. A multi-market spatial oligopoly model is formulated, calibrated, then simulated to gain insights into the workings of these interdependent markets.

In Chapter 4, an oligopoly model for the tissue and towel market in North America is formalized then calibrated. The objective of this chapter is to obtain an adequate picture of the consumer market, in which prices, qualities, and advertising are used to entice consumers. The model contains four firms, which produce a total number of ten brands among them. The simulation of the model yields detailed results on the intricate workings of the industry and results that cannot be expected from simple text- book oligopoly models.

Keywords: Pulp and Paper, Technical Efficiency, Environmental Regulation, International Trade, Spatial Oligopoly, Prices, Qualities, Advertising

JEL Classification: D21, D24, F10, L13, L73, Q53

INTRODUCTION TO THE THESIS

This thesis looks at the Canadian Pulp and Paper Industry at both the empirical level and the theoretical level. In the first half of the thesis, the empirical aspects of the industry are studied within the framework of the trade-off between environmental protection and efficiency of the plants. In the second half, several theoretical issues related to the market structure of the pulp and paper industry are analyzed. The thesis is made up of four chapters.

In Chapter 1, we present a brief introduction to the production process in the pulp and paper industry to provide the background for the subsequent empirical and theoretical analyses. The chapter includes a detailed account of the wood industry; how pulp is manufactured and the corresponding different manufacturing processes; the bleaching process; and the conversion of pulp into paper products. We have also provided an overview of the major trends in production and consumption as well as the market structure of the pulp and paper industry in North America and Europe.

Chapter 2 presents our empirical analysis of the industry and relates to the trade-off between plant efficiency and pollution control. Within that framework, an empirical analysis is undertaken to study the relation between technical efficiency and pollution. This analysis has far-reaching policy implications as it allows us to study empirically the effect of pollution control regulations on the performance of the firms. More specifically, the chapter carries out a productivity analysis for a group of Canadian pulp and paper mills, which provides some answers to the question of how successfully the producers in the Canadian pulp and paper industry have responded to the environmental regulations imposed upon the industry. The productivity exercise takes the form of a technical efficiency analysis for a group of Canadian mills and suggests how pollution can be integrated into the traditional framework of productivity analysis.

A pulp mill uses water, wood chips, chemicals, energy, labor, and capital – as inputs – to produce an output – pulp. In the production process, the mill generates several undesirable byproducts, such as Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS). The undesirable byproducts are known as pollutants or undesirable outputs. The output of pulp – a desirable output – produced by the mill depends obviously on the amounts of each of the inputs it uses. Now for two pulp mills that operate in the same environment and use the same quantities of inputs, the one that consistently produces more pulp but does not generate more pollution than the other can be said to be technically more efficient. The production of undesirable by-products, such as pollution, affects a firm's profitability since they are costly to be disposed of. However, in the traditional measures of total factor productivity (TFP) and technical efficiency, reduction of effluents is not taken into account on the output side, but the cost of abatement capital is included on the input side. As a result, biases in measurement arise and TFP growth is exaggerated. Furthermore, in many instances, policy makers are interested in obtaining a more precise picture of how environmental regulations have affected the performance of firms and how firms' responses to environmental regulations have affected their performance, a question that necessitates the use of firm-level data. However, the scarcity of suitable data has lead only to a limited number of studies that can provide a direct link between a firm's performance – as measured by its production efficiency – and environmental regulations, in line with the promise of the Porter hypothesis. This chapter attempts to take the first step in using micro-data for analyzing the technical efficiency of producers in the Canadian pulp and paper industry. In this endeavour, we are assisted by a detailed set of surveys conducted by Statistics Canada on 38 Canadian pulp and paper firms. These surveys provide data on production processes as well as detailed information on discharge levels for BOD and TSS. Data on environmental regulations at the firm level are also available through a detailed survey by Environment Canada (1990). As Hetemaki (1996), who used a panel of eight Finish pulp and paper industry plants to study the impact of pollution and environmental regulations, our micro-data oriented analysis could be used to shed further light on the impact of pollution/environmental regulations on firms' efficiency, a subject which was neglected in many countries, including Canada, but is recently gaining recognition due to progress made in the collection of data and improved methodology.

The empirical analysis presented in Chapter 2 indicates that considering pollution as a traditional input in a new classical production function could help one to incorporate both environment and technical aspects of the production process into technical efficiency analysis. Formulating the stochastic frontier model at the mill level using micro data could be a huge step in developing successful environmental regulations to eliminate market failure.

The estimation result shows a rather low coefficient of the pollution variable in the regression equation, which is an indication of a successful reduction of mills' pollution to such a low level that an increase in pollution would not significantly increase output. Since we estimated the stochastic frontier using cross- section data, the results cannot be used to analyze the change in productivity through time of the mills. Rather it can only be used to compare how the mills comply with environmental regulations.

Chapter 3 studies the international trade in market pulp, with specific focus on the trade among Canada, the US, and Europe. Market pulp is a homogenous product and is traded heavily in these three international markets. To analyze the pattern of trade, a theoretical model based on the characteristics of market pulp, as discussed in Chapter 3, is developed. The model specifies the set of domestic firms in each region and how these firms sell their products both at home and in the other two regions. The model deals only with the short run, and hence the capacity of each firm is fixed. This so-called multi-market spatial oligopoly model is then solved explicitly, and a unique Nash equilibrium, which is a solution to a concave programming problem, is found. To gain more insights on the working of these markets, a comparative static exercise is carried out. This analysis demonstrates the following results. First, it reveals that a booming US economy with excessive capacity leads to increase in US imports from the other two regions and, therefore, increase in the profits of all the firms, while there is no change in the Canadian and the EU markets. Second, it shows that booming US and EU economies, with excessive capacities, lead to an increase in shipments from the three regions to the US and the EU markets and, therefore, dramatic increase in the profits of the three representative firms, while no change takes place in the Canadian market. Third, it demonstrates that booming US and EU economies, with binding capacity constraints on all producers, lead to price increases in all the three regions. It shows that Canadian exports to the US and the EU increases, while the Canadian import from two the other regions declines. This simulation exercise confirms the intuition that the firms in all three regions would be better off when capacity constraints are binding. Fourth, it shows that when capacity constraints are binding, the appreciation of the Canadian dollar and the euro relative to US dollar enhances the competitive position of US producers and causes the price in the US market to rise, but depresses the prices in the Canadian and EU markets. This result means that the profits of the representative US firms rise, while the profits of the representative Canadian and EU firms both decline. It also shows that when the appreciation is high enough, Canadian exports to the EU and the EU exports to Canada both drop to zero. The last simulation exercise indicates that if firms in the EU are subject to more restrictive environmental regulations than firms in North America, then the EU firms are at a competitive disadvantage due to the extra cost induced by environmental regulations. The shipments of the EU firms to the US and the Canadian markets both drop to zero while the shipments from the US and Canada to EU both rise. The profits of the US and the Canadian firms both rise, but the profits of the EU firms decline.

Chapter 4 develops an oligopoly model for the tissue and towel market in North America. Unlike market pulp, which is homogenous and internationally traded, tissue and towel are highly differentiated products and, except for a limited number of cases, trade in these products is minor. In this manufacturing sector, brand loyalty and product characteristics, such as softness, strength, and absorbency, are obtained through technology advancement to entice consumers, while cost advantage is used to attract commercial and industrial institutions. To obtain an adequate picture of the consumer market, it is necessary to model explicitly the qualities chosen and incorporated into its product by a firm as well as its technological innovations. An economic model that embodies such a degree of complexity and that also contains a realistic number of firms – rather than the overworked duopoly – rules out the exclusive use of an analytical approach. Hence our recourse is to pursue the construction of an empirically guided model whose parameters can be numerically derived from quantitative and qualitative data. Insights about the functioning of the market can then be sought by simulative manipulation of the parameters in comparative static exercises. This approach to studying differentiated oligopolistic markets is propounded by Kuenne (1998), who refers to it as "simulative-theorizing," and who advocates the use of "*rivalrous consonance*" as a concept for analyzing the behavior of firms in a mature oligopolistic market.

In the model of Chapter 4, the main qualities of tissue are: basic weight, absorbency, softness, thickness (bulk), tensile strength, brightness, stretch, and appearance. However, the most important qualities chosen by tissue manufacturers for non-price competition are strength, softness, absorbency, and appearance. Since tissue manufacturers often stress strength, softness, and absorbency in the advertising of their products, Chapter 4 deals only with strength, softness, and absorbency. Following Kuenne (1988), we argue that in a "mature oligopolistic industry" the structure of the industry is best represented in what is called power structure matrix that captures the binary relations between each pair of firms. According to this model, in a mature oligopoly, self-protective motives, necessitate a communitarian mixture of competition and tacit collusion. Hence each player chooses a price set so to maximize an "*extended profit function*," rather than his own profit. This "extended profit function," is a function of not only his own profit but also of his competitors.' The degree of which this player weighs competitors' profit in his decision depends, among others, on the degree of maturity of the market.

In Chapter 4, we show that, after sufficient time has passed and the market has become stable, the strategy chosen by any firm should be a best response for this firm to the strategies chosen by all the other firms. In this sense, the combinations of strategies chosen by all the firms in a mature oilgopolistic market must constitute a Nash equilibrium. We then use the first order conditions that characterize the Nash equilibrium to analyze the structure and functioning of the North American tissue and towel market. For this purpose, we use a set of published data on the qualities chosen and incorporated into their product by the major firms in the North American tissue market. The data is obtained from the US Department of Commerce and Leading Edge Reports [1999].

We analyze two scenarios. The analysis of the first scenario reveals that when there is an improvement in the qualities of one brand, the industry's average qualities rise causing quality-induced sales of the other brands to deteriorate. It also shows that the improvement in qualities of the brand triggers an upward shift in the demand for the brand and simultaneously a downward shift in the demand for all the other brands. The ensuing result is a rise in the price of the brand as well as a rise in its output. The rise in revenues of the brand thus automatically triggers a rise in its advertising expenditures, which is a fixed percentage of revenues. The simulation exercise also reveals that the firm, that owns the brand, improves its overall financial situation, whereas the profits of other firms all decline. Also, the firm is more willing to vary the outputs of the other brands it owns than the rival firms.

The analysis of the second scenario reveals that when there is a fall in production cost of one brand, we observe an increase in output of this brand. We also observe that the brand is the sole beneficiary of its reduction in production cost, while all the other brands suffer. The firm that owns the brand improves its overall financial situation, whereas the profits of other firms all decline. It also reveals that the other brands react to the reduction in the brand's production cost in different manners. The percentage price changes of the brands that do not belong to the same firm owning the brand are somewhat smaller. It is our finding that the adjustments of other brands take place mainly through variations in advertising expenditures. We also observe that the own-price elasticities and the productiveness of advertising expenditures of the various brands are two factors that explain the different types of movements in the price and output of the examined brands, as a reaction to a fall in production cost of one brand. The simulation exercise also indicates the change in advertising-induced sales is rather low, which implies that the extra advertising expenditures of all the other brands are defensive in nature.

CHAPTER 1

THE PULP AND PAPER INDUSTRY A REVIEW OF PRODUCTION PROCESS AND TRENDS

1. INTRODUCTION

This chapter provides a brief account of the main production processes used in papermaking. It then proceeds to provide a brief overview of the major trends in production and consumption of the pulp and products. An adequate grasp of these processes as well as overall trends is necessary in understanding why a pulp or a paper mill, in its search for profits as well as in the pollutants it generates, adopts a certain production technique. The materials covered in this chapter serve as a basis for analyzing the economic decisions and the pollution abatement activities undertaken by a firm in the pulp and paper industry. The remainder of this section provides an introduction while the subsequent sections review the steps needed for the preparation of the raw materials (wood and non-wood), the chemical and mechanical pulping technologies; it also provides an overview of major trends in the production and consumption of the pulp and paper products.

Paper, in general terms, refers to a variety of pulp-based products (including paperboard) and, in specific terms, refers to two major classes of products - bulk production paper and paperboard, which are differentiated on the basis of thickness. The main ingredients of paper are natural fibers such as cotton mixed with wood pulp to make a suitable strong paper. Old rags are also fibers, which are short and found in the inner bark of numerous shrubs and trees. These fibers are less expensive and were the first ones used in papermaking. Straw is also a natural fiber from which paper is made; it is low in lignin and is specially suited for fine papers. Its use, however, has declined steadily over many years. There are two main sources of fibers for the paper industry today: softwood (coniferous species or gymnosperms) and hardwood (deciduous species known as angiosperms) trees. These two sources are different in terms of their nature, species, age, density, moisture content and the time that has passed since they were cut and vary significantly in fiber structure and wood chemistry. Hardwoods contain more cellulose and extractives but less lignin than softwoods; they also have a higher initial brightness. On the contrary, softwoods are three times longer than hardwood, which implies more inter-fiber bonding, which results in greater strength to the products into which they are made. Without this renewable source of fibers, the pulp and paper industry, as we know it would not exist.

2. PRODUCTION PROCESS

In general the making of paper can be divided into three stages: the assembly of wood at the mill; the reduction of the wood or other fibrous materials, such as waste paper to pulp; and the conversion of pulp to various paper products. In what follows we provide a brief review of each stage.[1]

[1] For a more detailed review of pulp and paper production technology, see Patrick (1999). The presentation of the production process provided in this chapter draws heavily from Tillman (1985, pp.11-15), Patrick (1999, pp. 23-54), McCubbin (1990, pp.15-28 and pp. 36-39], and Biermann (1996, pp. 62-72).

2.1. PRODUCTION ASSEMBLY

Pulpwood- the wood used in pulp or papermaking- is delivered to the mill as logs (round wood), bolts, and residues from sawmills and plywood plants. Chips are then processed from round wood. In the mill, round wood is processed either as short wood or long wood, depending on the mill specific process. However in recent years, the processing of long wood has been more prevalent because this practice is more efficient in maximizing chip yield. The log debarking is carried out before chipping through several methods. In later stages, fines and sawdust, along with residual bark, are sent to the mill's power boiler for fuel.

In general, any tree species can be used as pulpwood. Wood pulp is a globally traded commodity sold on the open market and is referred to as market pulp. In Canada, the world's largest market pulp supplier, softwoods are preferred because of their long fibers. Indeed, about 84 percent of all Canadian pulp is made from softwoods. Over the years, the proportion of round wood (whole logs) has declined while the share of wood residues and, to a lesser extent, the proportion of recycled paper, all have increased. Residues accounted for only 10 percent in the early 1960`s and the tremendous increase in subsequent years represents one of the most significant developments in the forest industry. In the past, round wood was consistently more expensive than wood chips, but now the prices per cubic meter are about the same. British Columbia, with its large number of saw and planning mills, uses a high proportion of wood residues (74 percent) as pulp raw material, the same proportion of wood residues as are used for Ontario.

Trucks transport about 70 percent of trees harvested in Canada. This mode of transport is used for short- and medium-distance moving. The long distance moving of logs by commercial railways along existing lines remains economical. Shipping on lakes and rivers was the traditional form of secondary log transport. However, now most river transport has been eliminated because of environmental concerns and losses through sinkage.

3. PULP MANUFACTURE

The second stage in the papermaking process is the manufacture of pulp. This stage comprises the final step for a mill that only produces pulp and sells the *market pulp* it manufactures to converters on the domestic or foreign markets. In an integrated mill, however, the pulp produced will be used as an intermediate input in the production of paper products, with the paper mill located at the same site as the pulp mill.

Papermaking is based on the process whereby cellulose fibers in an aqueous solution will begin to adhere to one another as the water is removed. Therefore, the first step is the conversion of the solid raw material (usually wood) into a uniform mixture known as pulp. This pulping operation was first limited to two distinct procedures - mechanical and chemical. The choice between these two operations was determined based on the type of wood species available and the nature of the end products to be fabricated. [Andrade, (2000)]. Over the years, a number of systems combining different processes were developed. These systems can be classified into four broad pulping processes: chemical, semi-chemical, chemi-mechanical, and mechanical pulping. They are in increasing order of mechanical energy required to separate fibers and decreasing reliance on chemical action.

3.1. *Ground Wood or Mechanical Pulping*

Ground wood or mechanical pulping is the oldest and simplest pulping method. In these processes the wood is reduced to its fiber components by mechanical forces. In mechanical pulping, fibers are separated and pulp is produced by using only mechanical attrition and the process relies completely on physical action to pulp lignocelluloses materials; no chemicals other than heat or steam are used. In 1999, the global supply of mechanical pulp totaled 47.2 million tons, with Canada's share amounting to 13.1 million tons or 28 percent of the total. From the standpoint of pollution control, mechanical pulping techniques are considered the least harmful to the environment.

3.2. *Chemi-Mechanical Pulping* (CMP)

The chemi-mechanical pulping process consists of two stages. A particularly mild chemical treatment is followed by a drastic mechanical action, but not as drastic as without chemical pretreatment. The most common chemi-mechanical process at the present time is chemi-thermo mechanical pulping (CTMP). The pretreatments are hot sulfite or cold soda and are particularly applicable to hardwoods, which otherwise do not give mechanical pulps of high quality. The CTMP process produces effluents of strong color and BOD[2], which may be difficult to treat. Environmental considerations have kept this process from being used in many locations.

3.3. *Semi-Chemical Pulping*

Semi-chemical pulping was discovered in the late 1800's, but this process only came into commercial practice in the 1920's. It is a cross between chemical and mechanical pulping techniques and is used mostly with hardwood fiber. The pulps produced by semi-chemical pulping method are insignificant in terms of yearly output. Generally, semi-chemical pulp is produced in a two-stage process. Wood chips or logs or lignin are partially softened with chemicals, then mechanically treated in disc refiners, which separate the fibers.

The most common semi-chemical pulping method is the natural sulfite semi-chemical (NSSC) process in which hardwood chips are cooked in a sodium sulfite liquor at a neutral pH. Sodium carbonate (soda ash) is added to buffer the acid produced during the cook. Hardwood is usually the fiber source, and NSSC hardwood pulp is approximately as strong as NSSC softwood pulp and even stronger than kraft hardwood pulp. Compared to other types of semi-chemi pulping, the one-time use of chemicals was historically affordable for sulfite mills.

NSSC mills face the difficult problem of finding a way to dispose of their spent cooking liquor. Because of the difficulties of chemical recovery or liquor burning, most NSSC mills have continued to empty all of their liquor into surrounding wastes water. These mills are thus one of the greatest sources of water pollution, with a potential BOD discharge in the range of 175-400 lbs/ton of pulp, depending upon the strength of the chemicals and the amounts of dissolved wood matter. NSSC has received attention in

[2] Biochemical Oxygen Demand

recent years, due primarily to innovations in the use of quinine pulping catalysts. There are two alternatives to dumping the effluents into rivers and lakes. The liquor may be concentrated and burned to recover the chemical sodium sulfate, which can then be used in kraft mills. The other alternative is to switch from sodium sulfite to another chemical, such as ammonium sulfite.

3.4. *Chemical Pulping*

Wood contains about 75 percent cellulose and hemi-cellulose fibers. The rest are lignin, tannis, resins, and oil. In addition to the separation of the cellulose fibers, chemical pulping also removes as much as possible the lignin and extractives. This results in a much lower yield but stronger fibers at a significantly higher cost with a wider range of paper types, qualities, and strength. The process uses a giant heated pressure cooker, called a digester. In the digester wood chips and chemicals are mixed and cooked at 130-180° C to dissolve the lignin and break apart the wood chips into fibers. Global production of chemical pulp in 1998 was about 115 million tons. Canada's share is 11 percent of global output, which is about 12.6 million tons. The common methods of chemical pulping are the kraft process (also called alkaline or sulfate process) and the various sulfite processes. The most common form of chemical pulping process in North America is kraft pulping.

The kraft[3] pulp process was first commercialized in 1885, and since then it has represented two thirds of the world's total annual production and 52 percent of Canada's total annual output of wood pulp. With this process, practically any species of wood can be used. It has a sophisticated recovery system in which chemicals used in the process are captured and extracted for re-use, minimizing both raw material cost and environmental impact. Unbleached kraft (UBK) is the main component in bag papers, shipping sacks, wrapping papers, and heavy cardboard. Bleaching makes it the main source of pulp for fine papers and food packaging as well. The cellulose fibers that are lost during the process can be discharged with wastewater, and can build up fiber beds, causing water pollution. However, technical improvements have largely eliminated the problem in this case. The kraft process has high capital costs and relatively low yields (45 percent-55 percent). It also causes corrosiveness in metals and equipments and poses environmental problems.

Conventional sulfite pulping has become the most important pulping process by 1900. However, after the innovation of the kraft pulping process, the conventional sulfite pulping only counted for 10 percent of total pulp production. The net result of conventional sulfite pulping is to increase the solubility of lignin in the solution. The conventional chemical recovery system for sulfite pulping is mostly the same as the kraft recovery system. Unlike the kraft process, which is unprofitable unless chemical recovery is practiced, the one-time use of chemicals was affordable for sulfite mills. Sulfite pulp is somewhat easier to bleach than kraft pulp. The soft sulfite pulp is less coarse and more absorbent than kraft pulp. It is also less flexible and adaptable than kraft pulp although the process yield is slightly higher than that of kraft pulping. Until the 1960's, the sulfite pulping liquor was dumped directly into rivers with no treatment. In the following decades, this process has received some attention due to some environmental friendly

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[3] kraft means strong in German.

innovations.

The output of conventional sulfite pulping is white enough to be used in manufacturing newsprint and other printing papers without bleaching. These paper products are cheap and can be discarded after use. The production of sulfite pulp produces fewer odors and with less pollution than kraft pulp, although sulfite pulp's water pollution and waste disposal are more severe. Over 55 percent of the weight of the wood and thousands of gallons of chemical solution can end up in the rain stream or lake adjoining the mill. Untreated sulfite effluent has a BOD level from 550 to 750 pounds per ton of pulp, the highest pollution load of any pulping process effluent. It causes discoloration of water, buildup of sludge deposits, and serious depletion of oxygen in the water.

4. BLEACHING

Kraft pulp is of great importance to the industry due to its high strength and ability to bleach to high brightness with very low brightness reversion or loss of strength. Bleaching is a chemical treatment of wood to increase the brightness. The nature of the bleaching process, if any, is determined by the type of pulping. For instance, sulfite pulp is much lighter that kraft pulp and is easier to bleach. Hence, close to 90 percent of the sulfite pulp is bleached. Most North American kraft mills use chlorine gas and chlorine dioxide to bleach pulp. Chemical bleaching involves lignin removal using chlorine gas, which yields stronger fiber bonding. Because it decreases the length of the fiber, it makes fibers weaker, while chlorine dioxide whitens the part of lignin that cannot be removed.

In full kraft bleaching processes, bleaching is usually carried out in a sequence of steps, using different chemicals and conditions at different steps. In the bleach plant, the brown stock is mixed with the bleaching agent and conveyed in stages through cylindrical vessels called towers. These stages include the chlorination stage, the extraction stage, and other stages, which involve using more of chlorine dioxide, oxygen, etc., with the aim of reducing chlorinated organics (such as dioxins and furans)[4] in the bleach washer filtrated. However, in mechanical pulp bleaching or pulp brightening process, lignin-preserves bleaching treatments are used when a pulp must be de-colored without solubilizing the lignin. These processes, since they do not solubilize the lignin, have very little effect on the environment. The full kraft bleaching processes raise environment concerns, primarily due to the formation of chlorination organic compounds in the delignification process.

5. THE CONVERSION OF PULP TO PAPER PRODUCTS

There are four basic steps involved in paper making: Forming - applying the pulp slurry to a screen; draining - allowing water to drain; pressing - further dewatering by squeezing water from the sheet; and drying - air drying of the sheet over a hot surface. The first step in manufacturing paper[5] consists of beating the pulp to make it mat or felt well. Pulp, which is taken from storage in either the bleach plant or the pulp mill, or purchased from the market of market pulp (when the mill is not integrated), is sent through a series of refiners or beaters.[6] For some types of paper, such as newsprint, the beating is slight; but for others, such as writing paper and similar grades, beating is an important operation.

[4] They are two by-products (pollutants) of chlorine bleaching.
[5] Paper consists of a web of pulp fibers from wood.

Color, loading, and size are usually added to the pulp in the beater: loading serves to fill tiny spaces between the pulp fibers and make a smooth sheet; it also gives opacity to the sheet and improves its ink-absorbing qualities. Size is added to the pulp in order to make the sheet resistant to water or ink. Sized paper can be written on without the ink spreading. After the pulp has been prepared in the beater and after loading, size, and color have been added to the pulp, it is fed into the paper machine.

Paper is a material used for a variety of purposes. The main difference in the manufacture of different grades of paper is in the types of fibers used and the weight of the paper. Newsprint, the paper on which newspapers are printed, consists of 80 to 85 percent ground-wood and 15 to 20 percent unbleached sulfite or bleached or partially bleached kraft pulp to increase the strength. Book papers are used principally for books, magazines, brochures, and commercial printing. Most book papers are made from chemical wood pulp, sulfite, bleached kraft, soda, and bleached semi chemical pulp, but some grades contain ground-wood or high-grade waste-paper pulp. Bag papers are made principally from unbleached and bleached kraft pulp, and they are used for making grocery bags and sacks, etc. Sanitary and tissue papers are made from bleached sulfite or kraft pulp; from bleached, semi bleached, or unbleached kraft combined with sulfite pulp from chemical and ground-wood pulp and from waste paper. They are soft and absorbent and moderately strong. Writing and other fine papers are made from rag pulp, bleached chemical wood pulp, and a combination of cotton fiber and wood pulps.

Paperboard, which is also called "board" is a thick, heavy-weight, rigid, single, or multi-

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[6] Beater is polishing equipment, which is also called jordan.

ply type of paper, with thickness and material varying, depending on its end use. Paperboard is made from wood pulp or waste paper. Some grades of board, such as chipboard or recycled paperboard, are manufactured almost entirely from waste paper with low density and quality; other grades are made entirely from virgin wood pulp and waste paper; still others consist primarily of waste paper. There are three principal categories of paperboards--boxboards, container- boards, and specialty boards. Boxboard is made from waste paper or from bleached or unbleached kraft or sulfite pulp. Container- board is used for manufacture of corrugated and solid shipping containers. Corrugated board consists of the inner corrugating material and the outer surface of line board. The corrugating material is made from semi-chemical specially NSSC hardwood pulp or kraft pulp or waste paper stock.

6. ORIGIN OF RAW WASTE LOAD

The primary pollution components in the pulp and paper industry are BOD, pH, and total suspended solids (TSS), in all categories of manufacturing. The severity of the problem depends on the type of the mill. For ground-wood, chemi mechanical, and thermo mechanical operations, the heavy metal ion zinc is of concern. For some other categories of pulp manufacturing, such as, kraft, soda, and natural sulfite semi chemical pulping (NSSC), the color of the effluent is of concern. The issue of toxic substances is also of concern, but which operations are most affected is uncertain. These parameters – BOD, TSS, pH, zinc, and color – have all been identified in the effluent limitation guidelines of the EPA. Technologies to control these pollutants in the effluents have been developed for all except toxics substances, and the research on managing the toxic substances is underway.

To understand the sources of pollution loads in a mill system, let consider an idealized paper mill using bleached kraft pulp as in SPRINGER ALLAN M. [1986]: Such a mill normally produces 500-1000 tons of products per day and the operation can be divided into five separate areas – wood yard, pulping, recovery, bleaching, and manufacturing. For the sake of simplicity, only the effluent volumes, TSS, and BOD are shown. A study of Figure 1.1 and Figure 1.2 provides several important observations. The largest volume of discharge comes from the Jasper[10] mill, and the bleaching plant. As SPRINGER ALLAN M. [1986] argues, volume reduction programs in the paper industry should be aimed first at these two sources. The largest BOD loads are produced by the bleaching plants, with the pulp mill second, and the paper mill a close third. The paper mill produces more than twice as much TSS as any other manufacturing area, while the recovery area stands at a distant second. This simple analysis indicates that the bleaching plant and the paper mill should receive primary attention in pollution abatement technologies.

[10] pulp mill in Alberta.

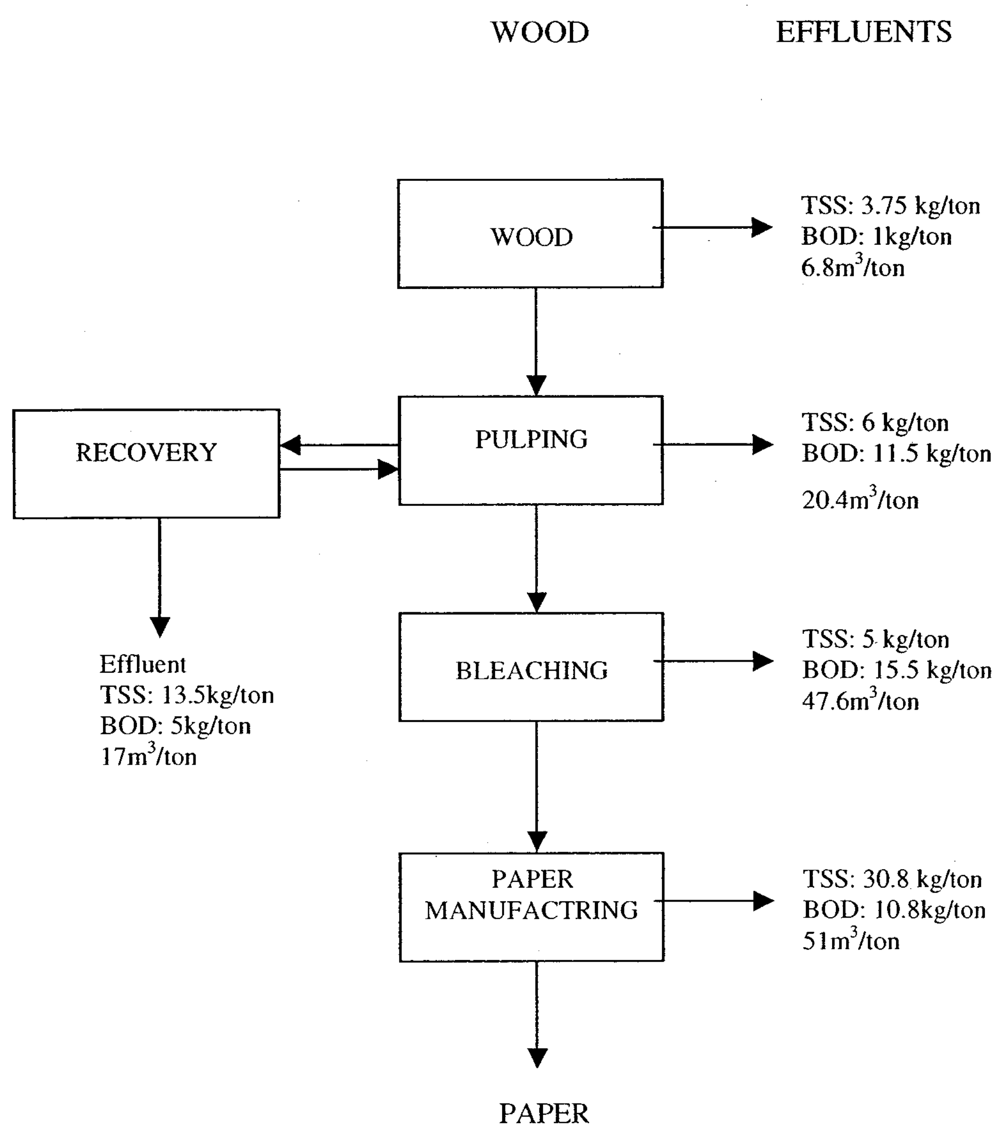

Figure 1.1- Representative bleached kraft mill loads
Source: SPRINGER (1986): "Industrial Environmental Control: Pulp And
Paper Industry," Department of Paper Science and Engineering, Miami University, Oxford, Ohio.

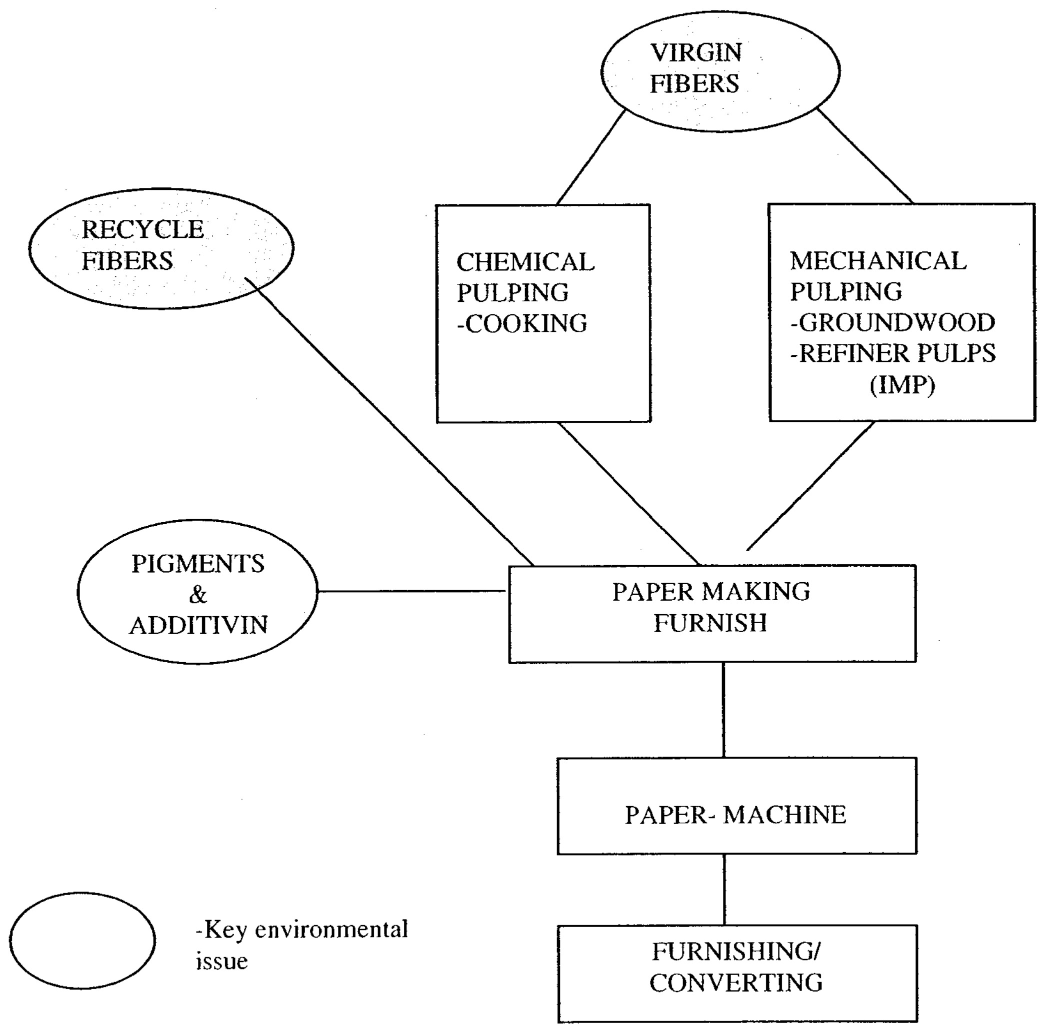

Figure 1.2- Environmental issues in pulp and papermaking
Source: SPRINGER (1986): "Industrial Environmental Control: Pulp And Paper Industry," Department of Paper Science and Engineering, Miami University, Oxford, Ohio.

7. TRENDS AND MARKET STRUCTURE

In this section, we provide an overview of the major trends in production and consumption of the pulp and paper industry in North America and Europe. We then proceed to provide a short presentation of the market structure.

7.1. *Trends in Production and Consumption*

The demand for pulp and paper has grown steadily in the last five decades or so, particularly in the industrialized countries. The industry manufactures a broad range of products, with pulp being the basic material for the production of paper and board and all the related products These products can be classified in many ways, including the processes used to separate the fibers (mechanical, thermo-mechanical, chemical etc.), the degree of bleaching (bleached, semi-bleached, and unbleached), or the wood used (conifers, leaf wood). The most common classification, based on the final use, is as follows:

- Graphics papers (newsprint, all printing and writing papers)
- Industrial papers and cartons (packaging paper, paper for liquid containers and for construction)
- Household and sanitary paper (including fluff tissues)
- Special papers

A large share of the products of the paper-manufacturing sector is converted into other paper products. These products can be grouped into four main segments:

- Packaging products (containers, bags, wrappings)

- Household and hygienic paper goods (cellulose, cotton tissue and crepe paper for use in nursing, baby care and feminine hygiene, kitchen towels, and toilet paper)
- Stationary and office supplies (envelopes, labels, printing and copying paper, and products for special applications such as fax paper)
- Miscellaneous products (e.g. tubes, wallpaper, metallised paper)

Table 1.1 shows trends in the bleached pulp production since 1990. The overall production has significantly increased from over 66 million tons in 1990 to more than 84 million tons by 2002. However, among the top three producers, only the Scandinavian countries have kept pace with the overall trend while both Canada and United States have witnessed their overall share shrink. The rest of the world, which includes Western Europe, has thus gained market share in the production of bleached chemical pulp.

Table 1.1
Bleached Chemical Pulp Production (millions of tons)

	1990	1995	2000	2001	2002
Canada	11.0	11.5	11.8	11.2	11.1
United States	27.3	27.3	27.2	26.9	26.9
Scandinavian	8.9	10.8	12.2	11.7	11.5
World	66.3	72.7	80.4	83.1	84.3

Source: AET International Survey, 2002

The overall value of the shipment value of the US paper and allied products industry ranks it in the top eight among all the US manufacturing industries. Table 1.2 presents trends for the production of pulp and paper in Canada, the US, and Western Europe. As can be seen from Table 1.2, since 1990 the production of newsprint has been rather stable in both Canada and the US, while it has jumped by almost 20 percent in Europe. On the other hand, writing and printing paper showed a sharp jump for the same period in all three regions; this jump, however, was more pronounced in Canada and Western Europe.

Table 1.2
Paper Production (000 tons)

		1990	1995	1998	1999	2000
Canada	Newsprint	9,068	9,226	8,581	9,204	9,222
	Kraft	492	544	536	534	531
	Printing	3,600	4,882	5,154	5,748	6,304
United States	Newsprint	6,610	7,002	7,248	7,179	7,261
	Printing	22,064	25,405	26,501	27,185	27131
Western Europe	Newsprint	8,412	10,013	10,332	10,334	10,473
	Printing	22,562	31,042	31,965	31,980	31,196

Source: Pulp and Paper Products Council and FAO, 2000

There has been an average increase of 1.8 percent and 1.6 percent per year in per capita consumption of paper, paperboard, and pulp in the period 1960-1980 and in the period 1980-1993, respectively. The rate of increase has fallen to 0.6 percent per year after that. In 1998, the consumption of paper (excluding paper board and building paper) increased from 326 lbs per capita, at 8 tons per million dollars of real GDP in 1980 to 407 lbs per capita, at 7.3 tons per million dollars of real GDP in 1998. This represents an increase of 25 percent in per capita consumption, but a decline relative to real GDP. By 2010, paper consumption is expected to increase by 53 lbs per capita, reaching 460 lbs per capita. [Ince et al. (2001)]

Table 1.3
Paper Consumption (000 tons)

		1990	1995	1998	1999	2000
Canada	Newsprint	1,085	1,091	1,147	1,206	1,231
	Kraft	156	142	141	140	138
	Printing	1,059	1,065	1,055	1,125	1,122
United States	Newsprint	13,612	13,072	12,988	13,271	13,323
	Printing	23,741	28,022	30,409	31,439	31,783
Western Europe	Newsprint	8,150	9,740	9,907	10,276	10,594
	Printing	20,454	25,467	26,338	26,218	24,731

Source: Pulp and Paper Products Council and FAO, 2000

As shown in Table 1.3, consumption of newsprint grew approximately 20 percent between 1990 and 2000 in both Canada and Western Europe, while it remained essentially flat in the US. However, in the printing and writing category, the U.S showed the biggest increase from approximately 24 million tons in 1990 to about 32 million tons in 2000. Western Europe also showed a substantial increase from 20 to 25 million tons, while Canadian consumption did not show any significant change.

7.2. *Market Structure*

The North American US pulp and paper industry has witnessed a quickening pace of corporate consolidation since 1980. The pace of this consolidation, however, has accelerated rather significantly since the early 1990s. It has been suggested that this intense consolidation is the response to less than impressive market performance caused by chronic excess supply. Due to the massive merger activity over the last two decades, the structure of the US linerboard industry has become more concentrated. [CPBIS[3], (2002)]

[3] Center for Paper Business and Industry Studies

Ince et al. (2001) report trends in market structure of the pulp and paper industry in the United States: "In general, the average size of pulp, paper, and paperboard mills increased from 1970 to 2000. In part, this shift is attributable to a decline in the number of operational mills from 666 in 1970 to 530.... During the same period, the total capacity of all paper, paperboard, and market pulp mills increased from 62.0 to 114.4 million tons. Thus, the average capacity per mill more than doubled, increasing from around 93 thousand tons per year to around 216 thousand tons per year. ...In 1970 there were 471 mills (out of a total of 666 mills) with capacity of less than 100 thousand tons per year. This was more than 71% of the total. By 2000, only 52% of the mills had capacity less than 100 thousand tons per year (277 mills out of a total of 530). Also, in 1970, there were only 14 mills with capacity greater than 500 thousand tons per year. In 2000, this number had increased to 72 mills, more than five times the number in 1970. In general, many mills became significantly larger while many smaller mills were closed, so that in effect, larger mills were replacing smaller mills, and thus capacity expanded even though there was an absolute decline in the total number of mills."

In a further note to this shift in market structure to larger and more integrated firms in the United States, Ince et al (2001) assert: "In 1970, the top ten companies accounted for less than 35% of total paper, paperboard and market pulp capacity. By 2000, the top ten companies accounted for nearly half of the total capacity. The capacity of each of the top ten producers more than doubled from 1970 to 2000. The top two producers did not change rankings between 1970 and 2000, but the other eight rankings were either different companies or the same companies in a different order."

A different picture emerges if one considers the concentration index for different US pulp and paper producers, as provided in Figure 1.3 This figure uses the Census of Manufacturers in CPBIS (2002) to report the CR4 (concentration ratio of top four producers). The figure shows that market pulp producers had the highest concentration jumping up to almost 60 percent in 1972, then climbing down to the mid 40's percent and then coming back up to 60 percent by 1997. In contrast, paper and paperboard producers have rather low concentration ratios, barely crossing over the threshold of 30 percent once in mid 1980's and another time in mid 1990's.

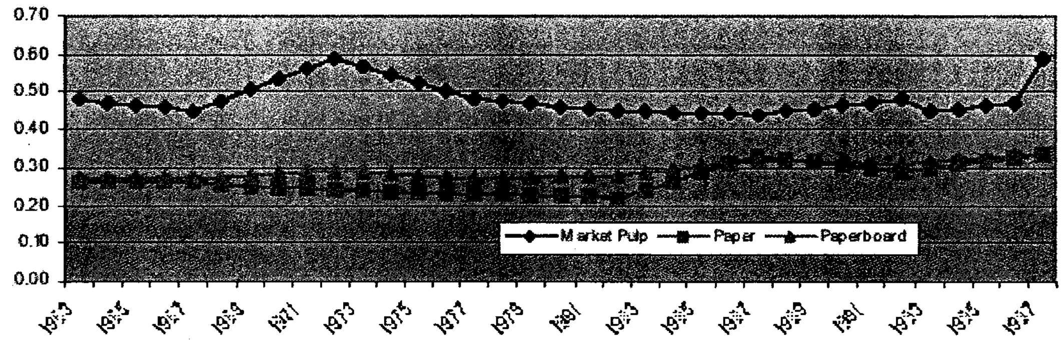

Figure 1.3- Pulp and Paper and Paperboard, CR4
Source: Census of Manufacturers, CPBIS (2002)

Figure 1.4 uses CR5s (concentration ratio of top five producers) reported by the Pulp and Paper Trade Journal and quoted in CPBIS (2002). Here the overall North-American capacity is used, including Canadian mills. Hence, the CR5s index reported significantly higher than other estimates, which are based solely on the US capacity. As in Figure 1.3, US bleached board CR5, increases from the low 50's percent in the 1970's to 80 percent in 2000, while linerboard CR5 climbs over the 60 percent mark towards 2000.

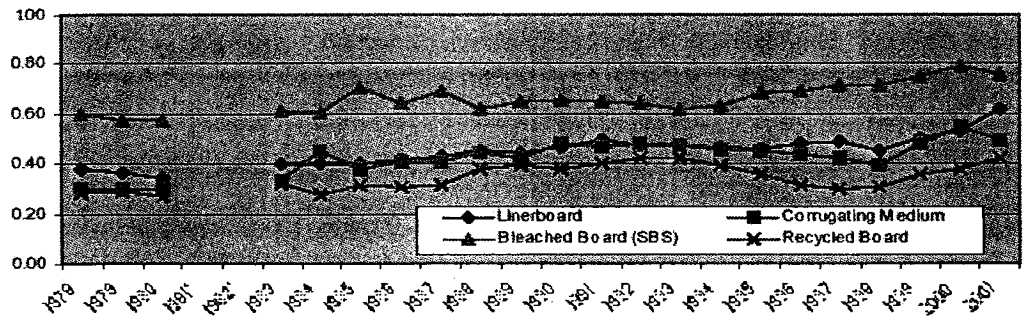

Figure 1.4- Paper Board Grades CR5
Source: Pulp and Paper Trade Journal, CPBIS (2002)

A more academic measure of industry concentration is the Herfindahl-Hirschman Index (HHI). In empirical analysis, the market concentration is often measured by the HHI and industries are divided into three categories, depending on the estimated index. Industries with HHI below 1,000 are often characterized as 'unconcentrated'. Industries with HHI between 1,000 and 1,800 are categorized as 'moderately concentrated', while other industries with HHI above 1,800 are characterized as 'highly concentrated'.[4]

The HHI index is calculated by adding up the square of the market share for each producer in a grade. This makes the cross-industries comparison between different paper grades easier. Therefore, HHI is preferred routinely over other concentration ratios since it incorporates information on all players in the market rather than say top 4 or top 5 producers.

According to the report by the Forest Product Laboratory [See Ince *et al.* (2001)] for the

[4] Horizontal Mergers Guidelines, U.S. Department of Justice and the Federal Trade Commission, revised: April 8, 1997.

period 1970-2000, measured by HHIs, only pulp shows relatively high industry concentration throughout the three decades, whereas paper and paperboard stand under the low 500's of the HHI scale with the paperboard being the most fragmented paper industries. Among the paperboard grades, only bleached board, or bleached board, reaches the high 1,800-HHI points towards the end of the 1990's. However, bleached board historically constitutes a small percentage (an average of only 13 percent) of total paperboard capacity. [CPBIS, (2002)]

CHAPTER 2

AN ENVIRONMENTAL AND TECHNICAL EFFICIENCY ANALYSIS OF PULP AND PAPER MANUFACTURING

1. INTRODUCTION

Industrial pollution has been one of the main concerns of the environmental economics literature since the 1960's. However, it was not until late 1990s that the problem of production externalities was addressed in the context of pollution. The central theme of the early literature was how to design an optimal control measure to reduce a firm's discharges to a fixed target level, and was thus mostly theoretical. The focus of the literature remained largely at the theoretical level until the late 1970's, when the impact of environmental regulations on producers' behavior was assessed by a number of empirical studies. In an attempt to analyze the observed productivity slowdown in the industrialized countries, especially that of the US in the post 1970's era, some focused on the common suspect – oil shocks; others went further and focused on the implemented environmental regulations. It was argued that the required abatement investments have crowded out the investments in plants and equipments and lead to a slowdown in productivity. As a result, numerous studies on productivity growth attempted to find out if this was indeed the case; see, for example, Denison (1978), The Data Resources Institute (1979), and Jorgenson and Wilcoxen (1990). The first group of studies were thus on the way, and they emphasized the importance of analyzing the impact of environmental regulations on a firm, an industry, or the whole economy, besides trying to design an optimal control policy for attaining a fixed abatement target.

More recently, Porter (1990, 1991) took a contrary position and argued in detail that properly designed environmental regulations could trigger innovations that might partially or fully offset the costs of complying with them and eventually raise a firm's competitiveness. This researcher claims that the innovation offsets occur mainly because pollution reduction is often coincident with improved efficiency of resource use. Thus, what has been known since as the *Porter hypothesis* relies heavily on the inference that the compliance with environmental regulations is accompanied by gains in production efficiency. This hypothesis has attracted a host of other studies, and a number of attempts have been made to identify other mechanisms that might support it. For instance, Palmer *et al*., (1995) examined the stylized facts regarding environmental expenditures and innovations in a panel of manufacturing industries. These authors find that lagged environmental compliance expenditures have a significant positive effect on R&D expenditures when they control for unobserved industry-specific effects. However, they find little evidence linking industries' inventive output -- as measured by successful patent applications - to compliance costs. Xepapadeas and deZeeuw (1998) developed a model, which suggests that if opportunities for higher competitiveness exist, firms do not have to be triggered by an extra cost. For the government, the trade-off between environmental and other targets thus remains. However, Xepapadeas and deZeeuw also drew attention to some general mechanisms that relax the trade-off considerably. The Porter hypothesis has thus shifted the focus from designing an optimal pollution control measure to analyzing the impact of environmental regulations on firms' behavior.

The emergence of environmental regulation during recent decades has added another dimension to the productivity puzzle: the linkages between environmental regulations and economic growth. In an attempt to provide an answer to the prolonged slower growth that characterized the post 1970's era, the earlier empirical studies focused primarily on the impact of environmental regulations on productivity growth. The more recent empirical studies, however, drew on the advent of the Porter hypothesis and focused more on the relations between performance of the firm, as measured by its production efficiency, and environmental regulations. Yet, the empirical literature on the relationship between environmental regulations and production efficiency remains rather scarce.

The main objective of this chapter is to carry out a productivity analysis for a group of Canadian pulp and paper mills. The results of the productivity analysis could provide some answers to the question of how successfully the producers in the Canadian pulp and paper industry have responded to the environmental regulations imposed upon the industry. The productivity exercise takes the form of a technical efficiency analysis for a group of Canadian mills and suggests how pollution can be integrated into the traditional framework of productivity analysis. In order to put our contributions in a proper perspective, we shall now discuss some of the attempts made in the literature to incorporate environmental damages into productivity analysis.

A pulp mill uses water, wood chips, chemicals, energy, labor, and capital – as inputs – to produce an output – pulp. In the production process, the mill generates several undesirable by-products, such as Biochemical Oxygen Demand (BOD) and Total

Suspended Solids (TSS). The undesirable by-products are known as pollutants or undesirable outputs. The output of pulp – a desirable output – produced by the mill depends obviously on the amounts of each of the inputs it uses. The pulp output also depends on shocks that emanate from the environment in which the mill operates and that are not under the control of the mill. These shocks are due to the variation in labor or machine performance or the vagaries of the weather. Less obvious, but quite intuitive, is the idea that the pulp output also depends on the efficiency of the mill in its production process. Now of two pulp mills, which operate in the same environment and which use the same quantities of inputs, the one that consistently produces more pulp but does not generate more pollution than the other can be said to be technically more efficient. The idea of incorporating technical efficiency of firms, in addition to the shocks that affect them, as an explanatory variable for the variations of outputs, contrasts sharply with the traditional approach to the estimation of production functions. In the traditional approach, the production function represents – in an ideal manner – the maximum attainable output, given a set of inputs. All the firms in the industry have access to this same ideal technique of transforming a set of inputs into a set of outputs. The variations in the outputs among a group of firms are then attributed to the shocks that affect these firms and that are not specific to any of them.

The production of undesirable by-products, such as pollution, affects a firm's profitability if they are costly to be disposed of. However, in the traditional measures of TFP and technical efficiency, reduction of effluents is not taken into account on the output side, but the cost of abatement capital is included on the input side. As a result, biases in measurement arise and TFP growth is exaggerated.

There are several methods to incorporate pollution into the analysis of technical efficiency. Pittman (1983) and Fare *et al.* (1989) suggested that multilateral productivity comparisons of firms producing multiple outputs, among which some are undesirable, could be obtained by making two modifications to the standard Farrell's (1957) measure of efficiency. The restriction that the production technology satisfies a condition known as the strong disposability of outputs is relaxed to allow for the fact that undesirable outputs may not be freely disposable, and the efficiency measures are modified to allow for an asymmetric treatment of desirable and undesirable outputs. These researchers proposed a method in which the performance measures that satisfy these requirements are calculated as the solutions to a mathematical programming problem.

Another method for incorporating pollution into the analysis of technical efficiency is to maintain the undesirable output at a given level. This approach was adopted by Hailu & Veeman (1998). They study the influence of the traditional inputs on the levels of the desirable outputs. They use a time series for the Canadian Pulp and Paper Industry covering the period 1959-1994 to analyze productivity trends in this industry. Using mathematical programming, they estimate a parametric input distance function that incorporates both desirable and undesirable outputs. Four desirable outputs (wood pulp, newsprint, paper other than newsprint, and paperboards and building boards), two major water pollutants (BOD and TSS), and seven inputs (energy, wood, residue, pulpwood, non-wood materials, production labor input, administration workers, and capital) were identified for the estimation of the input distance function. Their framework can also be used to generate information on the shadow prices of pollutants or pollution abatement costs to producers that are useful in environmental policy making.

To integrate the environmental impact of pulp and paper manufacturing into technical efficiency analysis, we follow Siebert et al. (1980) in treating undesirable outputs as inputs. The idea of treating net emissions as inputs has been exploited by Copeland and Taylor (1994), who formulated and analyzed a North-South trade model in which environmental quality is a component of comparative advantage. Under this approach, the conventional inputs and the net emissions together constitute the inputs of a traditional neoclassical production function whose outputs are all desirable.

Hailu and Veeman's study on the Canadian pulp and paper industry, op cit., relies primarily on industry level data that cover a span of several decades. Such a study might be useful if one intends to analyze the effect of environment regulation on total factor productivity, as was the objective of numerous earlier studies. However, the advent of the Porter hypothesis necessitates a much more micro-oriented approach for analyzing the performance of individual firms rather than that of the industry as a whole. Thus despite their advantages with regard to total factor productivity analysis, studies of this nature suffer from the usual aggregation problem. Furthermore, in many instances, policy makers are interested in obtaining a more precise picture of how environmental regulations have affected the performance of firms and how firms' responses to environmental regulations have affected their performance, a question that cannot be answered using industry aggregate data. It should also be argued that using a long time series covering several decades, as has been the theme in many of these studies, opens the door for swift technological change that may be hard to uncover and thus may distort the final results. Overcoming these potential problems requires using micro data at the firm level, a task which has been facilitated recently as quality of data has improved. However, the scarcity of suitable data has lead only to a limited number of studies that can provide a direct link between a firm's performance - as measured by its production efficiency - and environmental regulations, in line with the promise of the Porter hypothesis.

This chapter attempts to take the first step in using micro-data for analyzing the technical efficiency of producers in the Canadian pulp and paper industry. In this endeavour, we are assisted by a detailed set of surveys conducted by Statistics Canada on 38 Canadian pulp and paper firms. These surveys provide data on production processes as well as detailed information on discharge levels for BOD and TSS. Data on environmental regulations at the firm level are also available through a detailed survey by Environment Canada (1990). As Hetemaki (1996), who used a panel of eight Finish pulp and paper industry plants to study the impact of pollution and environmental regulations, our micro-data oriented analysis could be used to shed further light on the impact of pollution/environmental regulations on firms' efficiency, a subject which was neglected in many countries, including Canada, but is recently gaining recognition due to progress made in the collection of data and improved methodology.

The chapter is organized as follows. In Section 2, we discuss the concept of technical efficiency and the various approaches that attempt to measure it. In Section 3, we present the econometrics of Stochastic Frontier Analysis, our preferred approach to technical efficiency analysis. In Section 4, we present our model of technical efficiency analysis – along the line of the SFA approach and with pollutants as undesirable outputs -- for producers of the Canadian pulp and paper industry. The data used in estimating the parameters of the stochastic production frontier are discussed in Section 5. The estimates of the stochastic production frontier and the degrees of technical efficiency for the producers in the sample are presented and discussed in Section 6. Some concluding remarks are given in Section 7.

2. TECHNICAL EFFICIENCY

2.1. *Technical Efficiency without Undesirable Outputs*

Consider an industry in which the firms use n inputs, say $x_1,...,x_n$, to produce ℓ outputs, say $y_1,...,y_\ell$. All the outputs are assumed to be desirable. The technology used by the firms in this industry can be represented by a subset, say $\mathcal{T}$ in $R_+^{n+\ell}$. A *feasible production plan* is a list $(x_1,...,x_n,y_1,...,y_\ell)\in\mathcal{T}$. A feasible production plan $(x_1,...,x_n,y_1,...,y_\ell)$ is *inefficient* if there is another feasible production plan, say $(x_1^{'},...,x_n^{'},y_1^{'},...,y_\ell^{'})$, such that $x_1^{'}\leq x_1,...,x_m^{'}\leq x_m, y_1^{'}\geq y_\ell,...,y_n^{'}\geq y_\ell$, with at least one strict inequality holding. A production plan is *efficient* if it is feasible and not inefficient. For any list of outputs $(y_1,...,y_\ell)$, let

$$V(y_1,...,y_\ell)=\{(x_1,...,x_n)\in R_+^n \,|\, (x_1,...,x_n,y_1,...,y_\ell)\in\mathcal{T}\}.$$

As defined, $V(y_1,...,y_\ell)$ represents the set of input vectors that can be used to produce the output vector $(y_1,...,y_\ell)$. The boundary of $V(y_1,...,y_\ell)$, noted $\partial V(y_1,...,y_\ell)$, is the isoquant at the output vector level $(y_1,...,y_\ell)$.. If the technology, namely $\mathcal{T}$ is strictly convex, then $\partial V(y_1,...,y_\ell)$ is the isoquant for the perfectly efficient producer; that is, if $\mathcal{T}$ is strictly convex and $(x_1,...,x_n) \in \partial V(y_1,...,y_\ell)$, then $(x_1,...,x_n,y_1,...,y_\ell)$ is an efficient production plan.

For any feasible production plan $(x_1,...,x_n,y_1,...,y_\ell)$, let

$$D(x_1,...,x_n,y_1,...,y_\ell) = \max\{\lambda \,|\, \frac{1}{\lambda}(x_1,...,x_n) \in V(y_1,...,y_\ell)\}.$$

The function $D:(x_1,...,x_n,y_1,...,y_\ell) \in \mathcal{T} \rightarrow D(x_1,...,x_n,y_1,...,y_\ell) \in R_+$, which was defined by Shephard (1953), is known as *the input distance function.* It is clear that $D(x_1,...,x_n,y_1,...,y_\ell) \geq 1$. The value $D(x_1,...,x_n,y_1,...,y_\ell)$ is the maximum factor by which a radial contraction of the input vector $(x_1,...,x_n)$ can still be used to produce the output vector $(y_1,...,y_\ell)$. As such, $D(x_1,...,x_n,y_1,...,y_\ell)$ represents the technical inefficiency of the production plan $(x_1,...,x_n,y_1,...,y_\ell)$. Observe that the higher is the value of $D(x_1,...,x_n,y_1,...,y_\ell)$, the more technically inefficient is the production plan $(x_1,...,x_n,y_1,...,y_\ell)$.

Debreu (1951) and Farrell (1957) proposed the following *input-based measure of technical efficiency* associated with a feasible production plan $(x_1,...,x_n,y_1,...,y_\ell)$:

$$TEinput(x_1,...,x_n,y_1,...,y_\ell) = \min\{\theta \,|\, \theta(x_1,...,x_n) \in V(y_1,...,y_\ell)\}.$$

It is clear that $TEinput(x_1,...,x_n, y_1,..., y_\ell) \le 1$ and that

$$TEinput(x_1,...,x_n, y_1,..., y_\ell) = 1/ D(x_1,...,x_n, y_1,..., y_\ell).$$

The Debreu-Farrell out*put-based measure of technical efficiency* associated with a feasible production plan $(x_1,...,x_n, y_1,..., y_m)$ is given by

$$TEoutput(x_1,...,x_n, y_1,..., y_\ell) = \frac{1}{\max\{\phi \mid (x_1,...,x_n, \phi y_1,..., \phi y_\ell) \in V(y_1,..., y_\ell)\}}.$$

The Debreu-Farrell measure deals strictly with technical inefficiency. When the prices of inputs are given, the input vector $6(x_1,...,x_n)$, with $6 = TEinput(x_1,...,x_n, y_1,..., y_\ell)$, is not the input vector that minimizes the cost of producing the output vector $(y_1,..., y_\ell)$. This measure of technical inefficiency thus understates the economic inefficiency of the production plan $(x_1,...,x_n, y_1,..., y_\ell)$. The following figure illustrates this point for the case of two inputs, x_1, x_2, and a single output, y.

In Figure 2.1, point $\overline{P} = (\overline{x}_1, \overline{x}_2)$ represents the input vector used by a firm to produce the

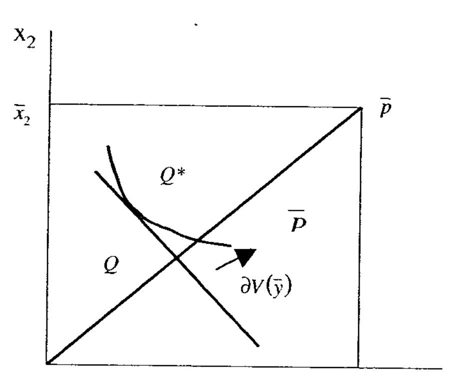

Figure 2.1- Technical Efficiency

output level $\bar{y}$. The boundary of the input requirement set $V(\bar{y})$ is depicted as $\partial V(\bar{y})$ in the figure. The curve $\partial V(\bar{y})$ is the isoquant, at the output level $\bar{y}$, of the perfectly efficient producer. The radial contraction of the input vector $\bar{P}$, beyond which even the perfectly efficient producer cannot use to produce the output level $\bar{y}$, is $\hat{P}$. Also depicted in the figure is the input vector Q^* that minimizes the cost of producing $\bar{y}$, given the prices of the inputs. The intersection of $O\bar{P}$ and the isocost line passing through Q^* is denoted by $\hat{Q}$. The Debreu-Farrell measure of technical efficiency for the producer in question is

$$TE = \theta = \frac{O\hat{P}}{O\bar{P}}.$$

On the other hand, the economic efficiency of the producer in question should be

$\dfrac{\textit{The cost of input vector } Q^*}{\textit{The cost of input vector } \bar{P}} = \dfrac{O\hat{Q}}{O\bar{P}}$, which is obviously less than $O\hat{P}/O\bar{P}$.

2.2. *Technical Efficiency with Undesirable Outputs*

The measures of technical efficiency defined in Section 2.1 deal with the case where all the outputs are desirable. When undesirable outputs exist, the traditional definition of technical efficiency must be modified to account for the negative impact of pollution. As already discussed in the introduction of the chapter, one can allow for an asymmetric treatment of desirable and undesirable outputs along the line of Pittman, op cit., and Fare et al., op cit., or one can maintain the undesirable outputs at a given level then proceed with the traditional measure of technical efficiency. We prefer to treat undesirable outputs as inputs in a traditional neoclassical production function.

2.3. *The Estimation of Technical Efficiency*

There are many approaches in the literature of technical efficiency analysis. Among them are Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA).

DEA starts from the premise that there exists a production frontier which constitutes the upper limit – called the efficient production frontier -- on the production activities of the producers in an industry and that the farther is a producer from the frontier, the more inefficient it is. When producers are heterogeneous, they will be found lying at varying distances from the efficient production frontier. Given the observed data on a set of producers, the DEA procedure constructs a hull around the data to obtain a production frontier and reveals which one among these producers are closest to that frontier. A firm that is technically efficient finds itself on the frontier, which in reality represents the best practice. Presumably, the larger the sample, the more information the procedure will reveal about the technical efficiency of these producers. The main strength of DEA is that it requires neither the form of the technology nor its parameterization. Its main drawback that it shares with the other deterministic frontier estimators is the inability to account for statistical noise or measurement errors in the model; any deviation by an observation from the frontier must be interpreted as inefficiency. For an exposition of the DEA methodology and computational aspects, we refer the reader to Aigner and Chu (1968), Lovell (1993), and Ali and Seiford (1993).

SFA was introduced simultaneously by Aigner, Lovell, Schmidt (1977), and Meeusen & and van den Broeck (1977). The stochastic frontier models formulated by these researchers allow for technical inefficiency on the part of producers as well as for random shocks that are outside their control. The great virtue of SFA is that the impact on output of shocks due to variation in labor and machinery performance and shocks emanating from the operating environment can be separated from the contribution of variation in technical efficiency. This is the main advantage of SFA over DEA, which explains our preference for the former technique.

3. STOCHASTIC FRONTIER ANALYSIS

In this section, the econometrics of stochastic frontier analysis is presented. For a complete exposition of this subject, we refer the reader to Greene (1997), Coelli *et al.* (1998), and Kumbakhkar and Lovell (2000). Our exposition of stochastic frontier analysis is based on Kumbakhkar and Lovell (2000, Section 3.2.2).

Consider a group of producers who manufacture a good from n inputs. The producers are indexed by i, $i = 1,\ldots,m$, and the inputs are indexed by j, $j=1,\ldots,n$. In what follows, y_i denotes the output of producer i and $x_i = (x_{i1},\ldots,x_{ij},\ldots,x_{in})$, where x_{ij} denotes the quantity of input j used by producer i.

Now the value of y_i clearly depends on x_i. Furthermore, because random shocks in the environment of a producer also affects her output, producer-specific shocks, such as luck, vagaries of the weather, or variations in labor and equipment performance, should be incorporated into the model. Finally, and this is the main objective of technical efficiency analysis, we should also allow for the degree of technical efficiency of a producer to have an impact on her output. A model that incorporates these three features is known as a stochastic production frontier.

To specify a stochastic production frontier for the group of producers under consideration, we suppose that the output of producer i is given by

$$(1) \qquad y_i = f(x_i, \beta)\exp(v_i)\exp(-u_i), \qquad (i = 1,\dots,m).$$

In (1), β is a vector of parameters that characterize the common technology used by the group of producers in question. As specified by (1), the function $f(.\ ,\beta)\ x_i \rightarrow f(x_i\ ,\ \beta)$ is invariant across producers. The symmetric stochastic noise v_i captures the impact of all the random shocks in the environment of producer i. As for u_i, it is a nonnegative half normal random variable. In the parlance of Bayesian games, u_i represents the type of producer i. In the literature of stochastic frontier analysis, $exp\ (-u_i)$ is called the technical efficiency of producer i. Observe that the higher is the value of u_i, the lower will be the technical efficiency of producer i. When $u_i = 0$, the technical efficiency of producer is 1, i.e., she is the most technically efficient. Also, note that we have adopted the output-based Debreu-Farrell measure in our specification of technical inefficiency.

Assuming that $f(x_i\ ,\ \beta)$ has the log-linear Cobb-Douglas form, we can rewrite (1) as :

$$(2) \qquad \ln y_i = \beta_0 + \sum_{j=1}^{n} \beta_j \ln x_{ij} + v_i - u_i$$

$$= \beta_0 + \sum_{j=1}^{n} \beta_j \ln x_{ij} + \varepsilon_i, \qquad (i = 1,\dots,m),$$

Where we have let $\varepsilon_i = v_i - u_i$. Observe that the composed error term ε_i is asymmetric because $u_i \geq 0$. In stochastic production frontier analysis, the objectives are twofold. First, obtain an estimate of the vector of technology parameters $\beta=(\beta_0, \beta_1,\ldots,\beta_n)$. Second, obtain an estimate of e^{-u_i}, the technical efficiency of producer i, $i=1,\ldots,m$. In carrying out these estimation exercises, we assume that a set of cross-sectional data $(y_i, x_i)_{i=1}^m$ is available. Also, we make the following distributional assumptions:

(i) $v_i \sim iid\ N(0,\sigma_v^2)$,

(ii) $u_i \sim iid\ N^+(0,\sigma_u^2)$,

(iii) v_i *and* u_i are distributed independently of each other and of the regressors.

Assumption (i) is standard. Assumption (ii) captures the plausible assumption that the type of the most technically efficient producer is $u_i = 0$ and that smaller values of technical efficiency are less likely if everything else, such as v_i, is constant. This assumption is also maintained for reason of tractability. As for assumption (iii), the independence of u_i and v_i does not seem unreasonable. On the other hand, the independence of u_i and x_i seems problematic. Intuitively, we expect that a producer has some knowledge about her type, i.e., her technical efficiency. Knowing that one is less technically efficient might induce a producer to use more inputs in her production plan to produce a certain expected level of output, that is, the choice of x_i will depend on u_i. This assumption can be relaxed if a set of panel data is available. However, in the current context and given the cross-sectional data at our disposal, we shall follow tradition and maintain assumption (iii).

According to assumption (i), the density function[10] of v_i is:

(3) $$f(v_i)=\frac{1}{\sqrt{2\pi}\sigma_v}\exp\left(-\frac{v_i^2}{2\sigma_v^2}\right),$$

As for u_i, its density function is

(4) $$f(u_i)=\frac{2}{\sqrt{2\pi}\sigma_u}\exp\left(-\frac{u_i^2}{2\sigma_u^2}\right), \qquad u_i \geq 0.$$

Because u_i and v_i are independent, their joint density function is

(5) $$f(u_i,v_i)=\frac{1}{\pi\sigma_u\sigma_v}\exp\left(-\frac{u_i^2}{2\sigma_u^2}-\frac{v_i^2}{2\sigma_v^2}\right),$$

Since $\varepsilon_i = v_i - u_i$, the joint density function of u_i and ε_i is

(6) $$f(u_i,\varepsilon_i)=\frac{1}{\pi\sigma_u\sigma_v}\exp\left(-\frac{u_i^2}{2\sigma_u^2}-\frac{(\varepsilon_i+u_i)^2}{2\sigma_v^2}\right),$$

The marginal density function of ε_i is given by

(7) $$f(\varepsilon_i)=\int_0^\infty f(u_i,\varepsilon_i)du_i$$

$$=\frac{1}{\pi\sigma_u\sigma_v}\int_0^\infty \exp\left(-\frac{u_i^2}{2\sigma_u^2}-\frac{(\varepsilon_i+u_i)^2}{2\sigma_{v^2}}\right)du_i$$

$$=\frac{2}{\sigma}\phi\left(\frac{\varepsilon_i}{\sigma}\right)\Phi\left(-\frac{\varepsilon_i\lambda}{\sigma}\right)$$

where $\phi(z)$ and $\Phi(z)$ denote, respectively, the density function and the cumulative distribution of the standard normal, i.e.,

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[10] By abuse of notations, all the density functions have the same head, namely f.

$$\phi(z)=\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{1}{2}z^2\right)$$

and

$$\Phi(z)=\int_{-\infty}^{z}\phi(z')dz',$$

Also, in the right-hand side of the third equality of (7), we have let $\sigma=\left(\sigma_u^2+\sigma_v^2\right)^{1/2}$ and $\lambda=\sigma_u/\sigma_v$,

Using (2) and (7), we obtain the following expression for the density function of $ln\ y_i$:

$$(10)\quad f(\ln y_i)=\frac{2}{\sigma}\phi\left(\frac{1}{\sigma}\left[\ln y_i-\beta_0-\sum_{j=1}^{n}\beta_j\ln x_{ij}\right]\right)\Phi\left(-\frac{\lambda}{\sigma}\left[\ln y_i-\beta_0-\sum_{j=1}^{n}\beta_j\ln x_{ij}\right]\right),$$

Because $lny_1,\ldots,lny_m$ are independent, the log likelihood function in a sample of the m producers in question is given by

$$(11)\qquad \mathcal{L}=\ln\left[\prod_{i=1}^{m}f(\ln y_i)\right]=\sum_{i=1}^{m}\ln[f(\ln y_i)]$$

$$=m\left(\ln 2-\ln\sqrt{2\pi}-\ln\sigma\right)-\frac{1}{2\sigma^2}\sum_{i=1}^{m}\left[\ln y_i-\beta_0-\sum_{j=1}^{n}\beta_j\ln x_{ij}\right]^2+$$
$$\sum_{i=1}^{m}\ln\Phi\left(-\frac{\lambda}{\sigma}\left[\ln y_i-\beta_0-\sum_{j=1}^{n}\beta_j\ln x_{ij}\right]\right),$$

Maximizing the log likelihood function $\mathcal{L}$ with respect to $\beta_0, \beta_1,\ldots, \beta_n$, λ, and σ, we obtain the maximum likelihood estimates, say $\hat{\beta}_0,\hat{\beta}_1,\ldots,\hat{\beta}_n,\hat{\lambda}$, and $\hat{\sigma}$, of these parameters. These estimates are consistent when $m\to\infty$. For each $i=1,\ldots,m$, the residual

$$(12)\qquad e_i=\ln y_i-\hat{\beta}_0-\sum_{j=1}^{n}\hat{\beta}_j\ln x_{ij}\ ,$$

estimates $\hat{e}_i$.

The next step is to obtain estimates of the technical efficiency of the m producers in question by extracting the information that e_i contains on u_i, $i=1,\ldots,m$. To this end, first note that the conditional density of u_i given ε_i is

$$(13) \quad f(u_i \mid \varepsilon_i) = \frac{f(u_i, \varepsilon_i)}{f(\varepsilon_i)}$$

$$= \frac{1}{1-\Phi\left(-\frac{\mu_i^*}{\sigma^*}\right)} \left[\frac{1}{\sigma^* \sqrt{2\pi}} \exp\left(-\frac{1}{2}\left[\frac{u_i - \mu_i^*}{\sigma^*}\right]^2 \right)\right],$$

where we have let $\mu_i^* = -\varepsilon_i \lambda / \sigma$ and $\sigma^* = \sigma_u \sigma_v / \sigma$. Observe that in (13) the expression inside the pair of square brackets is the density function of a normal random variable with mean μ_i^* and variance $(\sigma_i^*)^2$. The mean of u_i, conditional on ε_i , is

$$(14) \quad E(u_i \mid \varepsilon_i) = \int_0^{+\infty} u_i f(u_i \mid \varepsilon_i) du_i$$

$$= \mu_i^* + \sigma^* \left[\frac{\phi\left(-\frac{\mu_i^*}{\sigma^*}\right)}{1-\Phi\left(-\frac{\mu_i^*}{\sigma^*}\right)} \right] \quad = \sigma^* \left[\frac{\phi\left(\frac{\lambda}{\sigma}\varepsilon_i\right)}{1-\Phi\left(\frac{\lambda}{\sigma}\varepsilon_i\right)} - \frac{\lambda}{\sigma}\varepsilon_i \right],$$

A point estimator for u_i, say $\hat{u}_i$, *is* $E(u_i \mid \varepsilon_i)$, the conditional mean of u_i given ε_i. Because ε_i and the parameters λ, σ, σ^* that appear in $E(u_i \mid \varepsilon_i)$ are unknown, they must be replaced by their estimates in computing $\hat{u}_i$; that is,

$$(15) \quad \hat{u}_i = \hat{\sigma}^* \left[\frac{\phi\left(\frac{\hat{\lambda}}{\hat{\sigma}} e_i\right)}{1-\Phi\left(\frac{\hat{\lambda}}{\hat{\sigma}} e_i\right)} - \frac{\hat{\lambda}}{\hat{\sigma}} e_i \right], \qquad (i=1,\ldots,m).$$

In (15), we recall, $\hat{\lambda}$ and $\hat{\sigma}$ are the maximum likelihood estimates of λ and σ, respectively. As for $\hat{\sigma}^*$, it is an estimate of $\sigma^* = \sigma_u \sigma_v / \sigma$. Using the fact that $\lambda = \sigma_u / \sigma_v$ and $\sigma = \left(\sigma_u^2 + \sigma_v^2\right)^{1/2}$, we can obtain estimates of σ_u and σ_v say $\hat{\sigma}_u$ and $\hat{\sigma}_v$, from $\hat{\lambda}$ and $\hat{\sigma}$. Once $\hat{\sigma}_u$ and $\hat{\sigma}_v$ have been found, the estimate $\hat{\sigma}^*$ can be computed from the formula $\hat{\sigma}^* = \hat{\sigma}_u \hat{\sigma}_v / \hat{\sigma}$. Also, the composed error term ε_i has bean replaced by its estimate e_i, the residual of producer i.

Once $\hat{u}_i$ has been computed, the technical efficiency of producer i is then given by

$$(16) \qquad TE_i = \exp(-\hat{u}_i), \qquad (i = 1, \ldots, m).$$

Because the conditional density of u_i, given ε_i, is independent of the sample, the estimates of technical efficiency are not consistent. Unfortunately, this seems to be the best that can be achieved under the cross-sectional data framework.

4. PULP AND PAPER MILLS: ENVIRONMENT AND TECHNICAL EFFICIENCY

Consider a group of m integrated pulp and paper mills that produce a single paper grade. The inputs used by these mills are wood (w), chemicals (c), energy (e_0), labor (l_0), and capital (k_0). Two pollutants are generated in the production process: biochemical oxygen demand (bod_0) and total suspended solids (tss_0). Letting y denote the output of a typical mill, we can represent symbolically the production process of such a mill by the following transformation:

$\mathscr{T}_o : (w, c, e_0, l_0, k_0) \rightarrow (bod_0, tss_0, y)$,

The production function $\mathscr{T}_o$ represents the technology of papermaking used by the group of pulp and paper mills under consideration.

Now in a pulp mill, the digester and the chemical recovery boiler constitute the main components of its capital stock. How much wood can be cooked in the white liquor in a period of time depends on the volume of the digester. The size of the chemical recovery boiler determines how much of the chemicals in the black liquor that can be recycled for re-use. The sizes of the digesters and the chemical recovery boiler put an upper bound on the volume of the wood input, and a fortiori the output, per unit of time. As for the paper plant, the number of paper machines as well as the width and the speed of each of these machines limit its capacity. A mill, after being built, can be operated only up to its capacity during its lifetime. In the short run, the variable inputs are wood, chemicals, energy, and labor. Among these variable inputs, the raw materials, namely wood and chemicals, are constrained by the capacity of the mill.

An increase in the wood input, ceteris paribus, will increase the desirable output proportionally. An increase in the input of chemicals, every other thing constant, is expected to raise output, while a rise in the desirable output means less of the wood input will be rejected as wastes and thus less pollution will be generated. However, an increase in the use of chemicals means more chemicals will come out of the integrated mill, i.e., there will be more pollution. Without an appropriate engineering study, it is difficult to decide whether an increase in the use of chemicals will raise or lower the levels of the undesirable outputs. However, with an efficient chemical recovery system in a closed kraft mill, we can expect that the reduction in wood waste will dominate the negative impact of the increased use of chemicals. Thus, we shall assume that $\partial y/\partial c > 0$ but $\partial bod/\partial c < 0$ and $\partial tss/\partial c < 0$. As for energy and labor, an increase in one of these inputs, ceteris paribus, is expected to raise *y* but lower both *bod* and *tss*.

The effluent coming out of the integrated mill is treated in a primary treatment plant before being released into the environment. Formally, we can represent the technology of effluent treatment by the following transformation:

(18) $\quad \mathcal{T}_r\colon (e_1, l_1, bod_0, tss_0, k_1) \rightarrow (bod_1, tss_1),$

In (18), bod_0 and tss_0 represent, respectively, the biochemical oxygen demand and the total suspended solids that enter the primary effluent treatment facilities. Recall from (17) that bod_0 and tss_0 are the two undesirable outputs of the papermaking process. As for e_1 and l_1, they represent, respectively, the energy input and the labor input used in depollution activities. Also, k_1 denotes the capital stock of the primary effluent treatment plant. Finally, bod_1 and tss_1 represent, respectively, the parts of bod_0 and tss_0 that remain untreated and released into the environment; that is, bod_1 and tss_1 represent the net emissions of the two undesirable outputs. We expect that an increase in bod_0 and tss_0, ceteris paribus, raises both bod_1 and tss_1. On the other hand, an increase in e_1 and l_1, ceteris paribus, is expected to lower both bod_1 and tss_1.

Combining $\mathcal{T}_o$ and $\mathcal{T}_r$ we obtain the following transformation between the list of inputs and the list of outputs - desirable and undesirable- for the system made up of the integrated mill and its primary effluent treatment plant:

(19) $\mathcal{T}$: $(w, c, e_0, l_0, k_0, e_1, l_1, k_1) \rightarrow (bod_1, tss_1, y,)$,

Now let $\mathcal{A}$ be the set consisting of all the feasible lists of inputs $(w, c, e_0, l_0, k_0, e_1, l_1, k_1)$. For each list $(w, c, e_0, l_0, k_0, e_1, l_1, k_1) \in \mathcal{A}$, let

(20) $\mathcal{F}(w, c, e_0, l_0, k_0, e_1, l_1, k_1) = (w, c, e, l, bod_1, tss_1, k, y)$,

where

$e = e_0 + e_1,\ l = l_0 + l_1,\ k = k_0 + k_1$ and $(bod_1, tss_1, y) = \mathcal{T}(w, c, e_0, l_0, k_0, e_1, l_1, k_1)$.

Next, let $\mathcal{B}$ be the image of $\mathcal{A}$ under $\mathcal{F}$. An element of $\mathcal{B}$, say $(w, c, e, l, bod_1, tss_1, k, y)$, is thus a feasible production plan for the whole system - the integrated mill plus the primary effluent treatment plant. Under such a feasible production plan, w and c represent, respectively, the wood and chemical inputs used in the pulp and paper mill. The third element of the input list is e, which is the total energy input and used in papermaking and effluent treatment activities. Next l is the labour input for the integrated mill. The fifth and sixth elements of a feasible production plan- *bod* and *tss* - represent the net emissions of biochemical oxygen demand and the total suspended solids, respectively, which are the two undesirable outputs of the whole system. As for k, it is the total capital stock of the integrated mill. Finally, y, the last element of the list, is the output of the paper grade.

From the technical point of view, the components bod_1 and tss_1 in (20) are outputs, although undesirable from the economic point of view. If we adopt the economic point of view, these two components can be considered as inputs. Thus we say that a production plan ($w, c, e, l, bod_1, tss_1, k, y$) is efficient if it satisfies the following two conditions. First, it is an element of $\mathcal{B}$. Second, there is no other production plan, say $(w', c', e', l', bod_1', tss_1', k', y')$, such that

$$w \geq w', c \geq c', e \geq e', l \geq l', bod_1 \geq bod'_1, tss_1 \geq tss'_1, k \geq k', \text{ but } y \leq y',$$

with at least one strict inequality holding.

The set of efficient production plans for the whole system will be denoted by $\partial\mathcal{B}$. We shall assume that $\partial\mathcal{B}$ is the graph of a smooth function

(21) f: $(w, c, e, l, bod_1, tss_1, k) \rightarrow y$,

whose domain is a subset X of $\Re^7_+$ and whose range is $\Re_+$.

As it stands, f has the form of a neoclassical production function in which the two pollutants bod_1, tss_1 are treated as inputs in the same manner as the traditional inputs w, c, e, l, and k. The production function f exhibits a limited degree of input substitution, as can be explained as follows:

First, note that bod_1 and e (or l *or* k) can be substituted for each other in a limited manner. To see how, let us pick an efficient production plan ($w, c, e, l, bod_1, tss_1, k, y$). Next, suppose that we raise bod_1 by reducing only the energy input that goes into the treatment of biochemical oxygen demand. This action will cause bod_1 to rise and e to decline.

Because all the inputs used in the papermaking process remain the same, the output vector (bod_0, tss_0, y) will remain the same. The only two things that change are a rise in bod_I and a decline in e. There is thus possible substitution between e and bod_I. Now because w and c are fixed, their material contents are also fixed. Furthermore, because part of these raw materials going into the paper grade manufactured and the remaining part leaves the system as wastes, there will be an upper bound on bod_I. Hence, we can only substitute bod_I for e up to a limit fixed by w and c.

Next, note that bod_I can be substituted for w in the following manner. Suppose that we raise bod_I by transferring part of the energy input used in effluent treatment to papermaking. This action keeps e constant but raises y because now more energy is used in papermaking. To maintain y at the original level, we now have to lower w. A reduction in the wood input coupled with a rise in the energy input used in papermaking will lower the net emission of biochemical oxygen demand. However, the decrease in biochemical oxygen demand will not bring the net emission of this variable below its original level because if this were possible the original production plan would not be efficient. Therefore, at the end of the substitution the net emission of biochemical oxygen demand will be higher and the wood input will be lower than their original levels. The production function thus allows for substitution between w and bod_I. Again, as in the substitution between bod_I and $e(l)$, the substitution between bod_I and w is not unlimited. As w declines, the raw material content in bod_I will also decline. Hence, the wastes that give rise to bod_I cannot increase after w has declined to a certain level.

Other possibilities for input substitution can be similarly explained. Taking into account the fact that these possibilities are not unlimited, we must impose on X the condition that it is a bounded subset of $\Re^7_+$. For our econometric estimation and technical efficiency analysis, we shall assume that f has the form of a log-linear Cobb-Douglas production, say

$$(22) \quad \begin{aligned} \ln y &= \ln f(w,c,e,l,bod_1,tss_1,k) \\ &= \beta_0 + \beta_1 \ln w + \beta_2 \ln e + \beta_3 \ln l + \beta_4 \ln bod_1 + \beta_5 \ln tss_1 + \beta_6 \ln k \,, \end{aligned}$$

A stochastic production frontier for the group of m integrated pulp and paper mills is then, given by the following m production relations:

$$(23) \quad \begin{aligned} \ln y &= \ln f(w,c,e,l,bod_1,tss_1,k) \\ &= \beta_0 + \beta_1 \ln w + \beta_2 \ln e + \beta_3 \ln l + \beta_4 \ln bod_1 + \beta_5 \ln tss_1 + \beta_6 \ln k + v_i - u_i \,, \\ & \qquad (i = 1,\ldots,m). \end{aligned}$$

In (23), y_i is the output of paper produced from the *ith* pulp and paper mill and (w_i, c_i, e_i, l_i, bod_{1i}, tss_{1i}, k_i) is its input vector. Also, v_i is a symmetric statistical noise that captures all the random shocks in the environment of this mill. As for u_i, it is a nonnegative random variable that characterizes the type or the technical efficiency of the mill.

As in Section 2, we make the following distributional assumptions:

(i) $v_i \sim iid\ N(0,\sigma_v^2)$,

(ii) $u_i \sim iid\ N^+(0,\sigma_u^2)$,

(iii) v_i *and* u_i are distributed independently of each other and of the regressors.

5. THE DATA

This study uses confidential data. It contains information on the Canadian pulp and paper industry at the firm level. The data cover 38 kraft mills across Canada for the year 1991. Regional breakdown is as follows.

- B.C. Coast (all B.C. mills discharging into tidal water) and B.C. Interior (other B.C. mills);
- The Prairie (Alberta, Saskatchewan, Manitoba);
- Ontario (Province of Ontario);
- Quebec (Province of Quebec);
- The Atlantic Region (New Brunswick, Nova Scotia, Newfoundland).

The data contains information on 3 mills in the Atlantic region, 3 mills in the Prairie, 9 mills in Ontario, 15 mills in British Columbia, and 8 mills in Quebec within the specific SIC codes. The data encompass the following variables: number of employment, production volume, level of capital stock, level of discharge for BOD and TSS in kg/day, the amount of wood intake, the level of energy used in the manufacturing.

5.1. Industry Definition

According to the industrial classification of Statistics Canada, industries are classified according to their type of output. This study focuses exclusively on industries,[5] and deals

[5] The Pulp Industry (SIC 2711): Establishments primarily engaged in manufacturing mechanical, semi-mechanical and chemical wood pulp for sale as such. These establishments may manufacture paper as a secondary product. Establishments primarily engaged in manufacturing paper are classified in other classes of this industry group. Some, but not all of the products related to this industry include: chemical pulp; mechanical (ground-wood and refiner type) pulp; semi-chemical pulp; wood pulp, dissolving and special alpha (sulphite and sulfate); wood pulp, sulfate and soda, paper grade; wood pulp, sulphite, paper.

mainly with the following 4-digit SIC's:

- The Pulp Industry (SIC 2711), which is classified under the Paper and Allied Products Industries, a 2-digit level code.
- The Newsprint Industry (SIC 2712), which is classified under the Paper and Allied Products Industries, a 2-digit level code.
- The Paperboard Industry (SIC 2713), which is classified under the Paper and Allied Products Industries, a 2-digit level code.
- Other Paper Industries (SIC 2719), which is classified under the Paper and Allied
- Products Industries, a 2-digit level code.

5.2. The Variables

- Production: According to Statistics Canada, production is measured by the total value of shipments. Total shipments are defined as the revenue earned from the sale of goods produced. From an accounting perspective, the measure of total shipments is similar to a company's total revenues as expressed in the income

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The Newsprint Industry (SIC 2712): Establishments primarily engaged in manufacturing newsprint and ground-wood printing paper. Some, but not all of the products related to this industry include: ground-wood printing paper, newsprint.

The Paperboard Industry (SIC 2713): Establishments primarily engaged in manufacturing paperboard and building paper (used in asphalt coated vapour barrier or in the manufacture of insulation batts). Establishments primarily engaged in manufacturing building board are classified in (2714 - Building Board Industry). Some, but not all of the products related to this industry include: building paper, not impregnated or coated; chipboard (paperboard); corrugating board; liners, Kraft or paperboard; paperboard, container and boxboard grade; shoe board; strawboard for corrugated containers.

Other Paper Industries (SIC 2719): Establishments primarily engaged in manufacturing fine, specialty, and sanitary papers. Establishments primarily engaged in manufacturing newsprint (including ground-wood printing) are classified in (2712 - Newsprint Industry). Some, but not all of the products related to this industry include: blotting paper, mfg., book paper (exc. Ground-wood printing); Bristol paper; Decalcomania paper; duplicating paper; facial tissue stock, mfg., filter paper, fine paper, miscellaneous; lightweight paper; manifold papers; matrix paper; onion skin paper; printing papers (exc. Ground-wood printing); reproduction paper; serviette stock paper; toilet tissue stock; toweling stock paper.

statement. Total shipment per employee is a measure of productivity, specifically labor productivity. Labor productivity does not account directly for technological improvements but the addition of new equipment may result in increases in labor productivity. In addition, since these data are presented in current rather than constant dollars, this application of the measure does not control for the possible effects of inflation; it is, nonetheless, a useful barometer of changes in sectoral productivity. In our analysis, however, we do not have to worry about this aspect as our dataset is cross-sectional. We have divided the total value of shipment by the average price per tonne of Kraft paper in 1991 to calculate the total volume of shipment in tones.

- Employment: According to Statistic Canada, Employment is separated within the manufacturing sector into two major categories, production and administration. Production workers include those employees engaged in processing, assembling, storing, inspecting, handling, packing, maintenance, repair, janitorial, watchmen services and working foremen. Since administrative employees include all employees that are not involved in production and related manufacturing activities, the study does not include them.
- Wood intake: Wood is considered as the major raw material for pulping and papermaking. Mills can either purchase wood chips or process their own wood chips on site from whole logs (round wood) they buy or harvest from their own woodlands operations.
- Energy usage: According to Statistic Canada, overall mill energy balances, specially, the overall consumption of energy in bleaching chemicals is among the

most important operational parameters to consider. For example, the chemicals and enzymes consumed in the manufacture of bleached kraft pulp both consume energy in their production and comprise the greater part of the overall burden of chemical contamination emitted to the wider environment in the form of gaseous, liquid, and solid wastes. The energy unit is in kilowatt hours/ton (KWH) of pulp produced, consumed by the various chemicals from their manufacture to their end-use in bleaching processes.

- Pollution Level: Data include information on discharge level for Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) in kg/day and also in annual average discharge level at firm level across the regions. Also, production level of BOD and TSS at ton/day is included.
- Capital stock: In the 2001 Annual Directory of Pulp and Paper Canada are found the annual production capacities – in metric tones of pulp that a mill can produce when operated at full capacity – of Canadian mills. The annual capacity of a mill can be used as a proxy for its capital stock. In our calculations of the capital stocks of the pulp mills in the data set, we assume a fixed proportion between the capital stock of the production plant and the treatment plant and use the capacity of the treatment plant – measured in metric ton of the effluents that the treatment plant can handle when operated at full capacity – as the capital stock of the pulp mill. The data on the costs of the treatment plants and the annual amortization of the investment need to treat one ton of effluents – v and a in the formulas that follow – of Canadian pulp mills are taken from McCubbin Consultants Inc. (1990). The present value of the investment cost required to treat one ton of

effluent is $f(a)=\sum_{t=0}^{19}\frac{a}{(1+r)^t}$ In the preceding formula, the interest used is often the recommended value of $r=0.0819.$ Dividing v by $f(a)$, we obtain the capacity of the treatment plant – measured in the number of metric tones of effluents that the treatment plant can handle when operated at full capacity. Thus the capital stock for a pulp mill is given by $k[a,v]=\frac{v}{f(a)}$. Another way to compute the capital stock of a pulp mill is to add up the cost of the various components of the mill by using the list prices of different pieces of machines – boilers,... - as well as buildings. The capital stock computed in this manner is the dollar value of the plants and equipments of the pulp mill. This is an arduous process that we have eschewed. The capital stocks of the mills in our data set are in physical quantities, not in monetary value.

6. ESTIMATIONS AND THE RESULTS

In our empirical estimation, we assume a fixed proportion relation between the wood input and output and, therefore, we do not include the wood input. This assumption might be restrictive as the relation between wood input and output depends on the technology used as well as on the composition of the output. Hence the assumption of a fixed proportion relation between output and wood input implies homogeneity of the technology as well as the final output. It would have been more appropriate to either include the wood input or use the value-added as the dependent variable rather than the output. However, this assumption is deemed necessary, as the wood input was not available at firm level. An attempt to derive wood input from provincial level data posed significant difficulties for the interpretation of the capital/labor coefficients since, as one might suspect, the assumed wood input dominated the regression. Furthermore, because our sample is relatively small, we should expect some irregularities and hence the initial regression results should be analyzed with care. In our case, the initial regression yielded a very small (0.039) and insignificant ($t = 0.186$) labor coefficient, making the result rather suspect. We have also estimated the CES (Constant Elasticity of Substitution) production function to relax the assumption of unitary elasticity of substitution embedded in a Cobb-Douglass production function. The estimated substitution parameter was close to 0 (0.145) but with rather high standard error (1.18), which is in fact estimated consistently. This implies that our estimated range of elasticity of substitution is in conformance with the Cobb-Douglass production function used from hereon although it also includes a simple linear production function. A quick look at the labor inputs together with the corresponding output revealed that several observations were extreme. More specifically, we found that three firms exhibited a labor productivity that is much higher than the sample average. To bypass this problem, we have created a dummy variable to separate the most and the least productive firms and added this dummy to our estimation. To do so we first defined labor productivity as output divided by labor input. We then assigned the value 1 to the dummy variables of the firms with a labor productivity of at least 1 and 0 to the dummy variables of the remaining firms. To test the robustness of our empirical results, we estimated the model with the dummy and without by excluding the three so-called outliers.

The results for our OLS estimation are reported in Table 2.1. As indicated earlier, the initial estimation reported in Model 1 provided a labor elasticity close to zero, whereas the addition of the dummy variable increased the labor elasticity substantially (Model 2). The results are also confirmed if one drops the three extreme observations altogether (Model 3), as they do not change materially.

Table 2.1
Least Squares Estimates

	Model 1		Model 2		Model 3	
Variables	Coefficient	t- Stat	Coefficient	t- Stat	Coefficient	t- Stat
Constant	1.8264	0.413	2.0810	0.603	0.9840	0.269
Energy	0.1599	0.799	0.0119	0.751	0.0727	0.424
Labour	0.0389	0.186	0.2229	1.333	0.2738	1.558
Pollution	0.1387	0.723	0.0585	0.265	0.1170	0.425
Capital	0.5682	4.683	0.4769	4.935	0.4950	5.008
Dummy (Most Productive)			1.4769	4.713		
Observations	38		38		35	
Adjusted R-Squared	0.3435		0.6004		0.5143	

In general, the estimated production function is found in full accordance with the production theory, the labor and capital coefficients are both positive. In addition, capital is significant and labour is close to be significant. Furthermore, as one might expect from a capital-intensive industry such as the pulp and paper industry, the capital coefficient indicate that capital is the dominant input in the production function. The least square estimates of the parameters of the production function are used as the starting points for the maximum likelihood estimates. With the help of Mathematica, convergence is obtained in about thirty three iterations and are presented in the following table:

Table 2.2
Maximum Likelihood Estimates

Variables	Coefficient	t-stat[6]
Constant	2.68415	5.70
Energy	0.01278	0.05
Labour	0.22463	1.20
Pollution	0.06129	0.19
Capital	0.47875	3.90
Dummy	1.04011	4.50
σ	0.78981	0.079
λ	0.30017	0.085

As with the OLS estimation, here also, we find that the output of each firm is most elastic with respect to capital and labor in decreasing order. The results also reveal that the output of each firm is least elastic with respect to the energy input, which is consistent with the fact that there is no close substitute for energy.

Using the maximum likelihood estimate we obtain the technical efficiency for our sample. The results appear in the following list and are depicted in the histogram:

{0.875, 0.837, 0.833, 0.839, 0.859, 0.748, 0.862, 0.918, 0.949, 0.547, 0.856, 0.581, 0.693, 0.179, 0.774, 0.707, 0.794, 0.721, 0.879, 0.799, 0.509, 0.888, 0.789, 0.769, 0.830, 0.783, 0.906, 0.877, 0.133, 0.926, 0.754, 0.852, 0.626, 0.911, 0.789, 0.509, 0.866, 0.758}

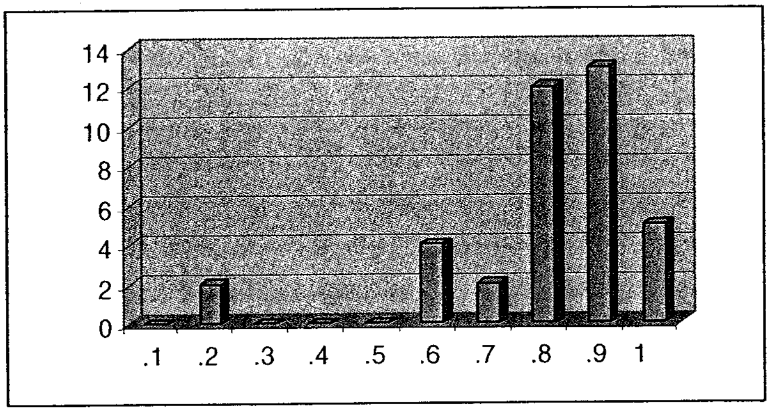

Figure 2.2- Technical Efficiency Histogram

The obtained result seems to agree with reality. With the exception of a handful of firms, the high level of the technical efficiency of the firms indicates that the firms comply well with the environmental regulation imposed by the federal government. We have also regressed the estimated technical efficiency on relative level of pollution. The estimated coefficient was found negative and significant further strengthening our result: the companies that comply sufficiently with environmental regulations have reported higher level of technical efficiency and hence those with higher relative pollutions are not necessarily more efficient.

The empirical results provided here fall short of a formal test for the Porter hypothesis. Under ideal circumstances, this hypothesis can be tested by comparing the pre-and post-regulation technical efficiencies for a sample of firms. For the Canadian pulp and paper industry, such a sample is currently not accessible. Alternatively, the Porter hypothesis can also be tested if one can differentiate between technical efficiency and environmental efficiency. If so, then a high degree of correlation between these two measures of efficiency would provide support for the Porter Hypothesis.[7] However, for a Cobb-Douglas technology, all output elasticities will be constant and hence the ranking of firms by environmental efficiency scores would be identical to a ranking by technical efficiency scores, and as a result, the environmental efficiency measure would add no information to the technical efficiency measure, according to Folmer and Reinhard (1999). The property of varying elasticities required for this type of analysis is satisfied by a host of functional forms, among which one can mention the often used translog

[6] The t-stat is reported based on robust standard errors.
[7] Folmer and Reinhard (1999) and Reinhard et *al.* (2000).

production function. Yet, our dataset reject these specifications and prevent us from using such an analysis. To follow up our analysis further, we need first to upgrade the quality of our dataset, both in terms of the number of observations and in terms of the years available. A potential panel dataset provides an ideal building block for a formal test of Porter hypothesis.

7. CONCLUDING REMARKS

In this study, we have incorporated pollution into technical efficiency analysis. The pollutants, which are undesirable outputs, are treated as inputs in a neoclassical production function. According to this interpretation of pollutants, a higher level of pollution means less capital is used to treat the waste and more capital is used in the production of the desirable output. Conversely, a low level of pollution implies that more capital is devoted to de-pollution activities and less capital to the production of the desirable output. Hence, given the fixed level of capital, more pollution means more output, i.e., pollution behaves like a traditional input in a neoclassical production function. Under this interpretation of pollution, the technique of stochastic frontier analysis can then be applied. The measures of technical efficiency computed thus embody both environment and technical aspects of the production process. The model has been formulated at the firm level using micro data. This is in contrast with the other traditional studies, which are carried out at the industry level. Our result thus can be used for policy analysis in the area of environmental regulation.

Our estimation results indicate that the technical efficiency levels of all the mills in the sample are uniformly high, i.e., they comply well with the environmental regulation imposed by the federal government. This result can also be seen by looking at the estimated coefficient of the pollution variable in the regression equation. The estimated coefficient is rather low and indicates that the mills have successfully reduced their pollution to such a low level that an increase in pollution would not significantly increase output.

We have estimated a stochastic frontier using cross section data. The results can only be used to compare how all the mills comply with the environmental regulation. These results cannot be used to analyze the change in productivity of the mills through time. To accomplish this goal, we must have access to panel data. Also, in our model we deal only with water pollution. The model could be extended to include both land and air pollution. It could also be extended to analyze the impact of R&D on productivity and pollution reduction.

CHAPTER 3

INTERNATIONAL TRADE IN MARKET PULP A MULTI-MARKET OLIGOPOLY MODEL

1. INTRODUCTION

Canadian market pulp is primarily produced in Quebec, Ontario, and British Colombia. British Columbia exports its product to the Asian pacific market, whereas Ontario and Quebec export their market pulp to the US and European markets. In the US market, however, competition is among American firms located mostly in the south of the US, Canadian firms, and European firms located primarily in Sweden and Finland. In the European market, firms from both Canada and the US, as well as Norway, Finland, and Sweden compete against each other.

Market pulp is a homogenous product. Hence one expects the price to be uniform and the production process to involve economies of scale. As a result, heavy investments are required, and to minimize costs, firms usually choose locations close to their raw material sources. These characteristics present strong barriers to entry, and, as a result, the market for market pulp is oligopolistic in nature.

A traditional bulk product such as standard market pulp is in the mature or even declining phase of its life cycle, and so it is traded as a commodity with well-specified properties on the international market (which thus continues to be highly speculative and cyclical).

The nature of this product permits no other strategy other than to maintain a competitive cost structure. Cost minimization can be achieved through several methods. First, firms can increase the size of their plants in order to achieve cost advantages through economies of scale. Second, firms can integrate the production of pulp and paper, and hence achieve cost advantage through economies of scale and scope. The objective of this chapter is to study the international trade in market pulp, with specific focus on the trade among the three aforementioned regions - Canada, the US, and Europe. As in the preceding chapter, the current chapter is also empirically oriented. The chapter is organized as follows.

In Section 2, the trends in production, consumption, and export of market pulp for the three aforementioned regions are presented. The structure and stylized facts presented in this section provide a good framework for the subsequent sectors in which the model is developed and analyzed. The theoretical model we formulate in Section 3 is a spatial oligopoly model based on the characteristics of market pulp discussed earlier. The analysis is original as we consider three firms with capacity constraint competing in three different markets, as opposed to having three players competing in a single market. In the literature on oligopoly, the market structure studied most of the time is nothing other than the worn-out duopoly model found in textbooks, rarely the market structure with more than two firms and two markets. Our objective here is to study the international trade in market pulp, and the structure of these markets dictates at least three players interacting in three different markets. We have also incorporated the capacity constraints for the three players to gain some insights into their behavior when one or two of the markets are tight. When markets are tight and the capacity constraints are binding, shipping one more ton of market pulp to one market means shipping one ton less to another market. Under such a scenario, the results of comparative static exercises are not simple to obtain. This is the main reason why we have chosen the numerical method, not the theoretical approach, to analyze the model. Certainly, complicated analytical techniques can be devised to analyze a linear Cournot model with more than three players with capacity constraints interacting in three markets, although we are not aware of any such research in the literature. Our interest in this chapter is not to carry out theoretical research on linear Cournot models, but to gain some understanding of the practical functioning of the pulp markets in Canada, the US, and the EU.

The existence and uniqueness of the Nash equilibrium are established in Section 4. In Section 5, we use the data for the year 2001 on shipments and the exchange rates between the US dollar, the Canadian dollar, and the euro - all in the year 2001- to calibrate a model of international trade in market pulp among these three regions. The calibrated model is simulated in Section 6 to gauge the impact of demand shifts, exchange rate fluctuations, and environmental regulations on the pattern of trade flows and the profitability of market pulp producers. Because real data have been used for calibrating the model, the results of the numerical comparative static exercises can be used for policy analysis. Thus we carry out simulations to gain insights about changes in the interregional shipping pattern induced by exchange rate fluctuations or shifts in demand. Section 7 contains some concluding remarks and a discussion on the policy implications of the model.[8]

2. MARKET PULP: STYLIZED FACTS

Like any other commodity, market pulp is characterized by cyclicality. In an up-cycle, the industry expands capacity while in the down cycle the added capacity becomes idle and is often shut dawn. Unfortunately, the added capacity in the up-cycle often arrives while demand softens, leading to cyclical imbalances and hence wild price swings. The cyclical nature of market pulp has often led to excess capacity. Policies that encourage employment can lead to construction of new pulp mills; attempts to utilize low-cost plantation fiber resources or the advent of new technology can encourage new projects. Periods of excess capacity have lead to wild swings in prices. When prices are rising, customers increase their purchase and create temporary shortages that drive prices artificially high, the opposite scenario occurs when demand stalls and prices start to fall. These cycles are in a sense unavoidable despite the fact that the industry has gone through changes to smooth out theses volatilities as much as possible.

The recent history of market pulp shows the same type of cyclicality. The commodity recession of late 90s resulted in major capacity reductions among major producers. In 1999, overall North American market pulp capacity declined 4 percent as the US removed capacity for the fourth time this decade, and Canada reduced capacity by 1.5

[8] We do not model transportation cost because the data is not fine enough to separate the transportation cost from the production cost. We can only calibrate the unit delivery cost. According to Lise Lachapelle, president & CEO of a Canadian pulp and paper company, it is well- known in the pulp and paper industry that the cost of transporting of one tone of market pulp from Canada to the US is about 20% of its delivered cost, CPPA, November 25, 1997. Given the high cost of transport, in the simulations, the variations between the prices in the three markets are not sufficient to induce cross-haulages (purchasing a product from a country and shipping it back to the country of origin in order to make profit).

percent. These reductions in capacity allowed market pulp demand to catch up with supply. Furthermore, this so-called rationalization of high cost capacity resulting from the closure of high-cost assets, together with lower fiber prices, better currency rates, and improved efficiencies, left the market pulp sector "poised for substantial profitability" in the near term. [David Pineault (1999), Resource Information Systems Inc. (RISI)]

The period 1998-1999 witnessed major capacity reductions among market pulp producers: Georgia-Pacific Corp., in Port Hudson, Louisiana (225,000 tons/year), Smurfit-Stone Container Corp. in Savannah, Georgia (235,000 tons/years of kraft pulp), Bowater Inc., in Gold River, British Columbia, (250,000 tons/year of northern bleached softwood kraft (NBSK)), and Kimberly-Clark Corp. in Mobile, Alabama. (200,000 of bleached hardwood kraft pulp (BKP)). Major new capacity additions during 1998-1999 include: International Paper Co., in Erie, Pennsylvania (150,000 tons/year of bleached hardwood kraft pulp), Advance Agro in Thailand, (150,000 tons/year of bleached hardwood kraft pulp (BHKP)), Aracruz in Brazil, (200,000 tons/year of BHKP); and Arauco in Chile (250,000 tons/year of softwood kraft pulp). [David Pineault (1999), Resource Information Systems Inc. (RISI)]

The annual growth of pulp capacity has been slowing down and paper/paperboard demand has been growing faster than average GDP growth. This has also been accompanied by producers' disciplined effort not to add new capacity, to buy existing capacity rather than build new mills, to separate timber assets from mill assets to stabilize fiber costs, and to use a formula of pulp pricing indexed to printing/writing paper prices.

In fact, investment in new market pulp capacity has reached its lowest level in nearly 20 years, with mounting mill closures leading to continued- capacity contraction in the US and Canada. The planned addition of 2.8 million metric tons of capacity worldwide over the next five years is offset by the closure of 1.9 million tons. Table 3.1 presents the capacities of the top ten world chemical market pulp producers. [Peter T. Pope (June 1999), Pope & Talbot Inc.]

Table 3.1
The Top Ten World Chemical Market Pulp Producers

Company	Total paper/fluff pulp capacity (000 tons)
Weyerhaeuser	2,140
Sodra	1,865
International Paper	1,605
Georgia-Pacific	1,410
Tembec	1,265
Aracruz	1,240
Arauco	1,125
Canfor	1,120
Stora	1,100
Parsons & Whittemore	1,060

Source: Pulp and Paper Magazine, August 2000.

Europe accounts for over 45% of the world consumption of market pulp, and hence European economic growth has a tremendous impact on total pulp demand. The market pulp industry in Europe has undergone enormous tremendous changes as a result of the creation of the European Union and the introduction of the euro. This has primarily been reflected in the major consolidations and integrations of market pulp producers witnessed in recent years. In general, market pulp in the EU has shown relative growth in the last two decades. Within the EU, this growth has been dominated by the Nordic producers to the extent that they are now among the largest pulp producers in the world. Large multinational suppliers, including Sodra Cell (1.5 million tons/year), Stora Enso (1.7 million tons/year), Metsa-Botnia (1.1 million tons/year), and UPM-Kymmene (1.0

million tons/year) have emerged as a result of the consolidations in the EU. In general, the European supply of market pulp grows slowly while their consumption is rising at a much faster pace, making the EU market by far the largest world destination for market pulp. [The Paper/Forest Products Global Outlook Conference (November 2000), New York]

Table 3.2 illustrates the trends in production, exports, and consumption of market pulp for three regions, Canada, the United States, and Western Europe since the mid 80's.

Table 3.2
Trends in Production, Consumption, and Export of Market Pulp (1000 tons)

	1985	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Canada Production	6441	7150	7689	8075	8001	9608	10110	9675	10112	9740	10640	11123	9583
Exports	5717	6276	7019	7135	7386	8830	8802	8819	9297	9043	9858	10026	9163
Consumption	810	723	728	710	746	838	885	814	823	839	931	830	
United States Production	6169	7982	6945	7865	7363	7610	8167	7493	7839	7302	7431	7892	7414
Exports			5408	6091	5054	5096	5252	5409	5362	4604	4552	4628	4673
Consumption		4905	4805	4855	5360	5840	5885	5525	6245	6440	7010	7055	6390
W. Europe Production	9580	9689				9399	9508	9355	10269	9991	10483	10557	
Exports*		619	664	689	780	563	487	702	759	715	915	944	1034
Consumption													

Source: Pulp and Paper Product Council, 2002.
*Represents European export to North America

As can be seen from this table, Canada has made the most gains in the production and export of the market pulp since the mid 80's. Canadian production of market pulp has increased by more than 60 percent since 1985, and export has almost doubled. The United States' production, however, has been stagnant and export shows a mild decline. Western Europe production and export of market pulp during the decade 1985-1995 have been flat, but a mild upward trend can be observed since. To understand the reasons behind this gain by Canadian and European market pulp firms, one should realize the factors that can affect the investment decision in the paper industry. According to the existing empirical analyses, factors influencing a firm's decision to invest in pulp lines and paper machines include the wage rate, the installed productive capacity, the price of paper, and the exchange rate. It is important to note that most pulp and paper producers are integrated in nature so the investment decision should be considered accordingly. Furthermore, since capital can easily be transferred across borders, factors, such as the interest rate that affects the cost of capital, do not usually play an important role in investment decision, whereas factors affecting the transportation costs for wood input are important since wood is a tradable commodity. In contrast, labor does not easily move across borders and thus will affect the competitiveness of market pulp producers. The cost of labor, itself, is not only affected by the labor structure of each country, it is also affected by currency fluctuations. The dramatic gain in export by the Canadian and European market pulp producers since the mid 1990s can be attributed to both technological advances and exchange rate fluctuations that saw the US dollar soaring over that period.

Different regions of the world offer different characteristics, as far as competitiveness is concerned. North America is the dominant region in terms of market size and fiber availability. Europe provides the most appealing export position, while Asia has a growing consumer market. European companies and in particular the Scandinaviancompanies are considered as pioneers of both new technologies, as well as a push towards more globalization. [The Paper/Forest Products Global Outlook Conference (November 2000), New York]

While lacking supply chain integration and commodity branding, North America, in general, has advantages in softwood fiber, environmental certification, and internet potential. More specifically, the market pulp in Canada has experienced a strong growth in recent years. In the first quarter of 2000, Canada's pulp and paper industry operated at full capacity and activities in the second quarter were also strong. In the middle of 2000, world pulp demand began to weaken and that continued till the end of the year. The down-trend was primarily caused by excess paper stock in Asia and weakening demand in the US, with chemical paper grades affected the most. This sluggish demand continued well into 2001, when Canadian exports of pulp, paper, and paperboard declined by 0.3 percent, and domestic shipments decreased by 1.0 percent. [The Paper/Forest Products Global Outlook Conference (November 2000), New York]

A more detailed analysis of the export destinations of market pulp is provided in Tables 3.3A, 3.3B, 3.3C, and 3.3D. As Table 3.3A reveals, the Canadian export of market pulp to Western Europe has not followed any strong trend. However, the export of market pulp to the US has shown a steady increase since 1991 - from 3704 thousand tons in 1991 to 5250 thousand tons in 2000 - an increase of more than 40 percent. The US export of market pulp to Canada does not reveal a specific trend. While the US export to Canada has decreased from 160 thousand tons, in 1991, to 141 thousands tons, in 1996, by 2000 the volume of export has rebounded to 221 thousand tons. However, as Table 3.3B reveals, the US export of market pulp to Western Europe has been in a declining trend since the early 1990s, and, despite the substantial gain in the year 2000, is still much lower then the levels at the beginning of the decade. The export market for the top two European market pulp producers, namely Sweden and Norway, is presented in Table 3.3C and Table 3.3D, respectively. As shown in these tables, the primary export market for these countries is Europe. Although Swedish producers have succeeded to some extent in increasing their exports to the US and Canada, their presence in the North America market still remains negligible. Within Europe, both Sweden and Norway have substantially increased their exports; however, Norway has outperformed Sweden and has increased her exports to other West European countries by almost 20 percent in the 1990s.

Table 3.3A
Canadian Market Pulp Exports To Major Importing Countries (1000 tonnes)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Finland	14	29	36	43	52	16	27	20	28	31
Sweden	13	28	5	22	39	20	14	20	13	5
Norway	0	0	0	0	0	0	2	0	0	4
Total West Europe	2599	2624	2466	2709	2928	2590	2654	2708	4559	2922
USA	3704	3869	4208	4412	4616	4267	4931	4535	5024	5280

Source: PPI's International Fact and Price Book, 2002

Table 3.3B
US Market Pulp Exports To Major Importing Countries (1000 tonnes)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Finland	2	9	2	3	2	<1	<1	2	<1	<1
Sweden	5	36	8	12	13	9	14	24	25	38
Norway	0	5	<1	1	1	1	0	0	<1	0
Total West Europe	2201	2506	1755	1827	1973	1810	1923	1773	1697	2066
Canada	160	184	178	134	149	141	175	155	199	221

Source: PPI's International Fact and Price Book, 2002

Table 3.3C
Swedish Market Pulp Exports To Importing Countries (1000 tonnes)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Finland	30	23	14	31	28	31	29	31	28	48
Norway	48	42	63	87	80	81	98	83	108	113
Total West Europe	2548	2527	2473	2519	2117	2274	2396	2382	2518	2550
Canada	0	<1	0	0	0	0	0	6	15	22
USA	22	26	33	17	17	22	19	31	36	22

Source: PPI's International Fact and Price Book, 2002

Table 3.3D
Finnish Market Pulp Exports to Major Importing Countries (1000 tones)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Norway	<1	0	<1	2	5	<1	0	<1	<1	0
Sweden	20	13	7	38	32	32	53	59	100	93
Total West Europe	1227	1172	55	1364	1140	1347	1497	1428	1535	1469
Canada	3	0	3	<1	0	0	0	0	0	0
USA	8	3	5	12	4	4	5	5	3	2

Source: PPI's International Fact and Price Book, 2002

Production costs differ rather significantly among the major regional market pulp producers. Costs are affected by many factors including, changes in the currency rate, labor cost, energy costs, transportation costs, and the costs of chemicals. For 2001, International Fact and Price book reported significant differences in the pre interest cost of production of northern bleached softwood kraft pulp (NBSK). The production cost for the top five major regional producers ranged from a low of US$362 per tonne to US$495 per tonne. Sweden reported the lowest cost at SEK3408 per tonne,[9] followed by Finland at FIM2348 per tonne,[10] East Canada at CAN$613 per tonne,[11] British Columbia Interior at CAN$664 per tonne, and British Columbia Coast at CAN$742 per tonne.

3. THE MODEL

Consider an economic space made up of three regions: the US (region 0), Canada (region 1), and the EU (region 2). For each j = 0, 1, 2, let $p_j = a_j - b_j q_j$ be the inverse market

[9] 2001 exchange rate for (SEK/US)= 9.415.
[10] 2001 exchange rate for (FIM/US)= 6.3145.

demand for market pulp in region j. Here a_j and b_j are two positive constants; q_j is the market demand; and p_j is the delivery price – in the currency of region j – of a ton of market pulp. We shall denote by $e_{jj'}$ the number of the units of the currency of region j needed to buy one unit of the currency of region j'. Thus e_{10} represents the number of Canadian dollars needed to buy one US dollar, while e_{12} represents the number of Canadian dollars needed to buy one euro.

Let F_0, F_1, F_2 denote, respectively, the set of firms that produce market pulp in the US, Canada, and the EU. The totality of all the firms in the model is then represented by the set $F = F_0 \cup F_1 \cup F_2$. For each j = 0, 1, 2, let I_j denote the set of mills in region j that produce market pulp. To keep the model from becoming excessively burdensome, we shall assume that the mills located in a region are owned by the companies that belong to that region. The totality of the mills producing market pulp in the model is thus $I = I_0 \cup I_1 \cup I_2$ .We shall denote by I^f the set of pulp mills owned by firm f, $f \in F$.

Consider a firm, say f. For each $i \in I^f$, let $c_i(y_i) = \bar{c}_i + \gamma_i y_i$ denote the total cost of producing market pulp from mill i. Here $\bar{c}_i$ is the fixed cost and γ_i is the constant marginal cost. Observe that the production costs of such a mill are expressed in its own local currency while its revenues are expressed in the currencies of the regions in which its outputs are sold. Also, let τ_{ij} denote the cost of transporting a ton of market pulp from mill i to the market in region j. We shall assume that the transport cost is expressed in

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[11] 2001 exchange rate for (CAN/U.S)= 1.4988.

terms of the currency of the region of origin. The variable cost of delivering one ton of market pulp to region j' from mill i is thus $\gamma_i + \tau_{ij}$. The capacity of mill i will be denoted by $\bar{y}_i$.

Because we are dealing with the short run in which capacities are fixed, it is more natural to assume that the firms choose quantities, instead of prices, as strategies. Certainly, price strategies can be used. However, the analysis will be considerably more complicated without yielding more insights. Now by a feasible production cum shipment plan for firm f, $f \in F$, we mean an array $y^f = (y_{ij})_{i \in I^f, j=0,1,2}$ of non negative numbers that satisfy the following constraints.

(1) $$\sum_{j=0}^{2} y_{ij} \leq \bar{y}_i, i \in I^f,$$

Here y_{ij} is the amount of market pulp produced from mill i and shipped to the market in region j. The set of feasible production cum shipment plans for a firm is denoted by Y^f. It is clear that Y^f is a convex compact subset of the Euclidean space of dimension $3|I^f|$, where $|I^f|$ is number of mills belonging to firm f. An element y^f of Y^f is called a strategy of firm f.

Let $(y^f)_{f \in F}$ be a combination of strategies for the firms in F. Under such a combination of strategies, the market supply of market pulp in region j is $\sum_{i \in I} y_{ij}$ and the delivery price of one ton of market pulp in this region is then $p_j = a_j - b_j \sum_{i \in I} y_{ij}$. For a firm, say

$f \in F_j$, the profits — in terms of the currency of the region of its origin — that it makes are given by

$$\text{(2)} \qquad \pi^f((y^{f'})_{f' \in F}) = \sum_{i \in I^f} \left[y_{ij'} \left(e_{jj'} [a_{j'} - b_{j'} \sum_{i' \in I} y_{i'j'}] - \gamma_i - \tau_{ij'} \right) - \bar{c}_i \right],$$

DEFINITION: A combination of strategies $(\hat{y}^f)_{f \in F}$ is Nash equilibrium if for any firm $f \in F$ and any strategy y^f for this firm, we have

$$\text{(3)} \qquad \pi^f((\hat{y}^{f'})_{f' \in F}) \geq \pi^f(y^f, \hat{y}^{-f}).$$

In (3), we have let $\hat{y}^{-f} = (\hat{y}^{f'})_{f' \in F, f' \neq f}$.

4. EXISTENCE AND UNIQUENESS OF THE NASH EQUILIBRIUM

In this section, we establish the existence and uniqueness of the Nash equilibrium. The results are contained in two lemmas and one proposition. Lemma 1 gives the first characterization of the Nash equilibrium. A more detailed characterization of the Nash equilibrium is given in Lemma 2, which is nothing other than a more explicit restatement of Lemma 1, when the linear structure of market demand is used. The two lemmas lead to the proposition, which asserts that Nash equilibrium is the solution of a concave programming problem. Because the objective function of the concave programming problem is defined and continuous on a compact set, it achieves a unique maximum in this set. The uniqueness of the solution of a concave programming problem means that the Nash equilibrium is unique. Therefore, the proposition establishes the existence and uniqueness of the Nash equilibrium and transforms the search for the Nash equilibrium into that of finding the solution of a concave programming problem. However, in the computations carried out for the various simulation exercises, we have used the characterization of the Nash equilibrium provided by Lemma 2.

Let $(\hat{y}^f)_{f\in F}$ be the Nash equilibrium for the multi-market oligopoly model formulated in Section 3. Now consider a firm $f \in F$. Pick a strategy $y^f = \left((y_{ij})_{j=0,1,2}\right)_{i\in \mathrm{I}^f}$ in Y^f and define $\phi^f(t) = \pi^f\left(\hat{y}^f + t\left(y^f - \hat{y}^f\right), \hat{y}^{-f}\right)$, $0 \le t \le 1$. Note that $\phi^f(t)$ is concave in t because $\pi^f(y^f, y^{-f})$ is concave in y^f, as can be seen from (2). Because $(\hat{y}^f)_{f\in F}$ is a Nash equilibrium, (3) must hold, i.e., $\phi^f : t \to \phi^f(t), 0 \le t \le 1$, attains a maximum at *t=0*, Hence

(4) $$\frac{d\phi^f(0)}{dt} = \sum\nolimits_{i\in \mathrm{I}^f} \sum\nolimits_{j=0}^{2} \frac{\partial \pi^f(\hat{y}^f, \hat{y}^{-f})}{\partial y_{ij}} (y_{ij} - \hat{y}_{ij}) \le 0,$$

Summing (4) over $f \in F$, we obtain

(5) $$\sum\nolimits_{f\in F} \sum\nolimits_{i\in \mathrm{I}^f} \sum\nolimits_{j=0}^{2} \frac{\partial \pi^f(\hat{y}^f, \hat{y}^{-f})}{\partial y_{ij}} (y_{ij} - \hat{y}_{ij}) \le 0 ,$$

Conversely, let $\left(\hat{y}^f\right)_{f\in F}$ be a combination of strategies for the firms in the spatial oligopoly model formulated in Section 2, and suppose that (5) is satisfied for any combination of strategies $y^f = \left((y_{ij})_{j=0,1,2}\right)_{i\in \mathrm{I}}$ in $\prod_{f\in F} Y^f$. We claim that $\left(\hat{y}^f\right)_{f\in F}$ is a Nash equilibrium. To see why, pick a firm f and an arbitrary strategy $y^f = \left((y_{ij})_{j=0,1,2}\right)_{i\in \mathrm{I}^f}$ for this firm. For any firm $f' \ne f$, set $y_{ij} = \hat{y}_{ij}$ for $i \in \mathrm{I}^{f'}, j = 0,1,2.$

Using the combination of strategies $\left(\left(y_{ij}\right)_{j=0,1,2}\right)_{i\in I}$ in (5), we can reduce this inequality to

$$\frac{d\phi^f(0)}{dt} = \sum_{i\in I^f}\sum_{j=0}^{2}\frac{\partial\pi^f(\hat{y}^f,\hat{y}^{-f})}{\partial y_{ij}}(y_{ij}-\hat{y}_{ij}) \le 0, \tag{6}$$

Using the concavity of $\phi^f(t)$, we can then assert that $\phi^f(t)$ is decreasing in $0 \le t \le 1$;

that is, $\pi^f((\hat{y}^{f'})_{f'\in F}) \ge \pi^f(y^f,\hat{y}^{-f'})$. Proving that $\left(\hat{y}^f\right)_{f\in F}$ is Nash equilibrium.

We summarize the results just obtained in the following lemma.

LEMMA 1: *Let* $\left(\hat{y}^f\right)_{f\in F}$ *be a combination of strategies for the firms in the multi-market oligopoly model formulated in Section 3. Then* $\left(\hat{y}^f\right)_{f\in F}$ *is a Nash equilibrium if and only if for any combination of strategies* $\left(\left(y_{ij}\right)_{j=0,1,2}\right)_{i\in I}$ *in* $\prod_{f\in F}Y^f$ *the following inequality is satisfied:*

$$\sum_{f\in F}\sum_{i\in I^f}\sum_{j=0}^{2}\frac{\partial\pi^f}{\partial y_{ij}}(\hat{y}^f,\hat{y}^{-f})(y_{ij}-\hat{y}_{ij}) \le 0, \tag{7}$$

Now using (2), we obtain the following more explicit expression of (4) for firm $f \in F_j$,

$$\begin{aligned}&\sum_{i\in I^f}\sum_{j'=0}^{2}\frac{\partial\pi^f}{\partial y_{ij'}}\left(\hat{y}^f,\hat{y}^{-f}\right)\left(y_{ij'}-\hat{y}_{ij'}\right) = \\ &\sum_{i\in I^f}\sum_{j'=0}^{2}\left[e_{jj'}(a_{j'}-b_{j'}\sum_{i'\in I}y_{i'j'}-b_{j'}y_{ij'})-\gamma_i-\tau_{ij'}\right]\left[y_{ij'}-\hat{y}_{ij'}\right] \le 0,\end{aligned} \tag{8}$$

Summing (4) first over $f \in F_j$ then over $j = 0,1,2$, and using (8), we obtain the following more explicit expression of (7)

$$(9) \qquad \sum_{j=0}^{2}\sum_{i\in I_j}\sum_{j'=0}^{2}\left[e_{jj'}(a_{j'}-b_{j'}\sum_{i'\in I}y_{i'j'}-b_{j'}y_{ij'})-\gamma_i-\tau_{ij'}\right]\left[y_{ij'}-\hat{y}_{ij'}\right]\leq 0,$$

In (9), we recall, I_j denotes the set of mills producing market pulp in region *j*, *j*=0,1,2. Using (9), we can restate Lemma 1 as follows.

LEMMA 2: *Let* $(\hat{y}^f)_{f\in F}$ *be a combination of strategies for the firms in the multi-market oligopoly model formulated in Section 2. Then* $(\hat{y}^f)_{f\in F}$ *is a Nash equilibrium if and only if for any combination of strategies* $\left((y_{ij})_{j=0,1,2}\right)_{i\in I}$ *in* $\prod_{f\in F}Y^f$ *the following inequality is satisfied:*

$$(10) \qquad \sum_{j=0}^{2}\sum_{i\in I_j}\sum_{j'=0}^{2}\left[e_{jj'}(a_{j'}-b_{j'}\sum_{i'\in I}y_{i'j'}-b_{j'}y_{ij'})-\gamma_i-\tau_{ij'}\right]\left[y_{ij'}-\hat{y}_{ij'}\right]\leq 0,$$

Now for each list (j,i,j'), j=0,1,2, $i\in F_j$, j'=0,1,2, and any combination of strategies $(y_{i'j'})_{i'\in I, j'=0,1,2}$, define

$$(11) \qquad \Psi_{jij'}\left((y_{i''j''})_{i''\in I, j''=0,1,2}\right)=\int\left[e_{jj'}[a_{j'}-b_{j'}\sum_{i'\in I}y_{i'j'}-b_{j'}y_{ij'}]-\gamma_i-\tau_{ij'}\right]dy_{ij'},$$

Next, let

$$(12) \qquad \Psi\left((y_{i''j''})_{i''\in I, j''=0,1,2}\right)=\sum_{j=0}^{2}\sum_{i\in I_j}\sum_{j'=0}^{2}\Psi_{jij'}\left((y_{i''j''})_{i''\in I, j''=0,1,2}\right),$$

As defined, $\Psi:(y_{i^-j^-})_{j^-\in I, j^-=0,1,2}\to\Psi(y_{i^-j^-})_{j^-\in I, j^-=0,1,2}$ is a real-valued, strictly concave, and continuously differentiable function defined on the convex compact set $\prod_{f\in F}Y^f$.

Hence it achieves a unique maximum at a point, say $\left(\hat{y}^f\right)_{f\in F}$, in $\prod_{f\in F} Y^f$. We claim that $\left(\hat{y}^f\right)_{f\in F} = \left(\hat{y}_{i''j''}\right)_{i''\in I, j''=0,1,2}$ is a Nash equilibrium. Indeed, let $\left(y_{i''j''}\right)_{j''\in 1, j''=0,1,2}$ be any combination of strategies in $\prod_{f\in F} Y^f$. Next, for any $0 \le t \le 1$, define

$$\phi(t) = \Psi\left(\left(\hat{y}^f\right)_{f\in F} + t\left[\left(y_{i''j''}\right)_{i''\in 1, j''=0,1,2} - \left(\hat{y}^f\right)_{f\in F}\right]\right), \tag{13}$$

Then $\phi(t)$ achieves a maximum at $t=0$, Hence

$$\phi'(0) = \sum_{j=0}^{2}\sum_{i\in 1_j}\sum_{j'=0}^{2} \frac{\partial \Psi_{jij'}\left(\left(\hat{y}^f\right)_{f\in F}\right)}{\partial y_{ij'}}\left(y_{ij'} - \hat{y}_{ij'}\right) \tag{14}$$

$$= \sum_{j=0}^{2}\sum_{i\in 1_j}\sum_{j'=0}^{2}\left[e_{jj'}(a_{j'} - b_{j'}\sum_{i'\in 1} y_{i'j'} - b_{j'} y_{ij'}) - \gamma_i - \tau_{ij'}\right]\left[y_{ij'} - \hat{y}_{ij'}\right] \le 0,$$

Observe that the expression on the right-hand side of the second equality in (14) has been obtained using the definition of $\Psi_{jij'}$, as given by (11). The claim is established by noting that the inequality in (14) is nothing other than (10).

Conversely, let $\left(\hat{y}^f\right)_{f\in F} = \left(\hat{y}_{ij}\right)_{i\in 1, j=0,1,2}$ be a Nash equilibrium. Next, let $\left(y_{i''j''}\right)_{i''\in 1, j''=0,1,2}$ be any combination of strategies in $\prod_{f\in F} Y^f$. According to (10), we must have.

$$\sum_{j=0}^{2}\sum_{i\in 1_j}\sum_{j'=0}^{2}\left[e_{jj'}(a_{j'} - b_{j'}\sum_{i'\in 1} y_{i'j'} - b_{j'} y_{ij'}) - \gamma_i - \tau_{ij'}\right]\left[y_{ij'} - \hat{y}_{ij'}\right] \le 0, \tag{15}$$

Now because Ψ is concave, we can write:

$$(16)\qquad \Psi\left(y_{i^{\cdot}j^{\cdot}}\right)_{i^{\cdot}\in I, j^{\cdot}=0,1,2} \leq \Psi\left(\hat{y}^{f}\right)_{f\in F} + \sum_{j=0}^{2}\sum_{i\in I_j}\sum_{j^{\cdot}=0}^{2} \frac{\partial \Psi_{jij^{\cdot}}\left(\left(\hat{y}^{f}\right)_{f\in F}\right)}{\partial y_{ij^{\cdot}}}\left(y_{ij^{\cdot}} - \hat{y}_{ij^{\cdot}}\right),$$

According to (15), the expression involving the summations in (15) is less than or equal to 0. Thus $\Psi\left(y_{i^{\cdot}j^{\cdot}}\right)_{i^{\cdot}\in I, j^{\cdot}=0,1,2} \leq \Psi\left(\hat{y}^{f}\right)_{f\in F}$ for all the combinations of strategies in $\prod_{f\in F} Y^{f}$; that is, a Nash equilibrium is also the combination of strategies in $\prod_{f\in F} Y^{f}$ that maximizes $\Psi\left(y_{i^{\cdot}j^{\cdot}}\right)_{i^{\cdot}\in I, j^{\cdot}=0,1,2}$.

We summarize the results just obtained in the following proposition:

PROPOSITION: *The multi-market oligopoly model formulated in Section 3 has a unique Nash equilibrium, which is the combination of strategies* $\left(y_{ij}\right)_{i\in I, j=0,1,2}$ *that solves the following concave programming problem:*

(17) *maximize* $\Psi\left(y_{ij}\right)_{i\in I, j=0,1,2}$

subject to the constraint that $\left(y_{ij}\right)_{i\in I, j=0,1,2}$ *belongs to* $\prod_{f\in F} Y^{f}$.

5. CALIBRATION

In this section, we calibrate[12] the demand and cost conditions for the model for the year 2001. The calibrated model represents the benchmark equilibrium, which is the starting point for several simulations exercises in the following section.

[12] Description of our calibration: we have a set of FOCs that characterize the best response of each firm and the market-clearing conditions. Once the data are substituted for the endogenous variables (p = a - bq), we

To simplify, we assume that there are 3 firms in the model: a US representative firm; a Canadian representative firm; and an EU representative firm. Furthermore, each firm owns exactly 1 mill located in its region of origin.

For each j= 0,1,2, the inverse market demand curve in region j is given by $p_j = a_j - b_j q_j$. Here, q_j is the market demand and p_j is the price of market pulp in local currency. Also, a_j and b_j are two positive parameters.

For each j = 0,1,2 and each j' = 0,1,2, let $c_{jj'}$ be the cost of delivering 1 ton of market pulp produced from region j to region j'. Observe that $c_{jj'}$ is the sum of the cost of producing 1 ton of market pulp in region j and the cost of transporting this ton of market pulp to region j', and that $c_{jj'}$ is expressed in the currency of region j.

For each j = 0,1,2 and each j' = 0,1,2, let $y_{jj'}$ be the amount of market pulp produced in region j and shipped to region j'. The shipment plan for the representative firm in region j is given by $(y_{jj'})_{j'=0}^{2}$. Also, let $\bar{y}_j$ be the capacity of the representative firm in region j. A shipment plan for the representative firm in region j is feasible if $y_{jj'} \geq 0, j' = 0,1,2,$ and $\sum_{j'=0}^{2} y_{jj'} \leq \bar{y}_j$.

have a system of equations in parameters, which are unknown in the calibration exercise. When there are more parameters than equations, we make up the value of the less important parameters. The number of the parameters that remain is then equal to the number of equations, and the system can be solved.

Given a shipment matrix $\left(\left(y_{jj'}\right)_{j'=0}^{2}\right)_{j=0}^{2}$, the profit made by representative firm in region j in the market of region j' is given by

$$\pi_{jj'}\left(\left(\left(y_{kk'}\right)_{k'=0}^{2}\right)_{k=0}^{2}\right) = y_{jj'}\left(e_{jj'}\left(a_{j'} - b_{j'}\left(q_{0j'} + q_{1j'} + q_{2j'}\right) - c_{jj'}\right)\right),$$

For the representative firm in region j, the total profits made in the three markets are given by

$$\pi_j[((y_{kk'})_{k'=0}^{2})_{k=0}^{2}] = \sum_{j'=0,1,2} \pi_{jj'}[((y_{kk'})_{k'=0}^{2})_{k=0}^{2}] \ ,$$

The profit maximization problem faced by the representative firm in region j is

$$\max \pi_j[((y_{j'j''})_{j''=0}^{2})_{j'=0}^{2}]$$

subject to $y_{jj'} \geq 0, j' = 0,1,2$, and $\sum_{j'=0}^{2} y_{jj'} \leq \bar{y}_j$,

The calibration exercise involves solving a system of equations for the values of the parameters of the model. This system of equations consists of the first-order conditions that characterize the best response of each representative firm and the market-clearing condition in each region. Assuming that the data in the year 2001— namely prices in local currencies of market pulp among the three regions, and the exchange rates among the US dollar, the Canadian dollar, and the euro— constituted a Nash equilibrium for that year, theses data – once plugged into the equations – yield a system of equations whose unknowns are the parameters of the model. In principle, the number of equations in the system should be equal to the number of parameters. However, we do not have sufficient data to obtain as many equations as the number of parameters of the model. Hence we have arbitrarily assigned numerical values to some of the parameters and solve the system for the remaining parameters. Given the numerical values of the parameters thus computed, the data in the year 2001 constituted a Nash equilibrium that we shall refer to as the benchmark equilibrium. The data on prices and shipments used in the calibration exercise are given in Tables 3.4 and Table 3.5, respectively. We computed the $US prices in local currency using exchange rate.

Table 3.4
Data on Prices[13] in Local Currencies for 2001: $p_j, j = 0,1,2$

Market	Year 2001
US	$US 454.593
CAN	$CAN 672.515
EU	€ 534.376

Source: computed from the data compiled in "The World Trade Atlas; Global Trade Information Services Inc.", and the data obtained on exchange rate from the Bank of Canada.

Table 3.5
Data on Interregional Shipments (in 10^6 tons) for 2001

	US	CAN	EU
US	53.3981	0.169443	0.044743
CAN	5.25274	11.2349	0.042523
EU	0.101074	0.010133	19.6584

Source: The World Trade Atlas; Global Trade Information Services Inc.

In 2001, the weakness in North American pulp and paper markets in combination with excess capacity led to a rather low operating rate of 89 percent. The prices of market pulp fell by 18.5 percent on average, and the quantity shipments also dropped by about 6 percent. This phenomenon reflects the cyclical nature of the demand for the market pulp. Compared to year 2000, 2001 was a period of recession. Capacity expenditures continued to drop since 1990 in the North American pulp and paper industry.

[13] In the industry, the practice is to quote the prices in $US. The data on shipment and revenue were obtained from "*The World Trade Atlas; Global Trade Information Services Inc.*" From these data, we computed the prices in $US. Using

During periods of slow economic activities, the demand for paper is sluggish, which in turn depresses the demand for market pulp. This results in a downward shift of the demand curve for market pulp. Furthermore, investments in new capacities are lumpy and often made during the upswing part of the cycle. The new pulp mills often come to live when the downswing part of the cycle begins. Weak demand coupled with excess capacities depresses prices and result in lower profits for market pulp producers. The year 2001 was a typical year in the downswing phase of a cycle in the evolution of the pulp and paper industry. In 2001, capacities were idle, and we interpret the market equilibrium in that year as an equilibrium under which the best response of each firm was an interior solution of its profit maximization problem. The Nash equilibrium in 2001, i.e., the benchmark equilibrium is then characterized by a set of equalities, which makes the calibration exercise relatively simple. During the upswing part of a cycle, when economic activities are high and when pulp mills are running at full capacities, the Nash equilibrium involves both equalities and inequalities (capacity constraints and nonnegative constraints on shipments to a certain region). Under such a scenario, the computation of the equilibrium, with the help of the Kuhn Tucker theorem, become much more complicated. Because of the capacity constraint, a firm can only ship more market pulp to one region by reducing the shipment to another region. Depending on the pattern of demand shifts in the three regions, and the exchange rates among the three national currencies, a firm might concentrate on only one market and leave the remaining markets to its competitors.

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the exchange rates for the year 2000 and 2001 compiled by the Bank of Canada, we transformed these prices into local currencies.

The results of calibration exercise are given in Tables 3.6 and 3.7. Table 3.6 presents the calibrated values of the demand parameters in each region, while Table 3.7 presents the calibrated values of the delivering cost of one ton of market pulp from one region to another. Given the values for the demand and cost parameters presented in Tables 3.6 and 3.7, the data on prices and shipments for the year 2001, as presented in Tables 3.4 and 3.5, constitute a Nash equilibrium that we shall call *the benchmark equilibrium.*

Table 3.6
Demand Parameters for 2001
The Benchmark Equilibrium

Market	a_j	b_j
US (region 0)	483.969	0.5
CAN (region 1)	843.732	15
EU (region 2)	731.833	10

Table 3.7
Cost Parameters (in local currency) for 2001: $c_{jj'}$, $j, j' = 0,1,2$
The Benchmark Equilibrium

	US	CAN	EU
US	\$US427.897	\$US432.683	\$US478.2
CAN	\$CAN699.832	\$CAN503.991	\$CAN740.483
EU	€507.514	€484.83	€337.793

Now a linear inverse demand curve is characterized by both the choke price (a_j) and its slope (b_j). The higher is the choke price and/or the flatter is the slope, the larger is the market. As can be seen from Table 3.6, the slope of the inverse market demand curve in the US is –0.5, while the numbers for Canada and the EU are –15 and –10, respectively. Judging the sizes of these markets only in terms of the slope of their respective inverse market demand curves, one might arrive at the conclusion that the US is the largest market, followed by the EU, then Canada. A drop in the price of market pulp by one US dollar will raise the demand in the US by 2 tonnes. For the EU, a drop in the price of market pulp by one euro will only raise demand by 0.1 tonne. As for Canada, when the price of market pulp increases by one Canadian dollar, demand only drops by 0.15 tonne. A look at the choke prices in the three regions reveals that the choke price in the Canadian market is quite high relative to those in the EU and US markets. The high choke prices in Canada and the EU alleviate somewhat the negative impact of the steeper slopes of the inverse market demand curves in three regions.

At the benchmark equilibrium, the price elasticities of demand for the US, Canada, and the EU are 0.0017, 0.0004, and 0.0003, respectively. These elasticities are quite low, which indicate that at the benchmark equilibrium the demand for market pulp in each region in 2001 was not very elastic.

Now Table 3.7 presents the delivery cost in the currency of the region of origin of one tone of market pulp from one region to another. To compare the cost competitiveness of the three firms, it is necessary to convert these unit delivery costs into the same currency. Table 3.8 presents the conversion of these delivery costs to US dollars.

Table 3. 8
Cost Parameters (in $US) for 2001: $c_{jj'}$, $j, j' = 0,1,2$
The Benchmark Equilibrium

	US	CAN	EU
US	427.897	432.683	478.2
CAN	466.928	336.263	494.050
EU	451.6875	431.49	300.635

For the representative US firm, the costs of delivery 1 tonne of market pulp to the home market, the Canadian market, and the EU markets are US$ 427.897, US$ 432.688, and

US$ 478.2, respectively. Observe that the unit delivery cost is higher to the Canadian market than to the domestic market, and that the unit delivery cost to the EU market is much higher than the unit delivery cost to the Canadian market. These numbers confirm our expectations that the cost of delivering one tonne of market pulp rises with the distance between the market and the location of the pulp mill. The same pattern is also found for the representative Canadian firm and the representative EU firm.

A closer look at Table 3.8 reveals that the representative EU firm is the most cost competitive among the three firms. The terms on the diagonal of Table 3.8 indicate that the delivery cost to its domestic market is lowest for the representative EU firm, at US$ 300.64 per tonne. Next, comes the representative Canadian firm with the delivery cost of US$ 336.26 per tonne, slightly 10% higher than the number for the representative EU firm. For the representative US firm, its delivery cost is at US$ 427.897 per tonne, almost 50% higher than that of the representative EU firm. At the level of first approximation, the representative EU firm seems to be the most efficient, with the representative Canadian firm coming second, and the representative US firm the least efficient.

The unit delivery costs in foreign markets also put the representative EU firm at the top of the list in terms of cost efficiency. It costs the representative EU firm US$ 451.69 to deliver one tonne of market pulp to the US market, while for the representative Canadian firm the number is US$ 466.93, even though the distance between Canada and the US is shorter than that between the EU and the US. The unit delivery cost to the Canadian market is also lower for the representative EU firm than for the representative US firm, with $US 431.49 for the representative EU firm and US$ 432.68 for the representative Canadian firm.

For the representative US firm and the representative Canadian firm, the numbers in Table 3.8 tell a different story: the costs of delivering one tonne of market pulp in foreign markets are higher for the representative Canadian firm. Given its reputation as a highly inefficient pulp producer, this privileged position in foreign markets of the representative US firm could probably be explained by a lower transportation cost. Because the bulk of Canadian market pulp goes to the US, the higher cost of delivering one tonne of market pulp in foreign markets does not sufficiently put the representative Canadian firm at a disadvantage relative to the representative US firm.

In the final analysis, the unit delivery costs in Table 3.8 indicate that European pulp producers are the most efficient and American pulp producers the least efficient, with Canadian pulp producers occupying the middle ground. The relative cost position of the three firms plays a determinant role in their reactions to changing market conditions and the environmental regulations imposed by the governments in the three regions.

6. SIMULATION EXERCISES

In this section, we carry out a series of simulations. The first two simulations attempt to analyze the reaction of the firms to shifts in demand in the US or/and shifts in demand in the EU. The third simulation deals with the impact of exchange rates variations on the pattern of shipments among the three regions and the profitability of the three firms. The fourth simulation deals with the impact of the more stringent environmental regulations in The EU on the pattern of trade flows among the three regions as well as the profitability of each firm.

6.1. *Demand Shift*

6.1.1. *Booming US Economy with Excess Capacities*

The starting point of the first simulation is the benchmark equilibrium. This simulation deals with the scenario under which the US economy is coming out of a recession: demand for market pulp starts growing, but capacities are still not fully utilized.

During the upswing phase of the cycle, the demand curve for market pulp in the US shifts outward. The shift can be represented by a rise in the choke price, with the slope of the inverse market demand curve constant; or a decline in the slope of the inverse market demand curve, with the choke price constant; or both a higher choke price and a flatter inverse market demand curve. In the first simulation exercise, the demand shift is represented by an outward rotation around the vertical intercept of the inverse market demand curve. More precisely, the choke price is assumed to be the same as the level found in the benchmark equilibrium, but the slope b_0 of the inverse market demand curve is assumed to fall from 0.50 to 0.45, a decline of about 10 percent. The results of the simulation exercise are presented in Tables 3.9, 3.10, and 3.11. Table 3.9 presents the equilibrium shipments.

Table 3.9
The Equilibrium Shipments (in 10^6 tons)
US Economy Coming out of a Recession

	US	Canada	EU	Total
US	59.3313	0.16944	0.04474	59.54548
Canada	5.83638	11.2349	0.04252	17.11380
EU	0.11230	0.01013	19.6584	19.78083
Total	65.2799	11.4144	19.7456	96.44012

As can be seen from Table 3.9, compared to the benchmark equilibrium (Table 3.5), the three representative firms sell more market pulp in the US but do not change the quantities of market pulp shipped to the other two regions. The result that all the firms increase their shipments to the US market is expected: an outward shift in the market demand in the US will induce the three firms to increase their shipments to this market. Given the assumption of excess capacities, the firms can ship more market pulp to the US without having to cut back their shipments to the other two markets. Furthermore, because unit delivery costs from one region to another are constant, the three markets are not interdependent under the present scenario. Together these two assumptions explain why the benchmark equilibrium in Canada and the benchmark equilibrium in the EU are not disturbed when the US economy emerges from a recession. Table 3.10 presents the equilibrium prices and quantities under the present scenario.

Table 3.10
The Equilibrium Prices and Quantities
US Economy Coming out of Recession

Market	Equilibrium Prices (in local currencies)	Equilibrium Quantities (10^6 tons)
US	$US 454.593	65.2799
CAN	$CAN 672.515	11.4145
EU	€ 534.376	19.7456

As can be seen from Table 3.10, the prices of market pulp in Canada and in the EU are the same as their levels under the benchmark equilibrium. This result confirms our intuition in the preceding paragraph about the independence of the three markets under the present scenario. Intuitively, we expect the shift in demand in the US to raise the price of market pulp in this region. Thus it is a little surprising to find out from Table 3.10 that the price of market pulp in the US market does not rise from a recession and when capacities are still idle. This result can be traced back to the linear structure of the US market demand curve and the assumption that a flatter slope – with the choke price remaining the same – characterizes the shift in demand for market pulp in the US. If one represents the demand shift by a rise in the choke price, the equilibrium price of market pulp in the US should rise with the upswing of economic activities in the US. Table 3.11 presents the profits made by the three firms under the present scenario.

Table 3.11
Profits $\pi_j, j = 0,1,2$
US Economy Coming out of a Recession

Firm	Benchmark (in millions)	Scenario (in millions)	Percentage Change in Profits
US	$US1425.98	$US1584.38	11
CAN	$CAN1914.73	$CAN1917.1	0.1
EU	€ 3864.52	€ 3864.52	0

As can be seen from Table 3.11, the representative US firm's profits – relative to the level under the benchmark equilibrium – rise by 11 percent. For Canada, the number is 0.1 percent. For the EU, the number is 0.0 percent, which means that when the US economy emerges from a recession, the initial impact on the representative EU firm is negligible. The result for the representative EU firm can be understood by looking at Table 3.5 (the shipments under the benchmark equilibrium) and Table 3.9 (the shipments under the present scenario). As can be seen from these two tables, the shipments by the representative EU firms to North America are negligible in both cases, which explain why the representative EU firm does not benefit from a modest rise in economic activities in the US. For the representative Canadian firm, the increase in the profit is a modest 0.1 percent. This result can be explained by the higher unit delivery cost to the US of the representative Canadian firm relative to the unit delivery cost to the domestic market of the representative US firm, as indicated by Table 3.8. The representative US firm benefits the most from the demand shift in its domestic market.

Because of its large market, the US is expected to be the engine of growth for Canadian and European market pulp producers. Any shift in demand in the US has a positive effect on the performance of producers elsewhere. However, in the present scenario the assumption of excess capacities prevents these firms from reaping the benefits of the demand shift. In prolonged up cycles, pulp producers will operate at full capacity, and the three markets will become highly interdependent. Whatever happens in one market will have repercussions in the other market because when a firm ships one more ton of market pulp to one region it has to cut back by one ton the shipment to another region. It is in the upswing phase of a cycle that pulp producers start building up capacities, and the new capacities come on line when the downswing of the cycle begins. Thus when the US economy emerges from recession, there will be idle capacities, and only when economic activities are in full swing will the firms be operating at full capacities.

6.1.2. *Booming US and EU Economies with Excess Capacities*

In the first simulation exercise, we study the impact of a shift in the demand for market pulp in the US. In the present simulation exercise, we look at the scenario under which there are demand shifts in both the US and the EU. Furthermore, relative to the demand shift considered in the first simulation exercise, the demand shift in the US is now more pronounced. Qualitatively, what differentiates the second simulation exercise from the first one is that the first simulation exercise attempts to analyze numerically the impact of a regional demand shift while the second simulation exercise deals with the scenario of a "booming world economy." Quantitatively, the demand shifts are much more pronounced in the second simulation exercise than in the first simulation exercise.

In the second simulation exercise, demand shifts are represented by a rise in the intercept and a decline in the slope of the inverse market demand curve in each of the two large economies. The values of the demand parameters adapted for the second simulation exercise are given in Table 3.12.

Table 3.12
Demand Parameters
Second Scenario (Booming US and EU Economies, with Excess Capacities)

Market	a_i	b_i
US	498.488	0.45
CAN	843.732	15
EU	746.469	9.5

Relative to the values calibrated for the year 2001, the choke price for market pulp in the US is allowed to rise about 3 percent, while the slope of the inverse market demand curve is allowed to decline by 10 percent. For the EU, the choke price for market pulp is allowed to rise by 2 percent and the slope of the inverse market demand curve is allowed to decline by 5 percent. As in the first simulation exercise, the capacity constrains in the second simulation exercise are assumed not to be binding. The results of the second simulation exercise are presented in Tables 3.13, 3.14, and 3.15.

As can be seen from Table 3.13, which gives the equilibrium shipments under the present scenario, the demand shifts in the US and the EU affect only the prices and the quantities shipped to these markets by each of the three firms.

Table 3.13
The Equilibrium Shipments (10^6 tons)
Second Scenario (Booming US and EU Economies, with Excess Capacities)

	US	CAN	EU	Total
US	67.3974	0.1694	0.4322	67.9991
CAN	13.9025	11.2349	0.4299	25.5673
EU	8.1784	0.0101	21.0782	29.2667
Total	89.4783	11.4144	21.9404	

The demand shifts have no impact on the Canadian market, as expected. As in the first simulation exercise, the assumptions of excess capacities and constant unit delivery costs together imply that the impact of a demand shift in any market is not propagated to any market, which explain why the initial equilibrium in the Canadian market is not disturbed. Table 3.13 indicates that shipments by the three firms to the US and EU markets all rise. Before the demand shift in the US market, the quantity of market pulp shipped to the US by the representative EU firm was negligible. The more pronounced demand shift in the US market considered in the present simulation exercise has induced the representative EU firm to increase its shipment to the US market by 7.2 percent. The equilibrium price and equilibrium quantities in each market are presented in Table 3.14.

Table 3.14
The Equilibrium Prices and Quantities
Second Scenario (Booming US and EU Economies, with Excess Capacities)

Market	Price (in local currencies)	Quantities (10^6 tons)
US	$US458.223	89.4784
CAN	$CAN 672.515	11.4145
EU	€ 538.035	21.9404

Observe that relative to the initial equilibrium, the prices of market pulp have risen in both the US and EU markets. As already intimated in the first simulation exercise, the price increases can be attributed to the rise in the choke price in each of these markets. Table 3.15 presents the equilibrium profits for the three firms under the current scenario.

Table 3.15
Profits (in National Currencies): $\pi_j, j = 0,1,2$
Second Scenario (Booming US and EU Economies, with Excess Capacities)

	Benchmark Equilibrium (in millions)	Current Scenario (in millions)	Percentage Change
US	$US1425.98	$US2045.95	30.3
CAN	$CAN1914.73	$CAN 2030.45	5.70
EU	€ 3864.52	€ 4254.36	9.2

Observe that the profits of the three firms rise dramatically with the pronounced shifts in demand in the two large economies. As can be seen from Table 3.15, the profits of the representative US firm rise by 30.3%. For the representative EU firm, its profits rise by 9.2%. The representative Canadian firm comes last with a 5.7% increase in the profits. As in the first simulation exercise, the size of the market and the unit delivery cost to its domestic market account for the dramatic rise in the profits of the representative US firm. In the present simulation exercise, the two large economies serve as the engine of growth of the pulp industry.

6.1.3. *Booming US and EU Economies, with Binding Capacity Constraints on All Producers*

In the first two simulation exercises, we study the impact of demand shifts on market equilibrium and the profitability of the firms. The first simulation exercise deals with regional demand shift – the emergence of the US economy from a recession – while the second simulation exercise attempts to analyze the impact, on the market pulp sector, of a growing world economy. A common assumption in both simulation exercises is that there are excess capacities in the industry. What distinguishes the second simulation exercise from the first one is that in the second simulation exercise the demand shift is more global. We have seen that the assumptions of excess capacity and constant unit delivery costs lead to the result that what happens in one market does not have any repercussion on the other two markets: the three markets are not interdependent, i.e., the behaviour of a firm in any markets depends only on the strategy of the other two firms in that market. Furthermore, the results of the first simulation exercise suggest that a regional demand shift benefits mostly the firm located in that region because it is cheaper for a firm to deliver one tonne of market pulp to its own domestic market than for its rivals to deliver one tonne of market pulp to this market. In the second simulation exercise, there are pronounced demand shifts in both the US and EU economies. Shipments of market pulp by all three producers to the US and EU markets rise and profits increase substantially.

Analysts of the market pulp sector often lament the "irrational behaviour" of pulp producers in building excessive capacities, which leads to the unintended consequences of overproduction, lower prices, and lower profits. Furthermore, those analysts also observe that capacities are often built up during the upswing phase of the cycle, when expectations of pulp producers are rosy, and the new capacities only come on line in the downswing phase of the cycle. The excess capacities in the downswing phase of the cycle induce pulp producers to cut prices, and collectively the profits of the industry suffer. Those analysts wonder if pulp producers could only restrain themselves from overproduction to keep prices from falling. There are several possible explanations for this cyclical behaviour of the market pulp sector. First, pulp mills are discrete, not infinitely divisible. Hence when new capacities are added, the capital stock of a pulp producer does not rise smoothly but take a discontinuous jump upward. Second, in fighting for market share, each pulp producer chooses a production cum shipment plan – subject to the capacity constraint – to maximize its profits, taking the strategies of its rivals as given. These best responses, although individually rational, collectively lower the profits of each firm. If each firm reduces its output slightly from the Cournot equilibrium level, then the profit of each firm will improve under this joint deviation. However, such a joint deviation is not a Nash equilibrium, i.e., if a firm deviates from the joint action while the other firms do not, then the deviating firm will increase its profits at the expense of all the other firms. Overproduction, lower prices, and lower profits are thus the unintended consequences of individual rationality. Third, the observed timing of capacity expansions by a firm – capacity build up in the upswing and completion of new capacities in the down swing – is not necessarily inefficient from the firm's perspective. To answer the question of whether such timing is optimal from a firm's perspective, we need to formulize a dynamic game in which production as well as investment decisions by each of the firms and their interactions must be analyzed explicitly. We shall not attempt to formulate the differential game needed in addressing this question.

The present and the third exercise that we carry out in this subsection has as its starting point the demand conditions adopted for the second simulation exercise, as presented in Table 3.12. What differentiates the third simulation exercise from the second simulation exercise is that there are now capacity constrains on all the three firms. Table 3.17 presents the capacity for the three firms.

Table 3.17
Capacities (in million tons)
Firms' Third Scenario: Booming US and EU Economies, with Binding Capacity Constrains

US	67.933
CAN	25.5012
EU	29.2006

In the second simulation exercise, the equilibrium outputs of the representative US firm, the representative Canadian firm, and the representative EU firm are 67.9991, 25.5674, and 29.2668 million tons, respectively. For each firm, the equilibrium output in the second simulation exercise is clearly higher than the capacity adopted for the third simulation exercise. Therefore, the equilibrium of the second simulation exercise will no longer be the equilibrium in the third simulation exercise. As in the first and second simulation exercises, the cost conditions adopted for the third simulation exercise remain the same as those of the benchmark equilibrium. The results of the third simulation exercise are presented in Table 3.18, 3.19, 3.20. Table 3.18 presents the equilibrium shipments under the third scenario.

Table 3.18
The Equilibrium Shipments (10^6 tons)
Booming US and EU Economies, with Binding Capacities Constraints

	US	CAN	EU	Total
US	66.4956	0.11980	0.38457	66.999
CAN	12.9387	11.1824	0.37895	24.500
EU	7.45982	0	21.0402	28.500
Total	86.89412	11.3022	21.80372	

Table 3.19 presents the equilibrium prices, and quantities in the three markets under the current scenario.

Table 3.19
The Equilibrium Prices and Quantities
Booming US and EU Economies, with Binding Capacities Constraints

Market	Prices (in local currencies)	Quantities (10^6 tons)
US	$US 459.386	86.8941
CAN	$CAN674.199	11.3022
EU	€ 539.334	21.8037

Table 3.20 presents the profits of the firms under the present scenario

Table 3.20

Profits: $\pi_j, j = 0,1,2$
Booming in Both US & EU Economy, with Binding Capacity Constrains

	No Binding Capacity Constraint	Binding Capacity Constraint	Percentage change
US	2045.95	2096.25	2.459
CAN	2030.45	2054.79	1.199
EU	4254.36	4280.81	0.622

As Table 3.20 reveals, the firms in all three regions would be better off - under the scenario of booming US and EU economies – when capacity constraints are binding than when the capacity constraints are not binding. When capacity constraints are binding, the producers are prevented from over producing, which explain why their profits all rise if they are all constrained.

Compared to the equilibrium of the second simulation exercise in which capacities are not binding, the price of market pulp rises in each market. In the US, the price of market pulp rises by 1.054 percent. In the EU and in Canada, the numbers are 0.250 percent and 0.928 percent, respectively. The results indicate that prices in the US rise the most, while in the EU, the market price for market pulp rises the least. The capacity constraint makes the three markets interdependent: shipping to one market means shipping less to another market. The shipment to the EU and the US rises while the shipment to the Canadian market declines due to the capacity constraint. That explains the price increase in Canadian market although demand conditions in this market have not changed.

When capacities are not binding, each firm is driven, in its best response to other firms' strategies, to increase production, with the ensuing the result of a lower market price. The end result is that every firm makes less profit. Each firm would rather have the capacity constraints binding on the other firms. Collectively, each firm is better off when every firm faces a capacity constraint.

Compared to the case when there is no capacity constraint on any firm, the profit of each representative firm rises: 2.5 percent for the US, 1.2 percent for Canada, and 0.6 percent for the EU.

6.2. *Exchange Rate Fluctuations*

In this subsection, we study the impact of exchange rate fluctuations on the behavior of firms and market equilibrium. Therefore, five simulations exercises — simulation exercises 4 through 8 in the series — have been carried out for this purpose. The demand and cost conditions adopted remain the same as in the second and third simulations exercises. The production capacities for the representative US firm, the representative Canadian firm, and the representative EU firm, however, are now given by 67.933 million tons, 25.5012 million tons, and 29.2006 million tons, respectively. Furthermore, at the initial equilibrium, the exchange rates are those of the year 2001. The production capacities have been arbitrary chosen so that under the initial equilibrium the capacity constraints are binding on all firms. Simulation exercises 4 through 8 correspond to the scenarios that both the Canadian dollar and the euro appreciate, respectively, by 2%, 4%, 6%, 10%, and 15% against the US dollar. The results of these simulation exercises are presented in Table 3.24 through 3.27. The role played by the exchange rates is important in determining the behaviour of exporters. This is because although the cost of production of market pulp is incurred in domestic currency and is more stable, its price is in US$ and will change as the value of the US dollar fluctuates on foreign exchange markets.

The initial equilibrium shipments and the equilibrium shipments under the various exchange rate fluctuation scenarios are presented in Table 3.24.

Table 3.24
Equilibrium Shipments (in million tons)
Various Exchange Rate Fluctuation Scenarios

	Initial Equilibrium	2 %	4 %	6 %	10 %	15 %
US to US	67.3373	66.894	66.220	65.051	62.937	60.481
US to CAN	0.16664	0.3285	0.5904	1.0760	2.0070	3.0896
US to EU	0.42909	0.7104	1.1215	1.8058	2.9881	4.3617
CAN to US	13.8431	7.4126	0	0	0	0
CAN to CAN	11.2321	11.160	11.029	10.786	10.321	9.7798
CAN to EU	0.42679	0.3372	0.2001	0	0	0
EU to US	8.11826	1.5741	0	0	0	0
EU to CAN	0.00733	0	0	0	0	0
EU to EU	21.075	20.985	20.848	20.606	20.015	19.3284

Table 3.24 reveals that as the Canadian dollar and the euro appreciate against US dollar, the shipments by the representative US firm to the domestic market decline, but its shipments to the two foreign markets both rise. Relative to the initial equilibrium and when the Canadian dollar and the euro both appreciate by 15% against the US dollar, the representative US firm ships about 10% less to its domestic market, but ships about 1754% and 916% more to the Canadian market and the EU markets, respectively. It

should be pointed out that in all scenarios of exchange rate fluctuations, the representative US firm always produces at full capacity.

As for the representative Canadian firm, its shipments to all three markets decline as the Canadian dollar and the euro appreciate against the US dollar. When the Canadian dollar and the euro appreciate by 2% relative to the US dollar, Canada's exports of market pulp to the US drop by 46%. For common rates of appreciation of 4% or more, the representative Canadian firm stops shipping market pulp to the US. The shipments by the representative Canadian firm to its domestic market also decline steadily as the Canadian dollar and the euro appreciate against the US dollar, although in a less dramatic manner. Relative to the initial equilibrium and at the common appreciation rate of 15%, the shipments to its domestic market by the representative Canadian firm drop only by about 13%. The shipments by the representative Canadian firm to the EU market also declines steadily as the US dollar depreciates against the other two currencies. When the Canadian dollar and the euro appreciate by 6% or more relative to the US dollar, Canadian exports of market pulp to the EU drop to zero. The picture that now emerges is that when the Canadian dollar and the euro appreciate against the US dollar, the representative Canadian firm's shipments to each market declines. Furthermore, when the appreciation rate is substantial (at or above 6%), the representative Canadian firm will abandon the foreign markets and concentrate all its activities in the domestic market. It is also worth pointing out that in all the scenarios of exchange rate fluctuations considered, the representative Canadian firm operates below capacity.

The analysis carried out for the representative Canadian firm also applies to the representative EU firm. When the Canadian dollar and the euro appreciate by 2% against the US dollar, the shipments of market pulp from the EU to the US decline from 8.11826 million tons to 1.5741 million tons - a drop of about 81%. [14] These shipments fall to zero when the appreciation rate is 4%. As for the shipments of market pulp by the representative EU firm to the Canadian market, they are not significant at the initial equilibrium. These shipments drop to zero when the appreciation rate is 2%. The general shipment pattern adopted by the representative Canadian firm as the Canadian dollar and the euro appreciate against the US dollar is also adopted by the representative EU firm: the representative EU firm abandons the foreign markets and concentrates on the domestic market. It also operates below capacity. The economic logic behind the results presented in Table 3.24 can be explained as follows. As the Canadian dollar and the euro appreciate at the same rate against the US dollar, the representative Canadian and EU firms become less competitive both at home and abroad, while the representative US firm become more competitive than the other two firms in all three markets. Without capacity constraints, we can expect the shipments to each market by the representative Canadian firm and the representative EU firm to drop while the shipments to each market by the representative US firm to rise. Because at the initial equilibrium the capacity constraints for the Canadian and EU firms are barely binding, these firms do reduce their shipments to each market and operate below capacity, as can be seen in Table 3.24. However, for the representative US firm, the capacity constraint is binding under each scenario of exchange rate fluctuations. The representative US firm chooses to ship more and more

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[14] The result seems to be rather sensitive which might be due to quality of our data.

market pulp to the foreign markets, but less and less market pulp to the domestic market as the Canadian dollar and the euro appreciate against the US dollar. Table 3.25 presents the equilibrium quantities in each market.

Table 3.25
The Equilibrium Quantities (in million tons) in Each Market
Various Exchange Rate Fluctuation Scenarios

Market	Initial Equilibrium	2 %	4 %	6 %	10 %	15 %
US	89.2986	75.880	66.220	65.051	62.937	60.481
CAN	11.4061	11.489	11.619	11.862	12.328	12.869
EU	21.9309	22.033	22.170	22.412	23.003	23.690

Table 3.25 indicates that as the Canadian dollar and the euro appreciate against the US dollar, the equilibrium quantities in the US market decline, but the equilibrium quantities in the Canadian and EU markets both rise. When the Canadian dollar and the euro appreciate by 15% against the US dollar, the equilibrium quantity in the US market drops precipitously by 32%, while the equilibrium quantities in the Canadian and the EU markets rise by 13% and 8%, respectively. The equilibrium prices in the three markets are presented in Table 3.26.

Table 3.26
The Equilibrium Prices in Local Currencies: p_j, j=0,1,2
Various Exchange Rate Fluctuation Scenarios

Market	Initial Equilibrium	2 %	4 %	6 %	10 %	15 %
US	US$458.304	464.342	468.688	469.215	470.166	471.271
CAN	CAN$672.64	671.397	669.433	665.791	658.809	650.689
EU	€538.126	537.155	535.853	533.553	527.937	521.413

Now given that the value of the Canadian dollar relative to the euro remains the same, one would expect the flows of market pulp between Canada and the EU to be stable. Thus, it is a little puzzling to discover from Table 3.24 that the flows — in both directions — of market pulp between these two regions drop to zero when the Canadian dollar and the euro to appreciate at or above 6% against the US dollar. This apparent paradox can be explained by pointing to the results that as the Canadian dollar and the euro to appreciate against the US dollar, the representative US firm ships more and more market pulp to the Canadian and EU markets, causing prices in these markets (see Table 3.26) to drop. Because it costs more to deliver one ton of market pulp to a foreign market than to the domestic market, the Canadian firm will abandon the EU market when the price in the EU market falls below its unit delivery cost to this market. The same argument applies to the representative EU firm. Finally the profits made by the firms under the various exchange rate fluctuation scenarios are presented in Table 3.27.

Table 3.27
Profits (in millions of national currencies): $\pi_j, j = 0,1,2$
Various Exchange Rate Fluctuation Scenarios

Firm	Initial Equilibrium	2 %	4 %	6 %	10 %	15 %
US	US$2044.61	2450.17	2734.93	2764.01	2856.69	3036.45
CAN	CAN$2032.59	1907.35	1825.25	1745.27	1597.89	1434.68
EU	€4256.12	4184.93	4129.24	4033.91	3805.78	3549.09

The results of our numerical analysis are in accordance with the findings of standard trade theories and suggest why governments are often wary of their appreciating national currencies, especially when the exports of raw or semi-processed commodities are concerned. The low price elasticity of market pulp and negligible product differentiation often oblige governments to resort to subsidies to mitigate the effect of rising national currency, and international disputes witnessed every now and then are a testament to this problem.

6.3. *Impact of Environmental Regulations*

In this subsection, we present the results of the last simulation exercise, which deals with the impact of more stringent environmental regulation in the EU. According to a study carried out by J. Poyry for the European Paper Industry, the mills located in the EU will have a competitive disadvantage relative to mills located in countries that refuse to sign the Kyoto protocol. The competitive disadvantage is due to the emission limits and the corresponding purchases of CO_2 allowances that the mills located in the EU have to face in their efforts to comply with the polices on climate change adopted by the EU. The author of the report estimated that the policies on climate change will raise the cost of producing a tonne of paper in the EU by 20 euros. The simulation exercise we carry out for this subsection is meant to study the impact of these polices.

The starting point of the current simulation exercise is the equilibrium associated with the scenario of booming US and EU economies and of pulp producers operating at full capacities, analyzed in Subsection 6.1.2. Starting from the equilibrium of Subsection 6.1.2, we now raise the unit production costs of pulp producers in the EU by 20 euros. Also, in the current simulation exercise we assume that the firms have built up enough capacities so that the capacity constraint is not binding for any one of them. The results of the ninth simulation exercise are presented in Tables 3.28, 3.29, and 3.30. Table 3.28 presents the equilibrium shipments

Table 3.28
Equilibrium Shipments (in million tons)
More Stringent Environmental Regulation in the EU

	Initial Equilibrium	Environmental Regulation
US to US	67.3373	70.1235
US to CAN	0.16664	0.17282
US to EU	0.42909	0.95858
CAN to US	13.8431	16.6287
CAN to CAN	11.2321	11.2383
CAN to EU	0.42679	0.95625
EU to US	8.11826	0
EU to CAN	0.00733	0
EU to EU	21.075	19.4992

As can be seen from Table 3.28, the increase in production costs of 20 euros per tonne of market pulp puts EU pulp producers at a severe competitive disadvantage relative to US and Canadian pulp producers. While the representative US firm and the representative Canadian firm increase their shipments to each market, the representative EU firm ceases to export market pulp to the US and Canadian markets and reduces its shipments to the domestic market by about 7.5%. The more stringent environmental regulation has reversed the trade flows between North America and the EU. The equilibrium quantity and equilibrium price in each market are presented in Table 3.29.

Table 3.29
Equilibrium Quantity (in million tons) and Equilibrium Prices in Local Currencies More Stringent Environmental Regulation in the EU

	Initial Equilibrium		Environmental Regulation	
Market	Quantities	Prices	Quantities	Prices
US	89.2986	US$458.304	86.7522	US$459.449
Canada	11.4061	CAN$672.64	11.4111	CAN$672.565
EU	21.9309	€538.126	21.4141	€543.035

Observe that the price of market pulp rises by 0.2% in the US market and by 0.9% in the EU market, which are positively related to the market shares of the EU firm in these markets. However, in the Canadian market, the price of market pulp practically remains the same. This last result is due to the fact that at the initial equilibrium, the market share of the representative EU firm is negligible. Finally the equilibrium profits are presented in Table 3.30.

Table 3.30
Equilibrium Profits (in millions of national currencies) $\pi_j, j = 0,1,2$
More Stringent Environmental Regulation in the EU

Firms	Initial Equilibrium	Environmental regulation	Percentage Change
US	US$2049.61	US$2220.9	+ 84%
CAN	CAN$2032.59	CAN$2099.2	3.3%
EU	€4256.12	€3612.1	-15.1%

Observe that the profits of the representative EU firm drop by 15.1%. The representative US firm benefits the most. Its profits rise by 8.4%, while the number for the representative Canadian firm is a modest 3.3%.

7. CONCLUDING REMARKS

In this chapter, we carry out a series of simulation exercises. The first two simulation exercises show the reaction of the firms to a shift in demand in the US or/and a shift in demand in the EU. The shift is represented either by a decline in slope of the demand curve or/and a change in its intercept (the choke price). The shift in demand might reflect a robust growth in the American economy. Assuming excess capacities in all three markets, we find that only the prices and the quantities shipped to the markets in which the shift in demand takes place change. We also see how a shift in demand in a market has a positive effect on the performance of producers elsewhere and that a regional demand shift benefits mostly the firm located in that region. The third simulation deals with the scenario of tight markets. In this simulation exercise, we specify the maximum output that each firm can produce. Otherwise, all the assumptions adopted in the preceding simulation exercise are maintained. The capacities of the three firms have been chosen so that in equilibrium the capacity constraint is binding on each firm. The results of the simulation exercise indicate that relative to the scenario under which each firm is allowed to produce any level of output it desires the profits of each firm improve. Furthermore, the prices of market pulp rise in all three markets.

The next five simulation exercises deal with the impact of an appreciation of the Canadian dollar and the euro relative to the US dollar on the behavior of market pulp producers and their profitability. The cost and demand conditions remain the same as in the second and third simulations exercises. The starting point of each simulation exercise in Subsection 6.2 is the equilibrium analyzed in the third simulation exercise. The results of the five simulation exercises – simulation exercise 4 through 8 – indicate that as the appreciation rates rises, the representative Canadian firm's shipments to each market decline. Furthermore, when the appreciation rate is substantial (at or above 6%), the representative Canadian firm and the representative EU firm will concentrate all their activities in the domestic market. Also, under all the scenarios of exchange rate fluctuations considered, the representative Canadian and EU firms operate below capacity while the representative US firm always produces at full capacity (*i.e.* shipping more and more market pulp to the foreign markets, but less and less market pulp to the domestic market). The results of the simulation exercises suggest why governments are often cautious about their appreciating national currencies, especially for the export of raw or semi-processed commodities. The homogenous nature of market pulp and its low price elasticity often require governments to subsidize market pulp producers to ease the effect of rising national currency.

The last simulation exercise examines the impact of more stringent environmental regulation in the EU on the behavior of market pulp producers and market equilibrium. Simulation exercise 9 takes as the starting point the equilibrium associated with the scenario of booming US and EU economies and of pulp producers operating at full capacities. The objective of the simulation exercise is to study the impact of the polices on climate change adopted by the EU on the behaviour of market pulp producers in North America and in the EU. The more stringent environmental regulation in the EU is represented by a rise of 20 euros in the production cost of one tonne of market pulp in the EU. In the simulation exercise, it is assumed that market pulp producers in North America and in the EU have built up sufficient capacities so that they are not operating under any capacity constraint. If markets were tight before the environmental regulation is adopted, they might still be tight after the EU has imposed the stringent environmental regulation on the pulp and paper industry in this region. Under such a scenario, the stringent environmental regulations will not induce any change in the behavior of market pulp producers in the three regions. Thus in the simulation exercise we assume that market pulp producers do not operate under any capacity constraint. The policies on climate change, which are represented by an increase of 20 euros in the production cost of one tonne of market pulp for the EU market pulp producers, put these producers at a severe competitive disadvantage relative to the US and Canadian pulp producers. The policy implication for the EU is profound: the environmental regulation adopted by the EU could reverse the interregional trade flow. The simulation, given that the data are used are real, could certainly give some insights about the magnitude of the impact. The results of the simulation exercise indicate that more stringent environmental regulation in the EU reverses the trade flows between this region and North America. Furthermore, the profits of the representative EU firm drop substantially while the profits of the other two firms both increase. It should be noted that the representative US firm benefits the most. The results of this simulation exercise explain why countries, such as the US and China, refuse to sign the Kyoto protocol.

The model of this chapter can also be simulated to gauge the impact of production cost shocks in all the three regions and how vulnerable each firm is to these shocks. Intuitively, we expect that adverse production cost shocks will induce all the firms to cut back production. However their market shares in each region depend on the relative shocks in the cost of production.

The model of international trade in market pulp that we have built in this chapter can be used for policy analysis. Because of scarce financial support, we were only able to pay for a limited set of data. There are detailed data on market pulp producers at the mill level. However, the cost of obtaining more comprehensive data is beyond the means of a Ph.D. student who would like to carry out research in this area. Certainly, a more detailed and accurate model of the trade in market pulp for North America and the EU can easily be built up from our model if such data are available. However, even with its limitations, our model – we believe – is useful and can be used to analyze some policy questions in the areas of innovation and environmental regulation. Finally, the globalization of markets means that our model of international trade in market pulp should be extended to include the Asian market.

CHAPTER 4

THE NORTH AMERICAN MARKET FOR TISSUE AND TOWEL
AN OLIGOPOLY MODEL WITH PRODUCT DIFFERENTIATION AND ADVERTISING

1. INTRODUCTION

In the preceding chapter, we formulated and analyzed a spatial oligopoly model of international trade in market pulp. In this chapter, we focus on the market for tissue and towel, or more precisely, the market for tissue and towel in North America.

In contrast with market pulp, which is homogenous and internationally traded, tissue and towel are highly differentiated products and, except for a limited number of cases, trade in these products is minor. Tissue and towel manufacturing is a manufacturing sector where brand loyalty and product characteristics - softness, strength, and absorbency - obtained through technology advancement are used to entice consumers, while cost is used to attract commercial and industrial institutions. [Pulp and Paper (1998), Volume 72, Issue Volume 72, Issue 4]

The US tissue business is considered highly competitive yet exhibits a relatively high profit margins and stable growth rates in the paper industry. This $8 billion business has undergone significant consolidations since the 1995 merger of Scott Paper Co. and

Kimberly-Clark Corp. (K-C). In the 1990s, the global tissue market grew at a rate close to 4 percent per year. Almost 60 percent of global tissue consumption is concentrated in the US and Western Europe, where annual *per capita* consumption of tissue products averages almost 50 lbs and about 28 lbs, respectively. While the growth rate steadied during the 1990s and per capita consumption settled at 42.6 lbs (21.3 kg), the present level is so high that many nations may never reach it. In comparison, the per capita consumption forecast for Western Europe is 31.9lbs (14.5 kg) for the year 2005, which is the same as the US per capita figure in 1970. In the US marketplace, the outlook for tissue is positive. [Soile Kilpi & Gary Helik (2004)]

The tissue markets consists of two sectors – one sector serving the at-home needs (consumers); the other sector serving the away–from-home demand (commercial and industrial users). Furthermore, the tissues offered for sale in these markets consist of several key grades: toilet, towel, facial, and napkin grades. A summary of the recent trends in the value and the quantity of the US market is provided in Table 4.1. As this table reveals, the rolled toilet tissue and paper towels show a slight up-trend in both value and quantity since 1990, with the up-trend being more transparent for consumers than for the commercial and industrial sectors. Furthermore, as might be expected, the average price for industrial rolled toilet tissue is somewhat lower that that of the consumer product. In 1998 and for the industrial product (consumer product), the price for single-ply tissues averaged $1,373 ($1,721) per ton, while the price for two-ply (or more) products was estimated at $1,436 ($1,806) per ton. [Pulp and Paper (1998), Volume 72, Issue 4]

Table 4.1
The US Market for Tissue and Paper Towels ($ Millions, Thousands of Tons)

	Rolled Toilet Tissue				Paper Towels			
	Consumer		Industrial		Consumer		Industrial	
	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity
1990	2,434	1,466	896	685	1,498	902	645	927
1995	2,627	1,558	1,023	779	1,637	983	749	1,090
1996	2,537	1,555	1,008	791	1,566	961	730	1,075
1997	2,680	1,607	1,077	795	1,668	978	789	1,103
1998	2,930	1,665	1,152	818	1,798	1,033	866	1,179
1999	2,876	1,641	1,096	795	1,721	1,053	848	1,182

Source: US Department of Commerce, Leading Edge Reports, 1999.

According to "The Leading Edge Group of Business Trend Analysts, Inc. [1999)", several large players dominate the away-from-home market. In this market, Fort Howard enjoys a market share of about one third, while Kimberly Clark holds about one quarter, with the remaining producers accounting for smaller shares. Cost considerations dictate that products sold in this market are made from recycled fibers and on large machines. The consumer market, on the other hand, is characterized by product innovation and higher quality. In 1998, the major brands that dominate the US tissue market were: Procter & Gamble (32 percent of the market), Fort James (17 percent of the market), Kimberly-Clark (22 percent of the market), Georgia Pacific (10 percent of the market), Private label (11 percent of the market). The model we formulate in this chapter deals with the at-home sector. Data for the market shares of the leading brands for both consumer tissues and towels are provided in the Table 4.2.

Table 4.2
Market shares (In terms of revenues) of Leading US Brands in 1998

Rolled Toilet Tissue			Paper Towels		
Brand	Producers	Market Share (Percent)	Brand	Producers	Market Share (Percent)
Charmin	Procter & Gamble	32	Bounty	Procter & Gamble	40
Quilted Northern	Fort James	17	Brawny	Fort James	11
Kleenex Cottonelle	Kimberly-Clark	12	Scot towels	Kimberly-Clark	9
Scott	Kimberly-Clark	10	Sparkle	Georgia-Pacific	6.5
Angel Soft	Georgia-Pacific	10	Kleenex Viva	Kimberly-Clark	4
Private Label		11	Mardi Gras	Fort James	3.5
All Others		8	Private Label		15
			All Others		11

Source: US Department of Commerce, Leading Edge Reports, 1999.

Tissue paper is a consumer product and as such branding is an integral part of its marketing. Hence, in addition to manufacturers' brands, the leading retailers have introduced their own private-label brands. In Western Europe, about half of all consumer tissues are sold under private labels. In some countries like Germany and Switzerland, the share of private labels is already well over 60 percent. In North America and many other regions, the share of private labels is much smaller, though gradually increasing. The consolidation and globalization of retail chains support this development. The trend toward private-label products leads to more price competition among tissue producers and forces them to improve their cost efficiency.

The tissue industry is highly concentrated and integrated with tissue converting. The top five producers account for about half of global tissue capacity. The concentration level is highest in North America, where the top three producers account for some 60 percent of the capacity. Both industry segments (at-home consumer business and those who similarly operate in the away-from-home) are highly concentrated, with just four producers responsible for 80% of each market. In North America and Western Europe, well over 90 percent of the tissue production is integrated with converting. The leading producers are global players, with tissue production and converting in several regions/countries. [Soile Kilpi & Gary Helik (2004)]

The tissue business as a whole, not just the tissue industry, is more consolidated than that of many other paper products. The structure of the industry in many segments of the supply chain is considered oligopolistic, where the top five companies account for 40-50 percent of the business. In the retail trade, however, the consolidation is somewhat smaller, with the top five companies accounting for 30-35 percent of the trade in Western Europe and North America, although this share is continuously increasing. This increasing consolidation adds stability to the business, but at the same time limits the choices the manufacturers of raw materials and machinery. It has been argued that this increased consolidation has benefited the consumers. The more concentrated competition has resulted in better advertising and wider promotional programs, while at the same time the quality has improved. [Soile Kilpi & Gary Helik (2004)]

Prices for commercial and consumer tissue paper products are affected by a number of factors. These include cost of raw material, industry capacity, operating rates, demand, general economic conditions, and product characteristics. While commercial and consumer prices generally tend to move in the same direction over time, the timing and magnitude of price changes in these two markets can vary significantly, in part due to different underlying competitive dynamics. In general, tissue prices are considered less volatile than those of other paper grades - such as pulp prices - but the differences are hard to quantify due to considerable discounting that occurs both at the wholesale and retail levels. [The Leading Edge Group of Business Trend Analysts, Inc. [1999)]

Brand recognition has been achieved through advertising.[15] The advertising strategy has for years primarily focused on issues such as squeezable softness, quilted softness, and cottony softness. Recently, however, a new trend has emerged to emphasize features such as softness, ability to remove bacteria, and a number of medical benefits.

To obtain an adequate picture of the consumer market, it is necessary to model explicitly the qualities chosen and incorporated into its product by a firm as well as its technological innovations. An economic model that embodies such degree of complexity and that also contains a realistic number of firms – rather than the overworked duopoly – rules out the exclusive use of an analytical approach. Our recourse is to pursue the construction of an empirically guided model whose parameters can be numerically derived from quantitative and qualitative data. Insights about the functioning of the market can then be sought by simulative manipulation of the parameters in comparative static exercises. This approach to studying differentiated oligopolistic markets is propounded by Kuenne (1998),[16] who refers to it as "*simulative theorizing,*" and

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15 Marshall (1919) made a quick reference to cooperative and predatory advertising. Early models of advertising appeared in the works of Chamberlin (1933), Buchanan (1942), and Dorfman and Stiener (1954). Nerlove and Arrow (1962) treat advertising as a stock of goodwill or capital good in an *n* firm oligopoly model under perfect information. To these researchers, advertising effects can be cooperative or predatory and advertising cost exhibits decreasing returns. The earliest formal modeling of an oligopoly with advertising that could be predatory or cooperative was of Shubik (1961).

16 According to Kuenne, op cit., pp. 21-23, there are five different approaches proposed in the literature for analyzing product characteristics (qualities). First and foremost among them is the pioneering work of Hotelling (1929). According to the Hotelling approach, one of the most important differentiating characteristics of many products is the location of their producers, sellers, and consumers in geographic space. Consumers must pay to move a product from the seller's location to their own locations. It shows how little is required for product differentiation. Von Thunen (1929), Weber (1909, 1929), Predohl (1928), Palander (1935), Losch (1954), Isard (1956), and Beckmann and Puu (1985) produced landmark scholarship efforts towards the modern spatial economic theory. The more recent approach to the analysis of product characteristics is that of Lancaster (1966, 1972, 1975, 1979, 1991) which treats products as variable bundles of qualities in a linear characteristics space. Here, consumers' preferences are defined over such variables rather than products themselves. Game theory is another approach to the analysis of product characteristics. It is well - known because it is the most powerful and abstract theoretical tool in economics. Tirole (1993, p.207), a leading theorist in game theory and industrial organization, speaks solely about conceptual problems in the field instead of empirical complexity in an operational world. Therefore, it does not contribute to the modeling of the strategic interactive decision making with price and productive characteristics rivalry with a great success. [Kuenne (1998)]

advocates the use of "*rivalrous consonance*" as a concept for analyzing the behavior of firms in a mature oligopolistic market. The chapter represents a first attempt, using these concepts of Kuenne, to model the North American market for tissue and towel in which several firms, each owning several brands, compete for consumers' loyalty through price, quality, and advertising. Relative to the models analyzed in Kuenne, op cit., the present model is more complex and contains more variables. The complexity of the model is not complexity for complexity's own sake, but reflects our desire to capture in a realistic manner, the functioning of a market with a rich structure.

Now in a mature market, when a firm makes a decision, it should take into account other firms' reaction. They live and die in a same market. Their action affects one another. Of course they compete but in a peaceful patterns of competition and cooperation. In this market structure, firms take into account other firms' retaliation in their profit maximization function. For a detailed explanation, we refer the reader to the book "*Price and Non-price Rivalry in Oligopoly,*" written by Kuenne (1998). The mature oligopoly structure, according to Kuenne, does not move toward chaos, which would indicate of game-theoretic properties associated with conflict in an environment of imperfect information. The mature market, instead, tends toward stability in price and non-price variables. The equilibrium in a mature market must then be a Nash equilibrium. In the literature on applied general equilibrium, the values of the parameters of a model are often lifted from the econometric estimates of empirical studies whenever possible. However, estimates of most parameters are not available. We are then forced to calibrate the remaining parameters by assuming the observations in a particular year as the benchmark equilibrium. The benchmark equilibrium then represents the starting point from which we carry out our comparative static exercises. Another terminology for the benchmark equilibrium is the reference equilibrium. We adopt the practice of using the terminology *benchmarking*, as it is used by Kuenne, op cit., to describe an approach to modeling in which the industry averages for the qualities of the brands serve as the benchmark for a firm's product demand. If the qualities of a brand owned by a firm deviate from the benchmark values, the demand for the brand will change, either in a positive or negative manner, depending on the coefficient that characterizes the impact of this quality deviation.

In this study, we model only one facet of advertising – informational advertising. The expenditure on informational advertising on a brand, according to Kuenne (1998, Chapter 12), is intended to affect the demand for the brands, not the supply conditions. Informational advertising aims at enhancing sales without causing movements of brands in the virtual product space. In other words, informational advertising brings publicity in order to induce consumers to accept the existing product with its existing quality and price. This can mostly be related to the brands that are weakly differentiated in the consumer's mind and for which, tacit collusion is not practiced. Following Kuenne, we do not treat informational advertising expenditure in the manner of firm policies by assuming MR=MC. Instead, we follow the empirical studies, which assume that the firms tend to determine advertising expenditure as a percentage of sales. Also, we adjust the advertising expenditure by the brand's price differentials.

The chapter is organized as follows. In Section 2, the model is laid out. In Section 3, the Nash equilibrium for the oligopoly model with price and non-price competition is defined. The first-order conditions, which characterize the best response of each firm to the strategies chosen by the other firms, are also derived. In Section 4, we use the data for the year 1998 to calibrate the model of the North American tissue market. The benchmark equilibrium is studied in some detail in Section 5. In Section 6, we carry out our simulative theorizing with the help of two simulation exercises – one dealing with the impact of the rise in qualities of a brand; the other dealing with the impact of a decrease in the production cost of a brand on the market. The two simulation exercises are intended to study how innovation might affect the strategic behavior of the players in the North American tissue market. Section 7 contains some concluding remarks.

2. THE MODEL

To formulate and analyze an oligopoly model with product differentiation that reflects the structure and functioning of the North American tissue and towel industry in a more realistic way, we adopt the approach propounded by Kuenne (1998).

The main qualities of tissue are: basic weight, absorbency, softness, thickness (bulk), tensile strength, brightness, stretch, and appearance (stylishness). However, the most important qualities chosen by tissue manufacturers for non-price competition are strength, softness, absorbency, and appearance. The strength and absorbency of a tissue can be physically measured. Softness involves tactile sensation and is more subjective. One method for measuring softness is Hand Feel (HF), according to which softness is assessed on a scale from 2 to 6. High-quality bathroom tissue has an HF score of 6, while an ordinary tissue with a high recycle fiber content has an HF score of 2. Appearance involves factors such as roll diameter, the cut of the roll edges, perforation, the pattern printed on the paper, etc., are the most subjective. If we are willing to accept the scaling technique proposed by Kuenne, op. cit., then appearance can also be assessed on a numerical scale. However, because tissue manufacturers often stress strength, softness, and absorbency in the advertising of their products, we shall ignore appearance in our modeling of non-price competition and deal only with strength, softness, and absorbency.

Let F be the set of firms in the consumer tissue market and I_f be the set of brands produced by firm $f, f \in F$. We shall assume that $I_f \cap I_{f'} = \phi$ if $f \neq f'$. The totality of brands offered for sale on the market is thus $I = \bigcup_{f \in F} I_f$. For each $i \in I$, let x_{i1}, x_{i2}, and x_{i3} denote, respectively, the strength, the softness, and the absorbency incorporated into brand i. An important component of non-price competition is advertising. We shall confine our analysis to informational advertising and let z_i denote the advertising expenditure made to educate consumers about the qualities of brand i. The list $\left((x_{ij})_{j=1}^{3}, z_i\right)$ represents the non-price competition measures adopted for brand i. Finally, let p_i be the price set by the firm that owns brand i. The array $\left(p_i, (x_{ij})_{j=1}^{3}, z_i\right)_{i \in I_f}$ thus represents a strategy for firm $f, f \in F$. Given a combination of strategies $\left(\left(p_i, (x_{ij})_{j=1}^{3}, z_i\right)_{i \in I_f}\right)_{f \in F}$, we shall assume that the demand for brand i product is given by

$$(1) \quad q_i\left(\left(\left(p_{i'},\left(x_{i'j}\right)_{j=1}^{3},z_{i'}\right)_{i'\in I_f}\right)_{f\in F}\right)=$$

$$a_i - b_{ii}p_i + \sum\nolimits_{i'\in I,i'\neq i} b_{ii'}p_{i'} + \sum\nolimits_{j=1,2,3}(\alpha_{ij}(x_{ij}-\mu_j) - \beta_{ij}(x_{ij}-\mu_j)^2) + \psi_i\,,$$

where $a_i, b_{ii}, b_{ii'}, \alpha_{ij}, \beta_{ij}$ are positive parameters, $i \in I, i' \in I, j = 1,2,3$.

In (1), μ_1, μ_2, and μ_3 represents, respectively, the industry's weighted averages of the strength, the softness, and the absorbency of the differentiated products offered on the market, with the weight of a firm being the share in the industry's total of its sales. It is assumed that in making its price and non-price decisions, firm f takes as given the values of μ_1, μ_2, and μ_3.

As specified by (1), q_i, the demand for brand i, depends linearly on its own price and the prices of its competitors. This specification also incorporates consumer "*benchmarking*" as an important assumption about economic reality. For each j = 1,2,3, the expression $\alpha_{ij}\left(x_{ij}-\mu_j\right)-\beta_{ij}\left(x_{ij}-\mu_j\right)^2$ embodies the assumption that consumers are only concerned with the deviation from the norm of the *jth* quality of brand *i*. The quadratic term $\beta_{ij}\left(x_{ij}-\mu_j\right)^2$ represents the loss in sale suffered by brand *i* as its quality x_{ij} moves away from the norm μ_j. This term reinforces the desire of the firm that owns this brand to move the brand closer to the benchmark. As x_{ij} drops below μ_j, the demand for brand *i* declines at an increasing rate. However, as x_{ij} rises above μ_j, there are diminishing returns to the demand for brand *i*. For each brand, the departure from the norm for each quality thus has an asymmetrical effect on the demand for the brand. The industry standards μ_j, j= 1,2,3, should be treated differently according to whether the model deals with the short run or the long run. In the long run, in which sufficient time has passed to permit consumers to absorb changes in standards, μ_j, j=1,2,3, should be considered endogenous and given by the sales-weighted averages of the qualities of all the brands offered for sale by the firms in the industry. In the short run, when consumers have not had sufficient time to become aware of the changes in standards, the standards should be set exogenously at their initial values or interpreted as being imposed by competitors from without the model.

The term ψ_i represents the net impact on the demand for brand i, as a function of the advertising expenditures made by all the firms in the industry. We shall assume that

(2) $$\psi_i = \sum_{i' \in I} z_i [\sigma_{ii'} - \tau_{ii'} z_i] e^{-kd(x_i, x_{i'})} - \sum_{i' \in I} z_{i'} [\sigma_{i'i} - \tau_{i'i} z_{i'}] e^{-kd(x_{i'}, x_i)},$$

In (2), $\sigma_{ii'}, \tau_{ii'}, (i \in I, i' \in \mathrm{I})$, and k are positive constants, while

(3) $$d(x_i, x_{i'}) = \sqrt{\sum_{j=1}^{3} (x_{ij} - x_{i'j})^2},$$

represents the distance – in the product space – between brand i and brand i'. Observe that the expression $z_i [\sigma_{ii'} - \tau_{ii'} z_i] e^{-kd(x_i, x_{i'})}$ represents the shift away from the demand for brand i' to the demand for brand i. This shift is the product of two terms. The first term, namely $z_i [\sigma_{ii'} - \tau_{ii'} z_i]$, is a quadratic function of the advertising expenditure spent to promote brand i. The second term, namely $e^{-kd(x_i, x_{i'})}$, depends on the distance between brand i and brand i'. This term declines exponentially at rate k when the distance increases. Similarly, the expression $z_{i'}\left[\sigma_{i'i} - \tau_{i'i} z_{i'}\right] e^{-kd(x_{i'}, x_i)}$ represents the shift demand away from brand *i* in favor of brand j'.

If we follow conventional economic theory, then the advertising expenditure z_i should be considered as a decision variable of firm that owns brand *i*. However, it is a stylized fact that advertising expenditures are largely a given fraction of sales. Hence following Kuenne (1998, Chapter12), we shall assume that the advertising expenditure made by a firm on brands it produces is equal to a certain percentage of the revenue made on this brand, modified by the differentials between the price of this brand and the prices of the other brands. [17]More specifically, we assume that

$$(4) \qquad z_i = \left(\phi_i + \sum_{i' \in I} \omega_{ii'} \left[\frac{p_i}{p_{i'}} - 1 \right] \right) p_i q_i, \qquad (i \in I).$$

In (4), $\phi_i, \omega_{ii'}$ are positive constants.

For brand *i*, the total cost of producing y_i units of output at qualities $\left(x_{ij}\right)_{j=1}^{3}$ is assumed to be given by

$$(5) \quad c_i\left(y_i, \left(x_{ij}\right)_{j=1}^{3}\right) = \bar{\gamma}_i + \sum_{j=1}^{3}\left[\bar{\xi}_{ij} x_{ij} + \bar{\eta}_{ij} x_{ij}^2\right] + \left(\gamma_i + \sum_{j=1}^{3}\left[\xi_{ij} x_{ij} + \eta_{ij} x_{ij}^2\right]\right)\left(y_i + \varepsilon_i y_i^2\right),$$

[17] Kuenne (1998) observes the plausibility of the assumption of advertising expenditure as a fixed proportion of sales revenue as an industrial practice. He indicates that usually advertising accounts for about 1-3% of total revenue. In this chapter, we follow Kuenne and, therefore, adopt the same assumption. In addition, we assume a second component of advertising expenditure, which would take into account the impact of the price differentials among the brands. Alternatively, we can abandon these two specifications and make the advertising expenditure endogenous. Our current assumption on advertising expenditure makes the model more complicated. However, it embodies a practice of the industry in a more realistic manner.

In (5), the expression $\bar{\gamma}_i + \sum_{j=1}^{3}\left[\bar{\xi}_{ij}x_{ij} + \bar{\eta}_{ij}x_{ij}^2\right]$ represents the fixed cost after the qualities x_{ij}, $j = 1,2,3,$, have been chosen, while the expression $\left(\gamma_i + \sum_{j=1}^{3}\left[\xi_{ij}x_{ij} + \eta_{ij}x_{ij}^2\right]\right)\left(y_i + \varepsilon_i y_i^2\right)$ represents the total variable cost. Here $\bar{\gamma}_i, \bar{\xi}_{ij}, \bar{\eta}_{ij}, \gamma_i, \xi_{ij}, \eta_{ij}, \varepsilon_i$ are all positive parameters. Observe that the total variable cost is a quadratic function of output and that it is proportional to a factor, namely $\left(\gamma_i + \sum_{j=1}^{3}\left[\xi_{ij}x_{ij} + \eta_{ij}x_{ij}^2\right]\right)$, which is allowed to depend upon the qualities chosen. We shall assume that the cost function (5) is only defined for the values of y_i and x_{ij} that satisfy the following constraints:

$$(6) \qquad 0 \le y_i \le \bar{y}_i, \qquad (i \in I)$$

$$(7) \qquad 0 \le x_{ij} \le \bar{x}_{ij}, \qquad (i \in I, j = 1,2,3)$$

Here $\bar{y}_i$ represents the capacity of brand i and $\bar{x}_{ij}$ represents the upper limit on the jth quality that can be incorporated into brand i, given the current technology. Through capital expenditures, the firm can raise $\bar{y}_i$. By engaging in an R&D program, the firm might be able to raise the value of $\bar{x}_{ij}$ and/or lower the values of the parameters $\bar{\gamma}_i, \bar{\xi}_{ij}, \bar{\eta}_{ij}, \gamma_i, \xi_{ij}, \eta_{ij}, \varepsilon_i$.

Let $\left(\left(p_i,\left(x_{ij}\right)_{j=1}^{3},z_i\right)_{i\in I_f}\right)_{f\in F}$ be a combination of strategies – for price and non-price competition – chosen by all the firms in the industry. Under such a combination of strategies, the profit generated by brand i is

$$\begin{aligned}(8)\qquad \pi_i\left(\left(\left(p_{i'},\left(x_{i'j}\right)_{j=1}^{3},z_{i'}\right)_{i'\in I_f}\right)_{f\in F}\right) &= p_i q_i\left(\left(\left(p_{i'},\left(x_{i'j}\right)_{j=1}^{3},z_{i'}\right)_{i'\in I_f}\right)_{f\in F}\right)\\ &\quad - c_i\left(q_i\left(\left(\left(p_{i'},\left(x_{i'j}\right)_{j=1}^{3},z_{i'}\right)_{i'\in I_f}\right)_{f\in F}\right),\left(x_{ij}\right)_{j=1}^{3}\right) - z_i\,,\end{aligned}$$

$$(i\in I)$$

The total profits made by firm f is then given by

$$(9)\qquad \Pi_f\left(\left(\left(p_{i'},\left(x_{i'j}\right)_{j=1}^{3},z_{i'}\right)_{i'\in I_f}\right)_{f\in F}\right)=\sum_{i\in I_f}\pi_i\left(\left(\left(p_{i'},\left(x_{i'j}\right)_{j=1}^{3},z_{i'}\right)_{i'\in I_f}\right)_{f\in F}\right),$$

Now Kuenne (1988, Chapter 3) argues that in a "*mature oligopolistic industry*" the complexity of structure and functioning of the industry is best encoded in a power structure matrix that captures the binary relations between each pair of firms. According to this researcher, in a mature oligopoly there develops, largely out of self-protective motives, a communitarian mixture of competition and tacit collusion.[18] The power structure of the industry can be characterized by a non-symmetric matrix, say $\left(\theta_{ff'}\right)_{f\in F, f'\in F}$, whose elements are called "*consonant coefficients.*" The consonant

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[18] This phrase is borrowed from Kuenne (1998). The idea that this phrase tries to describe is embodied in the extended profit function, which includes the firm's profits as well as the profits of the other firms.

coefficient $\theta_{ff'}$ is an index of deference that firm *f* accords to firm f' when firm *f* makes its price and non-price competition decisions. This coefficient reflects firm *f's* view on the capacity of firm f' to punish firm *f* for the initiatives that firm *f* might undertake and that might result in losses for firm f'. Note that in general $\theta_{ff'} \neq \theta_{f'f}$. Kuenne, op. cit., suggests that instead of maximizing its own profit function, namely (9), firm *f* should maximize the following *"extend-profit function:"*

$$\text{(10)} \qquad \Pi_f^e\left(\left(\left(p_{i'}, \left(x_{i'j}\right)_{j=1}^{3}, z_{i'}\right)_{i' \in I_f}\right)_{f \in F}\right) = \sum_{f' \in F} \theta_{ff'} \Pi_f\left(\left(\left(p_{i'}, \left(x_{i'j}\right)_{j=1}^{3}, z_{i'}\right)_{i' \in I_f}\right)_{f \in F}\right),$$

Of course, in maximizing (10), firm *f* should take $\mu_j, j = 1,2,3$, as well as the strategies of all the other firms as given. Because of our assumption of advertising expenditure as a given percentage of revenue for each firm, the strategy chosen by firm *i* must be constrained to satisfy (4).

Without any loss in generality, we can set $\theta_{ff} = 1, f \in I$, in the extended-profit function for firm *f*. If $\theta_{ff'} < 0, f \neq f'$, then firm *f* takes a predatory stance against firm *f'* in its price and non-price decisions. Such a stance might be reasonable in the short run when the industry is still evolving. However, in a mature industry, a negative value of $\theta_{ff'}$ cannot be justified. On the other hand, if $\theta_{ff'} > 1$, then firm *f* values the profit of firm *f'* strictly more than its own profit, which is also unreasonable. Hence in what follows, we shall constrain $\theta_{ff'}$ to belong to the unit interval [0,1]. In the special case of $\theta_{ff'} = 0, f \neq f'$, each firm maximizes its own profit without any heed for other firms; the model is reduced to the conventional Cournot solution. In the extreme case of $\theta_{ff'} = 1, f \in I, f' \in I$, each firm treats the profits of the other firms as its own. In more realistic situations, we should expect that $0 < \theta_{ff'} < 1, f \neq f'$, and this is the approach we adopt in what follows.

3. THE NASH QUILIBRIUM AND ITS CHARACTERIZATION

DEFINITION: Suppose that the industry standards μ_1, μ_2, and μ_3 are given. A combination of strategies $\left(\left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i \in I_f}\right)_{f \in F}$ is a Nash equilibrium under the industry standards μ_1, μ_2, and μ_3 if for each firm $f \in F$, the strategy $\left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i \in I_f}$ solves the following maximization problem:

$$(11) \qquad \max_{\left(p_i, \left(x_{ij}\right)_{j=1}^3, z_i\right)_{i \in I_f}} \Pi_f^e\left(\left(p_i, \left(x_{ij}\right)_{j=1}^3, z_i\right)_{i \in I_f}, \left(\left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i \in I_{f'}}\right)_{f' \in F, f' \neq f}\right),$$

subject to the following constraints:

$$(12) \qquad z_i = \left(\phi_i + \sum_{i' \in I} \omega_{ii'} \left[\frac{p_{i'}}{p_i} - 1\right]\right) \times p_i q_i \left(\left(p_{i'}, \left(x_{i'j}\right)_{j=1}^3, z_{i'}\right)_{i' \in I_f}, \left(\left(p_{i'}^*, \left(x_{i'j}^*\right)_{j=1}^3, z_{i'}^*\right)_{i' \in I_{f'}}\right)_{f' \in F, f' \neq f}\right),$$

$$(13) \qquad 0 \leq q_i\left(\left(p_{i'}, \left(x_{i'j}\right)_{j=1}^3, z_{i'}\right)_{i' \in I_f}, \left(\left(p_{i'}^*, \left(x_{i'j}^*\right)_{j=1}^3, z_{i'}^*\right)_{i' \in I_{f'}}\right)_{f' \in F, f' \neq f}\right) \leq \bar{y}_i,$$

$$(14) \qquad 0 \leq x_{ij} \leq \bar{x}_{ij}, j = 1,2,3,$$

Such equilibrium is called a long-run Nash equilibrium if the following additional conditions are satisfied:

$$\mu_j = \sum_{i \in I} \frac{p_i^* q_i^*}{\sum_{i' \in I} p_{i'}^* q_{i'}^*} x_{ij}^*, \qquad (j = 1,2,3) \tag{15}$$

where

$$q_i^* = q_i\left(\left(\left(p_{i'}^*, \left(x_{i'j}^*\right)_{j=1}^3, z_{i'}^*\right)_{i' \in I_f}\right)_{f \in F}\right)$$

is the demand for brand i under the combination of strategies $\left(\left(p_{i'}^*, \left(x_{i'j}^*\right)_{j=1}^3, z_i^*\right)_{i' \in I_f}\right)_{f \in F}$.

Recall that (12) is the constraint that the advertising expenditure of each brand is equal to a certain percentage of its revenue. As for (13) and (14), they represent, respectively, the capacity constraint and the constraint on qualities imposed on each brand by its own current technology. The use of Nash equilibrium as the solution concept for a mature oligopolistic market can be justified by the well-known convergence argument in economic theory. More specifically, after sufficient time has passed and the market has become stable, the strategy chosen by any firm should be a best response for this firm to the strategies chosen by all the other firms. In this sense, the combination of strategies chosen by all the firms in a mature oilgopolistic market must constitute a Nash equilibrium. [19]

The Lagrangian for the maximization problem constituted by (11) through (14) is

[19] The equilibrium can be interpreted as long run equilibrium because the market is a mature market. This equilibrium prevails until a new technology is introduced, which will disturb the old equilibrium and propel the system to the new equilibrium that is associated with the new technology.

$$\mathsf{L}_f = \Pi_f^e\left(\left(p_i, \left(x_{ij}\right)_{j=1}^3, z_i\right)_{i\in I_f}, \left(\left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i\in I_{f'}}\right)_{f'\in F, f'\neq f}\right)$$

$$-\sum_{i\in I_f}\lambda_i\left[\begin{array}{l} z_i - \left(\phi_i + \sum_{i'\in I}\omega_{ii'}\left(\frac{p_i}{p_{i'}}-1\right)\right)\times \\ p_i q_i\left(\left(p_i, \left(x_{ij}\right)_{j=1}^3, z_i\right)_{i\in I_f}, \left(\left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i\in I_{f'}}\right)_{f'\in F, f'\neq f}\right)\end{array}\right]$$

$$-\sum_{i\in I_f}\kappa_i\left[q_i\left(\left(p_i, \left(x_{ij}\right)_{j=1}^3, z_i\right)_{i\in I_f}, \left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i\in I_f, f'\neq f}\right) - \bar{y}_i\right]$$

$$-\sum_{i\in I_f}\sum_{j=1}^3 v_{ij}\left[x - \bar{x}_{ij}\right],$$

The following first-order conditions characterize the best response of firm f:

$$(16)\quad \frac{\partial \mathsf{L}_f}{\partial p_i} = \frac{\partial}{\partial p_i}\Pi_f^e\left(\left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i\in I_f}, \left(\left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i\in I_{f'}}\right)_{f'\in F, f'\neq f}\right)$$

$$-\lambda_i\left[\begin{array}{l} -\left(\sum_{i'\in I, i'\neq i}\omega_{ii'}\left(\frac{1}{p_{i'}}-1\right)\right)p_i q_i\left(\left(p_i, \left(x_{ij}\right)_{j=1}^3, z_i\right)_{i\in I_f}, \left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i\in I_f, f'\neq f}\right) \\ -\left(\phi_i + \sum_{i'\in I}\omega_{ii'}\left(\frac{p_i}{p_{i'}}-1\right)\right)\left(q_i\left(\left(p_i, \left(x_{ij}\right)_{j=1}^3, z_i\right)_{i\in I_f}, \left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i\in I_f, f'\neq f}\right) - b_{ii}p_i^*\right)\end{array}\right.$$

$$+\kappa_i b_{ii} = 0, \qquad (i\in I_f)$$

$$(17)\quad \frac{\partial \mathsf{L}_f}{\partial x_{ij}} = \frac{\partial}{\partial x_{ij}}\Pi_f^e\left(\left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i\in I_f}, \left(\left(p_i^*, \left(x_{ij}^*\right)_{j=1}^3, z_i^*\right)_{i\in I_{f'}}\right)_{f'\in F, f'\neq f}\right)$$

$$-\lambda_i\left[-\left(\phi_i+\sum_{i'\in I}\omega_{ii'}(\frac{p_i}{p_{i'}}-1)\right)\left(p_i^*\frac{\partial q_i}{\partial x_{ij}}\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_f},\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_{f'},f'\neq f}\right)\right)\right]$$

$$\kappa_i\frac{\partial q_i}{\partial x_{ij}}\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_f},\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_{f'},f'\neq f}\right)-\nu_{ij}\,,\qquad (i\in I_f,\,j=1,2,3)$$

$$(18)\quad \frac{\partial L_f}{\partial z_i}=\frac{\partial}{\partial z_i}\Pi_f^e\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_f},\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_{f'}}\right)_{f'\in F,f'\neq f}\right)$$

$$-\lambda_i\left[1-\left(\phi_i+\sum_{i'\in I}\omega_{ii'}(\frac{p_i}{p_{i'}}-1)\right)\left(p_i^*\frac{\partial q_i}{\partial z_i}\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_f},\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_{f'},f'\neq f}\right)\right)\right]$$
$$-\kappa_i\frac{\partial q_i}{\partial z_i}\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_f},\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_{f'},f'\neq f}\right)=0\,,\qquad (i\in I_f)$$

$$(19)\; z_i^*-\left(\phi_i+\sum_{i'\in I}\omega_{ii'}\left[\frac{p_i^*}{p_{i'}^*}-1\right]\right)p_i^*q_i\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_f},\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_{f'}}\right)_{f'\in F,f'\neq f}\right)=0,$$

$$(i\in I_f)$$

$$(20)\quad \kappa_i\geq 0,\qquad \kappa_i\left[q_i\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_f},\left(\left(p_i^*,\left(x_{ij}^*\right)_{j=1}^3,z_i^*\right)_{i\in I_{f'}}\right)_{f'\in F,f'\neq f}\right)-\bar{y}_i\right]=0,\quad (i\in I_f)$$

$$(21)\quad \nu_{ij}\geq 0,\qquad \nu_{ij}\left[x_{ij}^*-\bar{x}_{ij}\right]=0,\qquad (i\in I_f,\,j=1,2,3)$$

In the following section, we shall assign specific numerical values to the parameters of the model then compute the Nash equilibrium that corresponds to each set of numerical values thus assigned. The values of these parameters will be chosen to reflect as much as possible the structure and functioning of the North American tissue and towel industry. To obtain insights on the structure and functioning of the industry, the set of numerical values for the parameters of the model are next allowed to vary and the Nash equilibria corresponding to these sets of numerical values are analyzed in detail.

4. CALIBRATION OF THE NORTH AMERICAN TISSUE MARKET

In this section, the oligopolistic model for the North American market of tissues is calibrated. The raw data we use to calibrate the model are presented in Table 3. The table presents the data we have gathered for 10 brands of tissue of the following four major tissue and towel companies: Proctor and Gamble (P&G), Georgia Pacific, Kimberly Clark, and Fort James.[20] Table 4.3 shows different qualities, such as the level of thickness, softness, and strength for different brands. The table also shows the price range per roll of tissue, sales in 1998 dollars as well as the advertising cost in 1998 dollars for each brand.

[20] The 10 brands that we have chosen belong to the four largest North American tissue producers. Firm size is the reason why they are selected.

Table 4.3
Raw Data on Brand Characteristics

Firm's Name	Brand	A	p_i	x_{i1}	x_{i2}	x_{i3}	p_iq_i	z_i
P & G	Charming Ultra	4.5	$0.66	5	5	4	1,189	26,737
P & G	Charming Plus	3.9	$0.34	4	5	2		1,103
P & G	Charming	3.3	$0.65	4	5	2		4,328
Georgia Pacific	Coronet	4.1	$0.38	3	4	5		1,629
Georgia Pacific	Angel Soft	3.5	$0.24	3	4	2	371.6	4,732
Georgia Pacific	Soft & Gentle 2-Ply	3.5	$0.53	2	4	4	390.8	0
Georgia Pacific	Soft & Gentle 1-Ply	2.5	$0.67	1	3	2	307.1	0
Kimberly Clark	Cottonelle	3.2	$0.63	4	4	2	445.9	20,201
Kimberly Clark	Scott (Regular)	3	$0.68	2	3	3	371.6	1,948
Fort James	Quilted Northern	2.8	$0.58	2	3	2	631.7	6,158

Source: The US Market For Household Paper Products; The Leading Edge Group of Business Trend Analysts, Inc., (May 1999)

Notes:

1. A is overall rating (5 is the best); p_i is the price range per roll where there are 1 to 12 rolls per pack; x_{i1} is softness; x_{i2} is absorbency; x_{i3} is strength; p_iq_i is sales (in $\$10^6$) in 1998; z_i is Advertising (in $\$10^3$) in 1998.
2. The number 1,189 represents the combined sales of three brands (Charming Ultra, Charming Plus, and Charming) for P&G.
3. The total retail sales in 1998 were $3,176 million. The values reported for the sales are based on the share of each product. The reported shares, according to Leading Edge Reports, are: Charming (32 percent), Quilted Northern (17 percent), Kleenex Cottonelle (12 percent), Scott (10 percent), Angel Soft (10 percent), Private Label (11 percent), and All Others (8 percent).

There are several observations that we can make about the data presented in Table 4.3: Some firms, such as P&G, Georgia Pacific, and Kimberly Clark, offer more than one brand. Furthermore, and this is even more striking, a firm might offer a brand that is uniformly inferior in qualities to all the other brands that it offers. This is the case of Georgia Pacific, which offers four brands – Coronet, Angel Soft, Soft and Gentle 2-ply, and Soft and Gentle 1-Ply – with Soft and Gentle 1-Ply being of a lower quality than all the other three brand in terms of softness, absorbency, and strength. It seems that *brand proliferation* is also a strategy of competition. A possible justification for such a strategy is that because the various brands are differentiated products they attract different types of consumers who differ in preferences and incomes. Also, a brand might possess characteristics other than softness, absorbency, or strength, and these characteristics are not captured in Table 4.3. In the theoretical model we formulate in the preceding section such characteristics might be captured in the own-price and cross-price parameters $a_i, b_{ii'}$. Another possible justification is that the different brands have different production costs, which makes it possible for inferior brands to compete against much superior brands in the market. Insights into the working of a complex market, such as the North American market for tissues with multidimensional strategic interactions among three or more firms cannot be obtained with the help of the analytical approach. This is the justification for the simulative theorizing exercises we carry out in Section 6.

In the model we calibrate, the qualities of each brand are taken as given, i.e., they are not considered as decision variables by the firm that owns the brand. The calibrated model is thus of a short-term nature. In the long term, firms can carry out R&D to improve the qualities of their brands or to reduce production costs. Hence, the total cost function of each brand depends only on the output of this brand, which due to lack of data, is assumed to be quadratic in output, say $c_i(y_i) = \bar{\gamma}_i + \gamma_{i1} y_i + \frac{\gamma_{i2}}{2} y_i^2$, where the sum of the second and the third terms gives us the total variable cost.

As shown in Table 4.3, the combined revenues that Proctor and Gamble made from the three brands it owned, namely Charming Ultra, Charming Plus, and Charming, were 1.189 billion dollars in 1998. Because the breakdown for each brand is not available, we make the simple assumption that the revenues made by each brand were one third of the total. Thus dividing 1.189 billion dollars by 3, we obtain the revenues made by each brand in 1998. The sales figures for the two brands Soft & Gentle 1-Ply and Soft & Gentle 2-Ply are obtained by multiplying their market shares with the combined sales figures of all the brands in the market. It should be noted that in our calibration, we do not estimate fixed cost, as we do not need fixed costs for our analysis. We divide the total sales in dollar value of each brand by its price to obtain its output. Using "The US Market For Household Paper Products, 1999 Report,[21] we compute labor cost and material cost as 7 percent and 44 percent of total revenues, respectively. The sum of these costs gives us the total variable cost for each brand. Where advertising data is missing, we approximate it as 1 percent of total sales. The augmented data are shown in the following table:

Table 4.4
Augmented Raw Data on Brand Characteristics

Brand	x_{i1}	x_{i2}	x_{i3}	p_i	p_iq_i	q_i	R	L	z_i
Charming Ultra	5	5	4	0.66	396.3	600.5	182.3	31.3	26.7
Charming Plus	4	5	2	0.34	396.3	1165.6	182.3	31.3	1.1
Charming	4	5	2	0.65	396.3	609.7	182.3	31.3	4.3
Coronet	3	4	5	0.38	162.9	428.7	74.9	12.8	1.6
Angel Soft	3	4	2	0.24	371.6	1548.3	170.9	29.3	4.7
Soft & Gentle 2-Ply	2	4	4	0.53	390.8	737.3	179.7	30.8	3.9
Soft & Gentle 1-Ply	1	3	2	0.67	307.1	458.3	141.2	24.2	3
Cottonelle	4	4	2	0.63	445.9	707.7	205.1	35.2	20.2
Scott (Regular)	2	3	3	0.68	371.6	546.4	170.9	29.3	1.9
Quilted Northern	2	3	2	0.58	631.7	1089.1	290.5	49.9	6.1

Notes:

x_{i1} is softness; x_{i2} is absorbency; x_{i3} is strength; p_i is the price range per roll in \$ where there are 1 to 12 rolls per pack; p_iq_i is sales (in \$$10^6$) in 1998; q_i is Output per Brand (in 10^6 rolls); R is Raw Material Cost (in \$$10^8$); L is labor cost (in 10^6); and z_i is Advertising Cost (in \$$10^6$).

In the above table, the first three numbers on each row represent the quality data associated with softness, absorbency, and strength for each brand. The fourth number is the price per roll of tissue. The fifth number is the total sales in 1998 (in millions of US dollars). The sixth number shows the output per brand. The seventh and the eight

[21] Due to lack of data for simulation purpose, University of Ottawa purchased a report on "The US Market For Household Paper Products; The Leading Edge Group of Business Trend Analysts, Inc., May 1999" which provided us with values for some of our variables. However, since the required complete data set for my model simulation was very expensive and therefore, was beyond the allowable University budget, we had to calibrate the model in order to estimate the closest approximate for the parameters.

numbers represent raw material and labor costs, respectively. The last number stands for the advertising costs per brand.

Since the parameters amount to a few hundred, it is not feasible to estimate them by using econometric techniques. In addition, lack of data aggravates the problem. Hence a calibration approach is used to calculate the parameters of our model. In the calibration, the quantities are expressed in millions of rolls and prices and costs in millions of US dollars.

Using the data on variable costs and outputs for the 10 brands in Table 4.4, we fit a quadratic function that approximate as much as possible these data points. All the brands, except for brand 5, have the right signs for γ_{i1} and γ_{i2}. We fix this problem by changing the fitted coefficients for brand 5 slightly and in an arbitrary manner to obtain the correct sign (+). The end result of the calibration of the cost functions is given in Table 4.5.

Table 4.5
The Parameters of the Cost Functions for
Each Brand: $c_i(y_i) = \bar{\gamma}_i + \gamma_{i1} y_i + \frac{\gamma_{i2}}{2} y_i^2$

Brand	γ_{i1}	γ_{i2}
Charming Ultra	0.285957	0.00023
Charming Plus	0.047799	0.00023
Charming	0.279494	0.00023
Coronet	0.155004	0.00023
Angel Soft	0.111367	0.00023
Soft & Gentle 2-Ply	0.199984	0.00023
Soft & Gentle 1-Ply	0.307866	0.00023
Cottonelle	0.257322	0.00023
Scott (Regular)	0.303017	0.00023
Quilted Northern	0.186055	0.00023

The values of $\sigma_{ii'}$ and $\tau_{ii'}$, the parameters that characterize the impact of the advertising expenditures of each of the brands on demand of a particular brand are given in Tables 4.6 and 5.7. These numbers are chosen as in Kuenne (1998) and judged to be reasonable although somewhat arbitrary.

Table 4.6

Values of Advertising Parameters ($\sigma_{ii'}$, $i, i'=1,\ldots,10$)

Brand	1	2	3	4	5	6	7	8	9	10
Charming Ultra (1)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Charming Plus (2)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Charming (3)	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Coronet (4)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Angel Soft (5)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Soft & Gentle 2-Ply (6)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Soft & Gentle 1-Ply (7)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Cottonelle (8)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Scott-Regular (9)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Quilted Northern (10)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

Table 4.7

Values Of Advertising Parameters ($\tau_{ii'}$, $i, i'=1,\ldots,10$)

Brand	1	2	3	4	5	6	7	8	9	10
Charming Ultra (1)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Charming Plus (2)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Charming (3)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Coronet (4)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Angel Soft (5)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Soft & Gentle 2-Ply (6)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Soft & Gentle 1-Ply (7)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cottonelle (8)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Scott-Regular (9)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Quilted Northern (10)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

The values of α_{ij} and β_{ij}, the parameters that characterize the impact of the qualities of a brand on its own demand are given in the Tables 4.8 and 4.9. Note that we have assumed $\alpha_{i1} = \alpha_{i2} = \alpha_{i3}$ and $\beta_{i1} = \beta_{i2} = \beta_{i3} i$, i.e., the qualities of all the brands are treated as being symmetric.

Table 4.8

Quality Parameters (α_{ij}, i= 1,...,10, j=1,2,3)

Brand	α_{i1}	α_{i2}	α_{i3}
Charming Ultra (1)	5.65664	5.65664	5.65664
Charming Plus (2)	56.9467	56.9467	56.9467
Charming (3)	5.3395	5.3395	5.3395
Coronet (4)	7.03654	7.03654	7.03654
Angel Soft (5)	34.2322	34.2322	34.2322
Soft & Gentle 2-Ply (6)	9.38877	9.38877	9.38877
Soft & Gentle 1-Ply (7)	3.58684	3.58684	3.58684
Cottonelle (8)	7.16309	7.16309	7.16309
Scott-Regular (9)	4.39382	4.39382	4.39382
Quilted Northern (10)	15.6033	15.6033	15.6033

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

Table 4. 9

Quality Parameters (β_{ij}, i= 1,...,10, j=1,2,3)

Brand	β_{i1}	β_{i2}	β_{i3}
Charming Ultra (1)	0.056556	0.056556	0.056556
Charming Plus (2)	0.569467	0.569467	0.569467
Charming (3)	0.053395	0.053395	0.053395
Coronet (4)	0.070365	0.070365	0.070365
Angel Soft (5)	0.342322	0.342322	0.342322
Soft & Gentle 2-Ply (6)	0.093887	0.093887	0.093887
Soft & Gentle 1-Ply (7)	0.035868	0.035868	0.035868
Cottonelle (8)	0.071630	0.071630	0.071630
Scott-Regular (9)	0.043938	0.043938	0.043938
Quilted Northern (10)	0.156033	0.156033	0.156033

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

Recall that $e^{-kd(x_i,x_{i'})}$ represents the shift in demand from brand i to brand i', as a function of the distance $d(x_i,x_{i'})$ between these two brands. The parameter k represents the rate at which this shift factor declines as the distance $d(x_i,x_{i'})$ increases. As in Kuenne (1998), we assume that k=0.005.

In the theoretical model of Section 2, we assume that the advertising expenditure for each brand, say brand i, is equal to a fraction ϕ_i of sales, adjusted by the price differential between the price of brand i and the prices of the other brands and that the parameters that characterize the impact of the price differentials are $\omega_{ii'}, i, i' = 1,\dots,10$. The values assumed for these parameters are given in Tables 4.10 and 4.11, respectively.

Table 4.10
Values of Advertising Parameters
$(\phi_i, i = 1,\dots,10)$

Brand	ϕ_i
Charming Ultra (1)	0.0598011
Charming Plus (2)	0.0085340
Charming (3)	0.0036793
Coronet (4)	0.0140747
Angel Soft (5)	0.022676
Soft & Gentle 2-Ply (6)	0.0077883
Soft & Gentle 1-Ply (7)	0.0019211
Cottonelle (8)	0.0389013
Scott-Regular (9)	0.0031177
Quilted Northern (10)	0.0054412

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

Table 4.11
Values of Advertising Parameters ($\omega_{ii'}, i, i' = 1,...,10$)

Brand	1	2	3	4	5	6	7	8	9	10
Charming Ultra (1)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Charming Plus (2)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Charming (3)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Coronet (4)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Angel Soft (5)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Soft & Gentle 2-Ply (6)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Soft & Gentle 1-Ply (7)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Cottonelle (8)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Scott-Regular (9)	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Quilted Northern (10)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

It remains to assign values to the parameters $a_i, b_{ii'}, i, i' = 1,...,10$. Using the assumed values for the parameters of Tables 4.5 through 4.11, the values for a_i, $b_{ii'}$ can be computed in the following manner:

First, we assume that for each brand i, the cross-price parameters $b_{ii'}, i \neq i', i, i' = 1,...,10$, are assumed to be the same. Again, this assumption is made due to lack of detailed data. Second, the value of the intercept a_i is found by arbitrary adopting a choke price of $US2.5 per roll for the part of the inverse demand curve associated with its own price for each brand.

Third, the initial guesses needed for the computations of $b_{ii'}$ are such that the own-price part of the demand for each brand is about 85 percent of its total demand.

Fourth, we assumed that the augmented data of Table 4.4 represented a Nash equilibrium for the year 1998. Furthermore, under this Nash equilibrium, a firm maximized the total profits yielded by all the brands it owned, given the actions of all the other firms. In terms of the theoretical model formulated in the preceding section, this involves setting $\theta_{ff}=1, f \in F$, and $\theta_{ff'} = 0, f \neq f'$.

Using the assumptions just listed, we computed the values for $a_i, b_{ii'}$ by solving a system of linear and nonlinear equations, which characterize the Nash equilibrium as well as the market-clearing conditions. The results of these calculations are presented in Tables 4.12 and 4.13.

Table 4.12
Own-Price and Cross-Price Parameters ($b_{ii'}, i, i' = 1,\ldots,10$)

Brand	1	2	3	4	5	6	7	8	9	10
Charming Ultra (1)	2827	5.6556	5.6556	5.6556	5.6556	5.6556	5.6556	5.6556	5.6556	5.6556
Charming Plus (2)	56.94	56946	56.946	56.946	56.946	56.946	56.946	56.946	56.946	56.946
Charming (3)	5.339	5.3395	2669.7	5.3395	5.3395	5.3395	5.3395	5.3395	5.3395	5.3395
Coronet (4)	7.036	7.0365	7.0365	3518.2	7.0365	7.0365	7.0365	7.0365	7.0365	7.0365
Angel Soft (5)	34.23	34.232	34.232	34.232	17116.	34.232	34.232	34.232	34.232	34.232
Soft & Gentle 2-Ply (6)	9.388	9.3887	9.3887	9.3887	9.3887	4694.3	9.3887	9.3887	9.3887	9.3887
Soft & Gentle 1-Ply (7)	3.586	3.5868	3.5868	3.5868	3.5868	3.5868	1793.4	3.5868	3.5868	3.5868
Cottonelle (8)	7.163	7.1630	7.1630	7.1630	7.1630	7.1630	7.1630	3581.5	7.1630	7.1630
Scott-Regular (9)	4.393	4.3938	4.3938	4.3938	4.3938	4.3938	4.3938	4.3938	2196.9	4.3938
Quilted Northern (10)	15.60	15.603	15.603	15.603	15.603	15.603	15.603	15.603	15.603	78016.

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

Table 4.13
Intercept Parameters (a_i, i= 1,...,10)

Brand	a_i
Charming Ultra (1)	2394.22
Charming Plus (2)	20326.5
Charming (3)	2329.83
Coronet (4)	1741.39
Angel Soft (5)	5603.52
Soft & Gentle 2-Ply (6)	3208.47
Soft & Gentle 1-Ply (7)	1673.00
Cottonelle (8)	2909.77
Scott-Regular (9)	2046.3
Quilted Northern (10)	5591.05

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

5. THE BENCHMARK EQUILIBRIUM

Given the values of the parameters in Tables 4.5 through 4.13, the data in Table 4.4 constitute a Nash equilibrium for the year 1998 that we shall call *the benchmark equilibrium*. In this section, we discuss some of the main properties of the benchmark equilibrium.

First, we compute the own-price and cross-price elasticities of the 10 brands at the benchmark equilibrium. The results are given in Table 4.14.

Table 4.14
The Own-Price and Cross-Price Elasticities of Tissue Brands
The Benchmark Equilibrium

Brand	1	2	3	4	5	6	7	8	9	10
Charming Ultra (1)	-3.107	0.0032	0.0061	0.0035	0.0022	0.0049	0.0063	0.0059	0.0064	0.0054
Charming Plus (2)	0.0161	-16.60	0.0158	0.0092	0.0058	0.0129	0.0163	0.0153	0.0166	0.0141
Charming (3)	0.0028	0.0014	-2.846	0.0016	0.0010	0.0023	0.0029	0.0027	0.0029	0.0025
Coronet (4)	0.0054	0.0027	0.0053	-3.118	0.0019	0.0043	0.0054	0.0051	0.0055	0.0047
Angel Soft (5)	0.0072	0.0037	0.0071	0.0042	-2.653	0.0058	0.0074	0.0069	0.0075	0.0064
Soft & Gentle 2-Ply (6)	0.0042	0.0021	0.0041	0.0024	0.0015	-3.374	0.0042	0.0040	0.0043	0.0036
Soft & Gentle 1-Ply (7)	0.0025	0.0013	0.0025	0.0014	0.0009	0.0020	-2.621	0.0024	0.0026	0.0026
Cottonelle (8)	0.0033	0.0017	0.0032	0.0019	0.0012	0.0026	0.0033	-3.187	0.0034	0.0029
Scott-Regular (9)	0.0026	0.0013	0.0026	0.0015	0.0009	0.0021	0.0026	0.0025	-2.733	0.0023
Quilted Northern (10)	0.0094	0.0048	0.0093	0.0054	0.0034	0.0075	0.0095	0.0090	0.0097	-4.154

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottenolle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

In Table 4.14, the entry on row i and column j represents the elasticity of demand for brand i with respect to the price of brand j. As one might expect, the consumption of each brand is negatively related to its own price, and, according to substitution rule among normal goods, positively related to their rival brands' prices. Furthermore, compared to the other brands, brand 2 is the brand whose demand is most sensitive to its own price (its own-price elasticity is -16.60), while brand 7 is the one least sensitive to its own price (its own-price elasticity is -2.261). Table 4.14 also shows that brand 1 has the least cross-price elasticity with respect to brand 5 and highest cross-price elasticity with respect to brand 9. Brand 9, however, shows the highest cross-price elasticities with respect to brands 1, 3, and 7, but the least cross-price elasticity with respect to brand 2. This set of own-price and cross-price elasticities reveal the degree of competitiveness and rivalry among the 10 brands.

The quality-induced sales are represented by $\sum_{j=1,2,3}(\alpha_{ij}(x_{ij}-\mu_j)-\beta_{ij}(x_{ij}-\mu_j)^2)$. Table 4.15 presents the quality-induced sales under the benchmark equilibrium for each brand.

Here recall that $x_i = (x_{i1}, x_{i2}, x_{i3})$ represents the vector of qualities (softness, absorbency, and strength) of brand *i*, and $\mu = (3,4,2.8)$ represents the vector of the industry's average qualities.

Table 4.15
Quality-Induced Sales
The Benchmark Equilibrium

Brand	$x_i - \mu$	$\sum_{j=1,2,3}(\alpha_{ij}(x_{ij} - \mu_j) - \beta_{ij}(x_{ij} - \mu_j)^2)$
Charming Ultra (1)	(2,1,1.2)	23.38
Charming Plus (2)	(1,1,-0.8)	66.83
Charming (3)	(1,1,-.08)	6.26
Coronet (4)	(0,0,2.2)	15.13
Angel Soft (5)	(0,0,-0.8)	-27.60
Soft & Gentle 2-Ply (6)	(-1,0,1.2)	1.64
Soft & Gentle 1-Ply (7)	(-2,-1,-0.8)	-13.83
Cottonelle (8)	(1,0,-0.8)	1.31
Scott-Regular (9)	(-1,-1,0.2)	-7.99
Quilted Northern (10)	(-1,-1,-0.8)	-44.10

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonolle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

Table 4.15 reveals that brand 2's quality-induced sales are 66.83, which places this brand at the top of the list in terms of this component of demand. The value of this brand's quality-induced sales can be attributed to its relatively high qualities and to the exceptional coefficient $\alpha_{2j} = 56.9467, j = 1,2,3,$ of the linear term in the expression that captures the impact of the qualities of this brand on its own demand. As Table 4.15 shows, brand 2 would suffer a large loss if the quality of brand 7 improves. Table 4.15 also reveals that despite the relatively high coefficient of $\alpha_{10j} = 15.6033, j = 1,2,3,$ brand 10's quality- induced sales are –44.10, which places this brand at the bottom of the list in terms of this component of demand. The highly negative value of this brand's quality-induced sales can be attributed to its relatively low qualities.

The expression $z_i\left[\sigma_{ii'} - \tau_{ii'}z_i\right]e^{-kd(x_i,x_{i'})} - z_{i'}\left[\sigma_{i'i} - \tau_{i'i}z_{i'}\right]e^{-kd(x_{i'},x_i)}$ represents the approximate net flow of advertising-induced sales (in millions of rolls) from one brand to another in their advertising war. Table 4.16 presents the net advertising-induced sales of each brand generated by a marginal advertising expenditure of $1 million by each brand under the benchmark equilibrium. In Table 4.16, the entry on row i and column j gives the net sales (in millions of rolls) that brand i managed to divert from brand j to itself when, starting from the benchmark equilibrium, the advertising expenditures on each brand is raised by one million dollars. For example, relative to brand 2, the net flow of advertising-induced sales that brand 1 managed to entice in their advertising war was 0.05 million rolls.

Table 4.16
Approximate Net Flow of Advertising-Induced Sales (millions of rolls) from One Brand to Another Brand Induced by Marginal Spending of $1Milion by Each Brand:
$z_i\left[\sigma_{ii'} - \tau_{ii'}z_i\right]e^{-kd(x_i,x_{i'})} - z_{i'}\left[\sigma_{i'i} - \tau_{i'i}z_{i'}\right]e^{-kd(x_{i'},x_i)}$
The Benchmark Equilibrium

Brand	1	2	3	4	5	6	7	8	9	10	Total
Charming Ultra (1)	0.0	0.05	0.0	0.05	0.05	0.05	0.05	-0.10	0.05	0.05	0.25
Charming Plus (2)	-0.05	0.0	-0.05	0.0	0.0	0.0	0.0	-0.15	0.0	0.0	-0.25
Charming (3)	0.0	0.05	0.0	0.05	0.05	0.05	0.05	-0.10	0.05	0.05	0.25
Coronet (4)	-0.05	0.0	-0.05	0.0	0.0	0.0	0.0	-0.15	0.0	0.0	-0.25
Angel Soft (5)	-0.05	0.0	-0.05	0.0	0.0	0.0	0.0	-0.15	0.0	0.0	-0.25
Soft & Gentle 2-Ply (6)	-0.05	0.0	-0.05	0.0	0.0	0.0	0.0	-0.15	0.0	0.0	-0.25
Soft & Gentle 1-Ply (7)	-0.05	0.0	-0.05	0.0	0.0	0.0	0.0	-0.15	0.0	0.0	-0.25
Cottonelle (8)	0.10	0.15	0.10	0.15	0.15	0.15	0.15	0.0	0.15	0.15	1.25
Scott-Regular (9)	-0.05	0.0	-0.05	0.0	0.0	0.0	0.0	-0.15	0.0	0.0	-0.25
Quilted Northern (10)	-0.05	0.0	-0.05	0.0	0.0	0.0	0.0	-0.15	0.0	0.0	-0.25

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

Table 4.16 reveals that brand 8 is the best among all the examined brands. This brand will be able to increase its sales by 0.25 million rolls if the advertising expenditure on each brand is raised by one million dollars. Besides brand 8, brands 1 and 3 are the only ones that have positive net sales induced by an increase in their marginal expenditures on advertising. Therefore, they can also entice away consumers from other brands, except those loyal to brand 8.

The advertising-induced net sales flowing from one brand to another brand under the benchmark equilibrium are presented in Table 4.17. Relative to brand 2, the net flow of advertising-induced sales that brand 1 managed to entice in their advertising war was 3.2 million rolls. However, relative to brand 8, the situation was reversed: brand 1 was a loser in the advertising war with brand 8 and suffered a net loss of 1.3 million rolls. The overall net advertising-induced sales for brand 1 were 22.70 million rolls in the advertising war that this brand waged against all the other brands.

Table 4.17
Net Flow of Advertising-Induced Sales (millions of rolls) from One Brand to Another Brand:
$z_i\left[\sigma_{ii'} - \tau_{ii'} z_i\right] e^{-kd(x_i, x_{i'})} - z_{i'}\left[\sigma_{i'i} - \tau_{i'i} z_{i'}\right] e^{-kd(x_{i'}, x_i)}$
The Benchmark Equilibrium

Brand	1	2	3	4	5	6	7	8	9	10	Total ψ_i	z_i
Charming Ultra (1)	0.0	3.2	2.6	3.1	3.0	3.0	3.0	-1.3	3.1	3.0	22.70	26,737
Charming Plus (2)	-3.2	0.0	-0.5	-0.3	-0.1	-0.1	-0.1	-4.5	0.0	-0.1	-8.90	1,103
Charming (3)	-2.6	0.5	0.0	0.5	0.4	0.4	0.4	-4.0	0.5	0.4	-3.50	4,328
Coronet (4)	3.1	0.0	-0.5	0.0	-0.1	-0.1	-0.1	-4.4	0.0	-0.1	-2.20	1,629
Angel Soft (5)	-3.0	0.1	-0.4	0.1	0.0	0.0	0.0	-4.4	0.1	0.0	-7.50	4,732
Soft & Gentle 2-Ply (6)	-3.0	0.1	-0.4	0.1	0.0	0.0	0.0	-4.3	0.1	0.0	-7.40	3.9
Soft & Gentle 1-Ply (7)	-3.0	0.1	-0.4	0.1	-0.4	0.0	0.0	-4.4	0.1	0.0	-7.90	3
Cottenelle (8)	1.3	4.5	4.0	4.4	4.4	4.3	4.4	0.0	4.4	4.4	36.10	20,201
Scott-Regular (9)	-3.1	0.0	-0.5	0.0	-0.1	-0.1	-0.1	-4.4	0.0	-0.1	-8.40	1,948
Quilted Northern (10)	-2.9	0.1	-0.4	0.1	0.0	0.0	0.0	-4.4	0.1	0.0	-7.40	6,158

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

In Table 4.17, the total net advertising-induced sales for brand 8 are 36.10 million rolls, which is the highest among all brands. Brand 1 occupies the second place among the brands in terms of having relatively high total net advertising-induced sales of 22.70 million rolls. Table 4.17 also shows that the total net advertising-induced sales are negative for most of the brands. Brand 2 loses to all the other brands except brand 9, while brand 9 loses to all the other brands, except brands 2 and 4. Brand 5 loses only to brands 1, 3, and 8, while brand 7 loses to brands 1, 3, 5, and 8. Table 4.17 also reveals that although brand 10's advertising expenditure is almost four times that of brand 4, its total net advertising-induced sales are less than that of brand 4. In addition, the table shows that some brands, such as brands 1 and 8, have the highest total net advertising-induced sales, which are due to their relatively high advertising expenditures. Brands 2, 4, and 9 show the worse performance, reflected by their relatively low advertising expenditures.

According to equation (4) of the theoretical model formulated in Section 2, the advertising expenditures on each brand are assumed to be equal to a fixed percentage of its revenues modified by the differentials between the price of this brand and the prices of the other brands. Table 4.18 presents the price-induced advertising expenditures of each brand under the benchmark equilibrium.

Table 4.18
Price-Induced Advertising Expenditures
The Benchmark Equilibrium

Brand	$\sum_{i' \in I} \omega_{ii'} \left(p_i / p_{i'} - 1\right) p_i q_i$ (Million of dollars)	p_i (millions of dollars per million rolls)
Charming Ultra (1)	3.03	0.66
Charming Plus (2)	-2.27	0.34
Charming (3)	2.86	0.65
Coronet (4)	-0.663	0.38
Angel Soft (5)	-3.69	0.24
Soft & Gentle 2-Ply (6)	0.86	0.53
Soft & Gentle 1-Ply (7)	2.48	0.67
Cottenelle (8)	2.85	0.63
Scott-Regular (9)	0.78	0.68
Quilted Northern (10)	2.72	0.58

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

As shown in Table 4.18, brand 1 has the highest price per roll of tissues among the 10 brands, which induces Proctor and Gamble to spend the highest amount of price-induced advertising expenditures. Brand 5 shows negative price-induced advertising expenditure, which indicates that it is the cheapest brand.

6. SIMULATIVE THEORIZING

In this section, we carry out two simulation exercises.[22] The first simulation exercise deals with the impact of the improvement in qualities of a brand, brought about possibly by a new technology of tissue manufacturing, on the strategic behavior of all the players in the market. The second simulation involves the reaction involves the reduction in production costs, which is the fruit of a process innovation.

[22] We assume that market is initially in a Nash equilibrium. We carry out the two simulation exercises in order to find out what would happen if there was a strategy change due to, say R&D, which may lead to quality improvement or reduction in production cost of a brand. These exercises are interesting as they have implications for policies that encourage innovation.

6.1. *Impact of Quality Change on Market Equilibrium*

The simulation exercise carried out in this subsection involves a change in the qualities of brand 7 from (1, 3, 2) to (4, 4, 3) and yields insights into what may be called quality-induced sales. There are two reasons why we pick brand 7 for the simulation. First, brand 7, which is known as Soft and Gentle 1-Ply, belongs to Georgia Pacific, the biggest North American tissue producer. Georgia Pacific uses a new technology called through air drying (TAD), which is applied on new paper machines to achieve higher softness, bulk, and absorbency, but not strength. Second, the qualities of brand 7 are the lowest among the 10 brands we study, and thus this brand has much room for improvement in qualities. Because our interest in this subsection is to see how the improvements in the qualities of a brand affect the strategic behavior of the other brands, we can certainly choose some other brand for the simulation exercise.

Suppose then that Georgia Pacific has carried out an R&D program and managed to raise the qualities of brand 7 from (1, 3, 2) to (4, 4, 3). The improvements in the qualities of brand 7 raise the industry's average qualities from (3, 4, 2.8) to (3.3, 4.1, 2.9). Before the change, the deviations of the qualities of brand 7 from the industry's averages are given by the vector (-2, -1, -0.8). After the rise in its qualities, the deviations are now (0.7, -0.1, 0.1), which represent a net improvement for this brand. As for the other brands, because their qualities remain the same while the industry's averages go up their quality-induced sales deteriorate. The results on the change in the quality-induced sales of each of the brands are given in Table 4.19.

Table 4.19
Change in Quality-Induced Sales
The Qualities of Brand 7 Rise from (1,3,2) to (4,4,3)

Brand	$\Delta(x_i - \mu)$	$\Delta(\sum_{j=1,2,3}[\alpha_{ij}(x_{ij}-\mu_j)-\beta_{ij}(x_{ij}-\mu_j)^2])$
Charming Ultra (1)	(-0.2,0,-0.01)	-1.631
Charming Plus (2)	(-0.2,0,-0.01)	-16.9732
Charming (3)	(-0.2,0,-0.01)	-1.58527
Coronet (4)	(-0.2,0,-0.01)	-2.0737
Angel Soft (5)	(-0.2,0,-0.01)	-10.3464
Soft & Gentle 2-Ply (6)	(-0.2,0,-0.01)	-2.82768
Soft & Gentle 1-Ply (7)	(+1.8,0,+0.9)	9.847
Cottenelle (8)	(-0.2,0,-0.1)	-2.13
Scott-Regular (9)	(-0.02,0,-0.1)	-1.3446
Quilted Northern (10)	(-0.2,0,-0.1)	-4.77

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

As can be seen from Table 4.19, the improvements in its own qualities help to raise the quality-induced sales of brand 7 by 9.847 million rolls. As for the other brands, their quality-induced sales all drop, with brand 2, suffering the greatest loss. As discussed in Section 5, the parameters that represent the coefficients of the linear terms in the expression of the quality-induced sales for brand 2, namely $\alpha_{2j}, j=1,2,3,$ are exceptionally high. The high values of $\alpha_{2j}, j=1,2,3,$ magnify the gain or loss in quality-induced sales of this brand. Observe that next to brand 2, the brand that suffers most from the improvements in quality of brand 7 is brand 5. The remaining brands suffer in varying degrees from the rise in qualities of brand 7. The improvements in qualities of brand 7 thus trigger an upward shift in the demand for this brand and simultaneously a downward shift in the demand for all the other brands. As one might expected, the upward shift in demand will induce a rise in the price of brand 7 as well as a rise in its output, with the ensuing unambiguous rise in the revenues earned by this brand. As for the other brands, the downward shift in their demand induces a decline in both their prices and their outputs. As for advertising spending, we expect the advertising expenditures on brand 7 to rise and the advertising expenditures on the other brands to decline. The rise in advertising expenditures of brand 7 is due to the fact that the advertising expenditures of the brand are conditioned to be a fixed percentage of sales modified by the differentials between the price of this brand and the prices of all the other brands. The rise in revenues of brand 7 thus automatically triggers a rise in its advertising expenditures, as a fixed percentage of revenues. This increase in advertising expenditures is then reinforced by the rise in the price of brand 7 and the fall in the prices of all the other brands. The same economic logic, but applied in reverse, leads us to anticipate a decline in the advertising expenditures of all the other brands. These results are presented in Table 4.20. Also presented in Table 4.20 are the changes in profits of each brand and the changes in profits of the firms, which own these brands.

Table 4.20
Impact on the Market (Percentage Change)
The Qualities of Brand 7 Rise from (1,3,2) to (4,4,3)

Brand	Price	Output	Advertising Expenditure	Profits	Percent Change
Charming Ultra (1)	-0.09	-0.17	-0.27	-0.34	
Charming Plus (2)	-0.13	-0.16	-0.57	-0.32	
Charming (3)	-0.09	-0.16	-0.29	-0.33	
Total profits for Proctor & Gamble					-0.328
Coronet (4)	-0.17	-0.07	-0.59	-0.57	
Angel Soft (5)	-0.24	-0.5	-0.84	-0.92	
Soft & Gentle 2-Ply (6)	-0.13	-0.2	-0.44	-0.41	
Soft & Gentle 1-Ply (7)	1.40	1.5	4.79	2.92	
Total profits for Georgia Pacific					0.247
Cottonelle (8)	-0.10	-0.17	-0.30	-0.36	
Scott-Regular (9)	-0.07	-0.15	-0.26	-0.32	
Total profits for Kimberly Clark					-0.343
Quilted Northern (10)	-0.05	-0.19	-0.44	-0.38	
Total Profits for Fort James					-0.38

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

As one might expect, Table 4.20 reveals that brand 7 is the sole beneficiary of its improvements in qualities, while all the other brands suffer. Georgia Pacific, the firm that owns brand 7, improves its overall financial situation by 0.247 percent, whereas the profits of Proctor & Gamble, Kimberly Clark, and Fort James all decline. Also, observe that the other brands react to the increase in brand 7's qualities in different manners. Table 4.20 shows that the percentage price changes of the brands that do not belong to Georgia Pacific, the owner of brand 7, are somewhat smaller. For instance, brand 5's price change as a reaction to a rise in brand 7's quality is –0.24 percent, and the price change for brand 1 is –0.09 percent. This may be based on the fact that brand 5 also belongs to Georgia Pacific, while brand 1 belongs to a rival firm. One can also observe from Table 4.20 that Georgia Pacific, the firm that owns brand 7, is more willing to vary the outputs of the other brands it owns than the rival firms.

Finally, Table 4.21 presents the change in the net advertising-induced sales of each brand in reaction to the rise in the qualities of brand 7.

Table 4.21
Net Flow of Advertising-Induced Sales (millions of rolls) from One Brand to Another Brand:
$z_i\left[\sigma_{ii'} - \tau_{ii'} z_i\right]e^{-kd(x_i, x_{i'})} - z_{i'}\left[\sigma_{i'i} - \tau_{i'i} z_{i'}\right]e^{-kd(x_{i'}, x_i)}$
The Quality of Brand 7 Rises from (1,3,2) to (4,4,3)

Brand	1	2	3	4	5	6	7	8	9	10
Charming Ultra (1)	0.00	-0.05	0.03	0.02	0.00	0.01	0.03	-0.03	-0.02	-0.01
Charming Plus (2)	0.05	0.00	-0.02	0.27	-0.04	-0.03	-0.01	0.00	-0.05	-0.03
Charming (3)	-0.03	0.02	0.00	-0.01	-0.02	-0.01	0.01	0.02	-0.03	-0.01
Coronet (4)	-6.22	0.03	0.02	0.00	-0.01	0.00	0.02	-0.03	-0.02	0.00
Angel Soft (5)	0.00	0.04	0.02	0.01	0.00	0.01	0.03	0.04	-0.01	0.01
Soft & Gentle 2-Ply (6)	-0.01	0.03	0.01	0.00	-0.01	0.00	0.02	-0.04	-0.02	0.00
Soft & Gentle 1-Ply (7)	-0.03	0.01	-0.01	-0.02	0.37	-0.02	0.00	0.02	-0.04	-0.02
Cottenelle (8)	0.03	0.00	-0.01	0.03	-0.04	0.04	-0.02	0.00	0.02	-0.05
Scott-Regular (9)	0.02	0.05	0.03	0.02	0.01	0.02	0.04	-0.02	0.00	0.02
Quilted Northern (10)	-0.09	0.03	0.01	0.00	-0.01	0.00	0.02	0.05	-0.02	0.00

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

As remarked at the beginning of Subsection 6.1, Georgia Pacific could bring about the improvements in qualities of brand 7 by carrying out an R&D program. Whether such a project should be undertaken depends on the cost of the R&D program and the present value of the extra overall profits generated by this quality improvement.

6.2. *Impact of Reduction in Production Costs on Market Equilibrium*

In this subsection, we pick brand 1 (Charming Ultra), one of the three brands owned by Proctor and Gamble. The objective of the simulation exercise is to analyze the impact on the market of a process innovation, which reduces the unit production cost of a brand. For the simulation exercise, we assume a fall in production cost for brand 1 – brought about by a new technology (through-air drying) – which is translated by a drop of γ_{i1} from 0.285957 to 0.280957, holding everything else constant. The results of simulation are presented in Table 4.22.

Table 4.22
Impact on the Market Due to a Reduction in Production Costs of Brand 1 Translated by a Decrease of γ_{i1} from 0.285957 to 0.280957 Percentage change

Brand	Price	Output	Advertising Expenditure	Profits	Percent Change
Charming Ultra (1)	-0.2991	0.95	0.53	1.9394	
Charming Plus (2)	0.0024	-0.002	0.11	-0.0022	
Charming (3)	-0.0003	0.005	0.05	-0.0039	
Total profits for Proctor & Gamble					0.5842
Coronet (4)	-0.0008	-0.005	0.03	-0.0037	
Angel Soft (5)	-0.0008	0.001	0.02	-0.0030	
Soft & Gentle 2-Ply (6)	-0.0006	0.007	0.05	-0.0034	
Soft & Gentle 1-Ply (7)	-0.0009	0.011	0.06	-0.0051	
Total profits for Georgia Pacific					-0.0037
Cottenelle (8)	-0.0005	0.010	0.01	-0.0032	
Scott-Regular (9)	0.0138	0.011	0.03	-0.0041	
Total profits for Kimberly Clark					-0.0037
Quilted Northern (10)	-0.0007	0.002	0.05	-0.0032	
Total Profits for Fort James					-0.0032

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

When the unit production cost of brand 1 decreases, we witness an increase in output of 950 000 rolls for this brand. To sell the extra output, Proctor & Gamble can lower the price of brand 1 or increase the advertising expenditure on this brand. Table 4.22 confirms this result. As revealed by Table 4.2, brand 1 is the sole beneficiary of its reduction in production cost, while all the other brands suffer. Proctor & Gamble, the firm that owns brand 1, improves its overall financial situation by 0.5842 percent, whereas the profits of Georgia Pacific, Kimberly Clark, and Fort James all decline.

Table 4.22 also shows that the other brands react to the reduction in brand 1's production cost in different manners. Once the price of brand 1 drops, it shifts the demand for all the other brands downward through the cross-price effect. Furthermore, the increase in advertising expenditure on brand 1 diverts the sales from the other brands to brand 1. To counteract this negative impact of brand 1, other brands have two choices open to them:

changing prices or changing advertising expenditures. As Table 4.22 reveals, the percentage price changes of the brands that do not belong to the same firms owning brand 1 are rather somewhat smaller. For instance, brand 2's price change as a reaction to a decrease in brand 1's cost is +0.0024 percent, but the price change for brand 6 is only –0.0006 percent. This could be based on the fact that brand 2 belongs to the same firm that brand 1 does, while brand 6 belongs to a rival firm. So the adjustments take place mainly through variations in advertising expenditures.

Table 4.22 shows that for some brands the prices rise; for others, the prices go down. As for outputs, the same phenomenon happens; some outputs go up and some go down. The explanation for these different types of movements resides in the own-price elasticities and the productiveness of advertising expenditures of the various brands. Because the changes in prices for brands other than brand 1 are rather small, the cross-price effect is negligible. For brand 9, the table shows that its price goes up; its production goes up; and its advertising expenditure also goes up. For this brand, its own price elasticity is –2.733, which is not very elastic. Thus, the rise in price does not diminish substantially its demand. The slight decrease in demand is more than compensated by the increase in advertising expenditures. That is why its output rises. As another example, consider brand 4. We observe that its price goes down and its advertising expenditures go up. These variations will induce a rise in its sale. However, Table 4.22 reveals that the output of the brand goes down. The reason is that these variations are not sufficient to counteract the impact of the rising advertising expenditures of all the other brands. For brand 7, the decline in its price and the rise in its advertising expenditures are sufficiently strong to induce a rise in its output.

In Table 4.23 are found the advertising-induced sales associated with the drop in the unit production cost of brand 1. The advertising-induced sales under the benchmark equilibrium are also shown in the table for comparison. Table 4.23 reveals that the change in advertising-induced sales is rather low. This result indicates that the extra advertising expenditures of all the other brands are *defensive in nature*.

Table 4.23
Impact on the Advertising-Induced Sales Due to a Reduction in Production Costs of Brand 1 Translated by a Decrease of γ_{i1} from 0.285957 to 0.280957

Brand	Benchmark (10^6 rolls)	Simulation Result (10^6 rolls)	Percent Change
Charming Ultra (1)	22.6738	22.7946	0.532774
Charming Plus (2)	-8.75078	-8.76421	0.153472
Charming (3)	-3.58972	-3.60114	0.318131
Coronet (4)	-8.42118	-8.43543	0.169216
Angel Soft (5)	-7.34867	-7.36319	0.197587
Soft & Gentle 2-Ply (6)	-7.41436	-7.4285	0.190711
Soft & Gentle 1-Ply (7)	-7.63075	-7.64449	0.180061
Cottenelle (8)	36.1278	36.1179	-0.027403
Scott-Regular (9)	-8.2178	-8.23198	0.172552
Quilted Northern (10)	-7.42837	-7.44357	0.204621

The brands Charming Ultra (1), Charming Plus (2), Charming (3) belong to the firm P&G. The brands Coronet (4), Angel Soft (5), Soft & Gentle 2-Ply (6), Soft & Gentle 1-Ply (7) belong to the firm Georgia Pacific. The brands Cottonelle (8) and Scott-Regular (9) belong to the firm Kimberly Clark. The brand Quilted Northern belongs to the firm Fort James.

8. CONCLUDIND REMARKS

In this chapter, we have formalized an oligopoly model with product differentiation and non-price competition to gain some insights on the structure and functioning of the rich and complex North American tissue and towel market. To attain a certain degree of realism, we have included all the major players in this market and the various brands that each of these producers offer on the market. The firms considered in the model are Proctor and Gamble, Georgia Pacific, Kimberly Clark, and Fort James. Together, these firms offer for sale 10 brands on the market - with three brands belonging to Proctor and Gamble, four brands to Georgia Pacific, two brands to Kimberly Clark, and one brand to Fort James. The small number of firms captures the oligopolistic structure of the market. The fact that three of the four firms in the model – Proctor and Gamble, Georgia Pacific, and Kimberly Clark - offer for sale more than one brand on the market captures another facet of the competition in the North American market for tissue and towel: brand proliferation as a strategy of competition. In the model firms compete through prices, qualities, and advertising. A firm can raise the demand for a brand that it owns by lowering its price, raising its various qualities, or spending more to advertise the brand. Qualities can be improved and production cost can be lowered through innovation. The differentiated nature of the various brands considered in the model allows for brand loyalty, which means that even if two brands have the same qualities different consumers with different brand loyalties might prefer one brand to the other. In our formulation, brand loyalty is captured by allowing for different brands to have different choke prices $(a_i, i = 1,...,10)$ or different own-price and cross-price parameters $(b_{ii'}, i, i' = 1,...,10)$.

The theoretical model is calibrated with the help of a limited set of data for the market in 1998. Two simulation exercises are then carried out to gain insights into the functioning of the market. The first simulation exercise deals with the impact on the market of the improvement in qualities of a brand. The second simulation exercise deals with the impact on the market of the reduction in production cost of a brand.

In the first simulation exercise, we allow the qualities – softness, absorbency, and strength – of brand 7 (Soft and Gentle 1-Ply) – to rise from (1,3,2) to (4,4,3). The improvement in qualities shift the demand for brand 7 upward and the demands for all the other brands downward. Georgia Pacific, the owner of brand 7, raises the price of this bran as well as its output. Because the advertising expenditures on each brand are equal to a given fraction of the brand's revenues, modified by its price differentials with repect to all the other brands, the advertising expenditures on brand 7 rise. For all the other brands, the logic applies in reverse. The price, output, and expenditures on each of the other brands all decline. In terms of profitability, it is brand 7 that benefits at the expense of all the other brands. These results are intuitive and could be anticipated. However, the simulation exercise also yields some unexpected insights about the quantitative aspects of the reaction of the rivals of Georgia Pacific. As can be seen from Table 4.20, the rivals of Georgia Pacific cut the prices of their brand around 0.05 to 0.13% and quantities from 0.16 to 0.17%. Georgia Pacific, however, is willing to cut the prices of the two other brands that it owns more substantially – by 0.24 and 0.13%, respectively. Depending whether or not a brand belongs to the same firm that owns the brand whose qualities have improved, the magnitudes of the changes experienced by the former brand will be different.

In the second simulation exercise, we allow the production cost of brand 1 (Charming Ultra) to go down. As could be expected, Proctor and Gamble, the owner of Charming Ultra, cuts the price of this brand to raise its sales. The profit made by brand 1 rises while the profits made by all the other brands decline. The overall profits of Proctor and

Gamble increase and the overall profits of each of its rivals deteriorate. These results could be anticipated. However, what could not be easily anticipated is the reaction of each of the other brands. Intuitively, we expect the rivals of Proctor and Gamble to cut prices to maintain market shares. This is indeed the case for brand 9 (Scott Regular) of Kimberly Clark, which raises both the price and output of this brand. Of course, Kimberly Clark must also raise the advertising expenditures on brand 9 to make this action feasible. The actions taken by Proctor and Gamble are also unexpected. While this firm cuts the price of brand 1 to raise its sales, Proctor and Gamble raises the price of brand 2 (Charming Plus).

What has emerged from our simulative theorizing is that there are insights that can be gained from this approach that cannot be obtained by adopting the overworked and simplistic approach of modeling an oligopolistic by allowing for only two firms to make the analytical approach more tractable. The number of firms, the proliferation of brands, their complex interdependence, and the multifaceted nature of a market, such as the North American market for tissue and towel, make it difficult to justify the duopoly model expounded in traditional textbooks. Finally, the numerical analysis we have carried out in this chapter deals only with the short run and the two simulation exercises are only exercises in comparative static. This is due to lack of data on R&D processes. An avenue for future analysis is to formulate R&D process pursued by the firms in the market and make innovation a strategic action for each firm.

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