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Smart Market for Woodchips

Marie Corriveau, Marcelin Joanis,
Jacques Robert

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Foreword

This paper presents the results of work conducted by researchers at CIRANO (*Centre Interuniversitaire de Recherche en ANalyse des Organisations*, or Center for Interuniversity Research and Analysis on Organizations) as part of the AGEM (Automated Generation of Electronic Markets) project, jointly funded by Bell Canada and CIRANO. It arises out of a commission from the Quebec Ministry of Natural Resources.

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Summary

This paper presents the outline for a smart market geared to Quebec's woodchip industry. It aims to explain how such a market operates, and to show how it fits into or modifies the existing trading system.

The proposed smart market has two main objectives. The first is to enhance the *efficiency* of the woodchip market. The electronic market is a favoured means of enhancing market flexibility and thus controlling the accumulation of unsold inventory. Such a mechanism maximizes the industry's overall profits by ensuring that each firm can identify all business opportunities within its reach and realize the additional profits associated with them. The second main objective is *continuity* of trade practices. Long-term contracts between sawmills and paper mills are an important market reality, and they will be an integral part of the smart market.

The keystone of our proposal is the *Optimized Periodic Market (OPM)*. Somewhat along the lines of the *Encan électronique du porc* (EÉP, or electronic pork auction), set up by the *Fédération des producteurs de porcs du Québec* (Quebec's pork producers federation), we are proposing to establish an electronic woodchip exchange which would open up periodically (monthly, for instance) to allocate Quebec's entire woodchip output. At the close of an electronic market session, exchanges for the month will be determined, and everyone will know who he is to receive his woodchips from, or who he is to deliver them to, along with the price of each transaction and the merchandise shipment schedule.

The OPM fulfils three main functions: (1) it co-ordinates players' actions with a view to reducing inventory surpluses and meeting paper mills' needs as closely as possible; (2) it keeps transportation costs down by determining the least costly exchanges between sawmills and paper mills with respect to supply; and (3) it offers an effective tool for renegotiating long-term contracts.

An OPM session is in three main stages: *pre-sale*, *sale* and *after-sale*. At the pre-sale stage, the system gathers the information it will use to determine optimum exchanges. This information concerns two key variables in the woodchip market: quality requirements, and transportation costs. Buyers first express their technical requirements: on a BBS, they indicate the quality of the woodchips they wish to purchase and the penalties that will be applied should delivery not be in compliance with the specified technical requirements. The sellers are then invited to provide a production cost indicator for their woodchips that meets each paper mill's requirements. Sellers must also indicate the unit transportation costs (UTC) which they will have to pay if they deliver to each of the buyers. An auction mechanism for transportation costs, where buyers and third parties will be able to try to lower transportation costs, may also be set up.

The sale stage involves an auction which takes place in successive rounds. Buyers' bids are demand schedules, and sellers' bids are supply schedules. At the start of the opening round, buyers and sellers enter their bids through an electronic interface linked to a server. Sellers must also provide a list of the types of woodchips they wish to market, and this list will be valid for the duration of the sale. Depending on the classification of the woodchips they put up for sale and their ability to sort species, they will have the choice of offering low density chips, high density chips, and/or jack pine chips. Buyers take part in a single market grouping together the three types of woodchips. At the start of the opening round, they have to specify the minimum and maximum proportions of each type of woodchips they wish to acquire.

When all the bids have been tallied, the system generates the quantities traded and the equilibrium price paid or received by each participant. In light of this information, players can raise or lower their bids in line with their assessment of the market. Buyers can also revise the proportions of each type of woodchips they are asking for. Another round is then initiated, ending with the re-optimization of the system and disclosure of the new allocations. If no one wishes to alter his bid after the prices and quantities are announced at the end of a round, the efficient bilateral exchanges become official, and the delivery schedule for the period is established. Bid changes from one round to the next are governed by an *eligibility rule* whose function is to give impetus to the market, to prompt participants to be active in the market, and to reveal their real needs as early as possible.

The OPM is a medium-term market in that it lies between a long-term *compensatory market* and a short-term *spot market*. Sawmills and paper mills wishing to guarantee their supply by signing long-term agreements will be able to go the *compensatory contract* route. A long-term compensatory contract between a sawmill and a paper mill specifies a price and quantity of woodchips for each OPM period (each month). In this way, the paper mill is guaranteed a certain quantity of woodchips at a certain price, and the sawmill is guaranteed a price for a given portion of its output. Data from these compensatory contracts are then taken into consideration by the OPM. Somewhat like term markets, compensatory contracts are agreements on financial flow alone. It is the OPM which determines the actual exchanges of woodchips.

The proposed market mechanism is designed to ensure that participation in the OPM is to everyone's benefit. With *flexibility*, *transparency* and the implementation of an *open competitive mechanism*, *beneficial participation for all* is one of the guiding principles of the smart market for woodchips. A participant bound by a compensatory contract is guaranteed to find himself, after an OPM session, in a situation at least as beneficial as that provided for in the contract. The spirit of the compensation mechanism is that if one of the partners receives an unfavourable price on the OPM, he will be compensated by his partner. In this way, the OPM compensation rule and renegotiation mechanism offer a procedure guaranteeing: (1) each participant the equivalent of what is negotiated in the long-term contract; and (2) all participants the possibility of discovering and realizing additional profits that are accessible but have not yet been realized.

The proposed smart market is rounded out by a very short-term spot market on which sawmills will be able to liquidate their surpluses and paper mills will be able to procure additional quantities of woodchips, thus dealing with surpluses and unfilled requirements not anticipated in the OPM session. The spot market may be presented in the form of a BBS through which each facility will be able to initiate an auction.

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Part I: Introduction

What distinguishes the smart market is that it manages market players' supply and demand so as to determine the quantities of commodities traded and the amount of the transactions. In Quebec, there is already at least one experience of this type of market: the *Encan électronique du porc* (EÉP, or electronic pork auction).

The architecture of the EÉP does not, however, appear to us to be appropriate for the woodchip market. While the EÉP certainly determines bilateral exchanges, it addresses the question of transportation of the commodity, and then that of buyers' quality requirements, only secondarily. But the woodchip market stands out precisely owing to its high transportation costs and the special requirements expressed by buyers during transactions. That is why we have placed these two variables front and centre in the market mechanism we propose in these pages.

Objectives: Efficiency and continuity

Our fundamental objective is the enhancement of market *efficiency*, and that supposes a degree of change in current trade practices. We believe, however, that this objective may be attained while ensuring *continuity* with traditional procedures. We have attempted to develop a market mechanism which will enable the paper companies to pursue their current provisioning strategies while allowing each player to enhance his market position. Whether it be a sawmill or a pulp and paper mill, the facility thus remains free either to maintain past gains or to harness the new tools that will be available to it.

Solution: the Optimized Periodic Market

At present, the woodchip market is governed primarily by long-term contracts between buyers and sellers. Underlying these contracts are special, long-established relationships between paper mills and sawmills. A particular form of this provisioning strategy is the integration of sawmills with paper mills. Approximately 70% of woodchips are produced by integrated sawmills. The vast majority of woodchips are sold to a subsidiary or under medium and long-term contracts. These special relationships are therefore at the core of business strategy in the industry, aiming to guarantee and stabilize the provisioning of pulp and paper mills.

Standing alongside this "long-term market" is an informal spot market. This market complements the long-term market by permitting exchanges not anticipated in long-term contracts (excess demand from paper mills, excess supply from sawmills). Now we note that, in its present configuration, the woodchip market is far from being as flexible as it could be and is unable to curb the accumulation of inventory or to meet firms' needs. Unsold inventory and inadequate output are symptoms of a market's inefficiency.

We propose the creation of an *Optimized Periodic Market* (OPM) in the medium term to complement the current annual contract/spot market sequence. This centralized market will determine optimal exchanges (who sells to whom? who buys from whom?) for a given period (one month), on the basis of data from long-term contracts and after having gathered a certain amount of relevant information. This information primarily concerns transportation costs between the producing and client facilities, sawmill supply, and paper mill demand and requirements.

The OPM will seek:

- to *coordinate players' actions* with a view to reducing surplus inventory and ensuring that paper mills' needs are adequately met;
- to *reduce transportation costs* by determining the least costly exchanges between sawmills and paper mills with respect to provisioning;
- to offer an effective tool for renegotiating long-term contracts.

An efficient market...

The OPM will allocate the resource as efficiently as possible, in light of the available information. In other words, the OPM is a mechanism aimed at maximizing the profits of the industry as a whole. Consider the viewpoint of the manager of the vast enterprise which would result from total integration of the industry, that is, grouping together all pulp and paper mills and all sawmills into a single enterprise. For this manager, it would be important for production to be organized so that exchanges among the various corporate components generated the lowest possible costs (in particular transportation costs between facilities) and maximized the profits of each production unit. Managers or management systems fulfilling this task would achieve their prime objective: maximization of profits. The more efficient an industry is, the higher its overall profits are. The OPM must act a little like the manager of this perfectly integrated enterprise and target maximization of the industry's overall profit.

Continuity in trade practices...

Continuity, our second major objective, is inseparable from the issue of paper mills' steady provisioning. For a paper mill, long-term contracts are genuine insurance policies, since they guarantee it regular provisioning from suppliers with whom it often has special relations. Through these contracts, which are important factors in controlling exchanges, the facility contributes to the stability of the market and the industry. Far from bringing this type of market into question, we believe it could benefit from the electronic tools developed for the OPM and that it would have a good chance of enhancing its flexibility. Indeed, the same is true for the spot market.

The price of the resource is generally negotiated each year. Since a fluctuation in this price is necessarily profitable to only one of the two contracting parties, negotiating long-term agreements on the basis of the state of the market is most often more than a little arbitrary. The spectre of renegotiating these agreements is detrimental to their credibility, and therefore lessens their ability to stabilize exchanges.

While they exert a stabilizing influence, long-term agreements may sometimes represent an iron collar. Their widespread use actually deprives contracting parties and the industry as a whole of additional profits. Whence the att6raction of a shorter-term market mechanism emphasising potential gains and providing the opportunity to realize them while maintaining longer-term guarantees with respect to supplies. Provided a paper mill or sawmill can upwardly revise their needs or output without at the same time being forced to go back on the terms of the contracts binding them with their partners, the OPM will be able to bring back credibility to long-term contracts and reduce the arbitrary dimension of the negotiations at their signing.

The OPM will therefore permit the establishment of a rigorous, non-arbitrary framework for renegotiating long-term contracts, thus conferring the legitimacy essential to the signing of equitable contracts. No longer having to negotiate them systematically whenever the market fluctuates, facilities will be able to measure all the implications, both legal and financial, of their long-term contracts. It is important to specify here that to be taken into consideration by the OPM, a long-term contract will have to specify not only a quantity exchanged, but also a price. Now, in the industry there is a trade practice which involves contracting very long-term agreements on quantities, without considering the price of the commodity or the amount of the transaction. This type of transaction will remain possible, but outside the OPM, which will not take it into account in determining exchanges.

The periodic market will also enable paper mills which do not wish to sign long-term contracts to guarantee their provisioning through the OPM. Likewise for the sawmills, which will, if they wish, be able to sell their output exclusively through the OPM. It is reasonable to believe that the possibility of an agreement other than over the long term will have the effect of levelling the playing field between the parties during negotiations. In this way, the transparent, equitable character of the market will be enhanced.

Guiding principles

In formal terms, attaining efficiency and continuity objectives by setting up an Optimized Periodic Market for woodchips will have to follow the four guiding principles set out below.

1- Participation beneficial for all parties

Our proposal for a smart market for woodchips would not be timely if it did not guarantee that participation will be beneficial for all parties. To state that participation in the OPM is beneficial for all market players is to say that the OPM is a system within which no facility or group will be able to enhance its position in isolation.

Furthermore, the OPM incorporates current trade practices instead of substituting new ones for them. There is nothing to prevent a sawmill and a paper mill from taking part in the OPM, while continuing to sign long-term agreements between themselves. The market mechanism we propose is designed so that each facility (sawmill and paper mill) receives at least the equivalent of what it has negotiated under long-term contracts. In other words, a facility which has signed a long-term agreement will never find itself, at the end of an OPM session, in a situation less enviable than that described in the terms of the contract. None the less, since negotiated agreements do not necessarily correspond to the optimum allocation, the OPM will be able to find more efficient allocations. If the bilateral exchange negotiated by contract proves to be optimal, the OPM will recommend it, but if it is beneficial to only one of the contracting parties, a compensation system will offset the losses sustained by the other party and thus enable the parties to complete the transaction. Through its operation, the OPM guarantees each party a share of the benefits associated with the profits of the exchange.

2- Flexibility

It is essential that the market mechanism attribute to paper mills woodchips which meet their requirements. That is why the OPM authorizes them to set the quality requirements which suit them. The flexibility of the OPM makes it possible, in particular, to intervene in the market to request a single type of woodchips (low density, high density or jack pine) or more than one in variable proportions. The market must also be in a position to provide the paper mills with the quantity of woodchips they want.

We feel it is important that the market mechanism allow buyers to pursue provisioning strategies that are appropriate to them. The OPM offers all the latitude desired for market players to be able to conclude beneficial bilateral agreements in the relatively long term, while remaining fully involved in the market mechanism. For instance, a paper mill wishing to buy on a priority basis from its own sawmills will be in a position to do so. In fact, paper mills will be able to favour a sawmill, on the grounds, for instance, that the transportation cost between them is zero. They will not, however, be able to give unfavourable treatment to a specific sawmill.

3- Transparency

An efficient market is a market where all parties are treated equitably. Thus, the OPM is based on clear, non-arbitrary rules. As far as possible, these rules must limit the opportunities for collusion. Seeking transparency in this way involves respecting the anonymity of participants, although certain phases of the OPM may not be anonymous.

4- A competitive, open mechanism

The OPM is intended to be a flexible mechanism which enables buyers to revise their demand and sellers to revise their supply according to the state of the market. That is why no one is limited to his first assessment of his needs or his desire to produce. The possibility of benefiting from a belatedly noticed business opportunity remains open throughout the process, in line with objective rules that are known to everyone. Thus, the OPM at all times permits the paper mills and sawmills to buy or sell the quantities they wish, provided they are prepared to accept a fair price for the merchandise.

Brief description of the smart market for woodchips

The Optimized Periodic Market (OPM) described in this paper is a market for woodchips which opens up at set intervals. Hypothetically, we have set this interval at one month, but it will be up to the industry to define the frequency which best meets its needs. At the end of each session, the computer system generates the bilateral exchanges (which sawmill sells which quantity of which type of woodchips to which paper mill) and sets the purchase and selling prices. The prices and quantities exchanged are deemed to be only those which maximize the industry's efficiency.

Throughout the process, the quantities and prices generated by the system depend on two critical variables in the woodchip market.

1. Buyers' technical requirements: their public announcement is the first event in this session, so that they act as the backdrop to the entire process.
2. Transportation costs: the sawmills are first invited to announce the cost of forwarding their merchandise to the different pulp and paper mills in the market. This public announcement is used as the basis for an auction on transportation costs where sawmills, carriers and paper mills compete openly so that transportation of the merchandise is paid for by those in a position to do so at the lowest cost.

These announcements form the core of the activity of a market session before the sale proper of woodchips begins. Allocation of output (who will sell or buy how much) takes place according to an auction process where buyers' bids are their demand schedule (which quantity of woodchips am I prepared to buy and at which prices) and sellers' bids are their supply schedule (which quantity of woodchips am I prepared to sell and at which prices). Buyers and sellers are invited to bid, to disclose their supply and demand, through a computer interface linked to a server.

The auction takes place in successive rounds. At the start of each round, buyers and sellers key in their bids on their microcomputers. Once the bids have been tallied, the system generates the quantities exchanged, purchase prices and selling prices. In light of this information, the players alter their bids on the basis of their appreciation of the state of the market, and a new round is initiated, ending in its turn with re-optimization of the system and disclosure of the new allocations. If no one wishes to change his bid after the prices and quantities are announced, efficient bilateral exchanges are deemed to have been determined.

An OPM session ends with the officialization of the bilateral exchanges that will take place during the period leading up to the next market session. The delivery and transportation schedules are then established.

The long-term contracts negotiated prior to the OPM sessions are inserted in the form of compensatory contracts. These contracts specify cash transfers that will be paid by the various parties. The structure of the financial compensation is such that a buyer is compensated if the price obtained on the OPM exceeds that negotiated in the contract, and vice versa for the seller. It is therefore necessary for these long-term contracts to specify a quantity and a price. So long as no price has been negotiated under a long-term agreement, this will not be considered by the OPM in the exchange optimization process.

Finally, the spot market enables sellers and buyers to clear stock quickly or to procure surplus woodchips. In this way, it helps paper mills and sawmills deal with unexpected contingencies.

Part II: Operation of the smart market

This section presents a detailed description of the smart market. First, in Section 1, we describe the operation of the Optimized Periodic Market (OPM). This market will be open at set intervals. The frequency remains to be determined: in this paper, we postulate one-month intervals. The OPM is distinguished by the complexity of its operation, over which, it should be noted, long-term contracts have no direct effect.

In Section 2, we describe how long-term contracts are negotiated and how they fit into the context of the OPM. Long-term contracts are interpreted by the OPM as compensatory contracts; if a seller obtains a price on the OPM lower than that negotiated in his long-term contracts, he will be compensated by the buyers with whom he negotiated those contracts. The converse applies when the buyer has to pay more than the negotiated price.

In Section 3, we present the operation of the spot market with regard to additional quantities to be exchanged during the period covered by the OPM.

Where necessary, the reader may refer to the two appendices following this paper. Appendix I presents a glossary of the different terms used in the paper. The more technical Appendix 2 explains the operation of the OPM optimization module.

1- Operation of the Optimized Periodic Market

The market opens up once a month. The woodchips available are classified by type: low density, high density and jack pine. Sellers may offer several types of woodchips separately if they grade their trees, otherwise they may offer only a single woodchip type corresponding to their main output.[1] Buyers take part in a single market bringing together the three types of woodchips. They must, however, specify the types of woodchips they wish to procure, and the quantities they wish to buy. Each OPM session takes place in three main stages: *pre-sale*, *sale* and *after-sale*.

First stage: Pre-sale

The pre-sale stage is divided into three distinct, sequential phases: *announcement of technical requirements and UTC*, *announcement of QAF*, and *adjustment of UTC and QAF*. A public announcement enables each party, in a first phase, to know the technical requirements of the buyers (paper mills) and the unit transportation costs (UTC) of the sellers (sawmills). In the second phase of the pre-sale, the sellers disclose their quality adjustment factors (QAF), calculated on the basis of the buyers' technical requirements as disclosed in the previous phase.

[1] Clearly, the industry will have to handle the task of establishing the different criteria defining woodchip types (high density, low density, jack pine or other). For instance, the following standard could be established. For a seller's woodchips to be classified in the "high density" category, they should not contain more than 5% jack pine. Beyond this threshold, a seller who is not in a position to grade his trees will have to identify his output as "jack pine" type woodchips.

These first two phases are followed by a final UTC and QAF adjustment phase. This phase permits negotiation between buyers and sellers. It is essentially a competitive phase, where buyers, sellers and carriers vie with each other to offer the best transportation costs between sawmills and paper mills.

Phase 1: Announcement of technical requirements and UTC

1. Announcement of technical requirements

Buyers express their own technical requirements. They do so by disclosing at the sale a table describing the quality of the woodchips they are asking for (excluding woodchip types - high density, low density, jack pine - which will be specified at the sale stage) and the penalties which will be applied in the event the delivery does not meet the specified technical requirements. All the technical requirements the buyers deem necessary may be announced.

2. Announcement of UTC

The sellers announce their unit transportation costs (UTC), that is, the costs they will have to sustain if they themselves have to handle the transportation of the woodchips sold to the paper mills, regardless of the transportation mode used. In Phase 1, it is the sellers (sawmills) which announce the UTC, but we shall see below (cf. Phase 3) that, at the end of the session, they are not necessarily the ones handling transportation of the merchandise and paying for it.

Once each UTC is announced, a transportation matrix may be generated. One could imagine such a transportation matrix for n vendors (V_1, V_2, …, V_i, …, V_n) and m buyers (A_1, A_2, …, A_j, …, A_m):

Table 1: Transportation matrix

	A_1	A_2	…	A_j	…	A_m
V_1	t_{11}	t_{12}				
V_2	t_{21}	t_{22}				
…						
V_i				t_{ij}		
…						
V_n						

Each t_{ij} indicates the UTC between seller i (source) and buyer j (destination). Thus, if t_{11} = $50, it is estimated that it would cost $50 to transport one unit of woodchips from seller V_1 to buyer A_1. Since it represents costs, a UTC is by definition positive or zero. If a sawmill considers that it cannot afford to deliver the merchandise to a given paper mill, it will then set for that paper mill a UTC substantially higher than for its other potential clients.

Phase 1 ends when all the tables of technical requirements have been received, along with every UTC. A deadline is then set.

Phase 2: Announcement of QAF

Phase 2 is initiated by the disclosure of the technical requirements defined during the previous phase. This information must be known by all market players so the sellers can provide their QAF, which depends directly on the buyers' technical requirements. This second phase must therefore necessarily include a set period of observation of buyers' technical requirements by the sellers.

1. Announcement of QAF

Once they have perused each buyer's technical requirements, the sellers determine and announce their QAF for each potential buyer. Once each QAF has been announced, a first technical matrix may be generated. Such a technical matrix could be imagined for the same n sellers (V_1, V_2, …, V_i, …, V_n) and m buyers (A_1, A_2, …, A_j, …, A_m):

Table 2: Technical matrix

	A_1	A_2	…	A_j	…	A_m
V_1	s_{11}	S_{12}				0
V_2	s_{21}	S_{22}				0
…						0
V_i				s_{ij}		0
…						0
V_n						0

Each s_{ij} indicates the QAF established by sawmill V_i to produce woodchips meeting the technical requirements of buyer A_j. Each s_{ij} indicates the additional premium which sawmill V_i requires to produce woodchips whose quality differs from the industry standard. In the table above, we have supposed that buyer A_m is asking for woodchips of the "industry reference" type. We thus obtain s_{im} = 0 for any i, that is, for all sawmills; s_{ij} is therefore positive, negative or zero depending on whether the quality of the woodchips requested is higher than, lower than or equal to the industry standard.

We could also find r_{ij} in the technical matrix. Rather than being an additive factor, that is, instead of corresponding to the additional premium demanded by sawmill V_i to produce woodchips whose quality differs from the industry standard, r_{ij} would instead be a multiplicative factor. In that case, when buyer j asks for the reference quality, then $r_{ij} = 1$ for any i. An $r_{ij} = 1.1$ indicates, for instance, that it costs sawmill i the equivalent of 1.1 tonnes of reference woodchips to produce one tonne of woodchips of the quality demanded by buyer j. Similarly, $r_{ij} = 0.9$ indicates that it costs sawmill i the equivalent of 0.9 tonnes of standard woodchips to produce one tonne of woodchips of the quality demanded by buyer j.

It is possible to use either parameter, s_{ij} or r_{ij}. It is also possible to use both together. The choice will have to be made so as to reflect the actual situation as closely as possible.

Phase 2 ends when each QAF has been received.

Phase 3: Adjustment of UTC and QAF

Once Phase 2 has been completed, the transportation matrix generated in Phase 1 is disclosed. Phase 3 must necessarily begin with a period for observation of this matrix by all market players. As these potentially include third parties (carriers), the transportation matrix must therefore be known to everyone.

Phase 3 is first of all a phase of UTC adjustment. Each UTC potentially becomes the subject of a small auction among buyers, sellers and potential carriers. A paper mill may, during this phase, announce a UTC lower than that initially announced by a sawmill. When a paper mill announces such a UTC, it automatically commits itself to meeting the transportation costs on this segment. Similarly, a third party ("carrier") so inclined could undertake to pay for transportation at a UTC below the buyer's or seller's.

Furthermore, during this phase, the sawmills are also authorized to re-evaluate their QAFs. These re-evaluations may stem from direct negotiations between buyers and sellers, since the flexibility of the system in fact allows buyers to intervene with their potential suppliers to lower their costs, in particular their QAF. That is why each buyer will receive at the start of Phase 3 only the information that concerns him in this regard. The technical matrix is not to be made public. On the other hand, buyer A_j will have to receive the information in column j of this matrix. Column j lists the QAF of each sawmill corresponding to the technical requirements disclosed by buyer A_j in Phase 1. Armed with the information thus conveyed to them, the buyers will be able to intervene on an ad-hoc basis with the sawmills and force them to re-evaluate the QAF set by them to meet their customers' technical requirements.

The closure of Phase 3 also marks the end of the pre-sale stage. This first stage may end at a pre-set moment (for instance, 12 hours prior to the start of the sale proper), or if no change has been recorded in the UTC or QAF within the prescribed time (for example, five minutes).

Second stage: Sale

The sale essentially involves successive rounds during which the buyers indicate the quantities of woodchips they wish to buy during the following month (period between each market session), the different prices they are prepared to pay, and the proportions of the woodchip types they are interested in. While the sellers do the same for the quantity of each type of woodchips they are prepared to sell at different prices.[2] It is from this information that the system will calculate and determine the optimal allocation, that is, the best allocation of woodchips from the standpoint of efficiency. Bilateral exchanges (which sawmill will sell to which paper mill, which quantities will be exchanged on each market, and at which prices) will be determined at the end of the sale.

Each round includes two distinct, successive phases: a first phase of *submission of bids*, and a second phase of *optimization*. The submission of bids phase determines the input of the optimization

[2] From a seller's viewpoint, each woodchip type (high density, low density and jack pine) may be exchanged on a separate market. In practical terms, the offers of a seller whose batch includes three types of woodchips will be made on three "markets".

problem whose output will determine the bilateral exchanges on each market. In light of the results of this optimization process, another round is triggered in order to enable the players, in line with the eligibility rule, to re-evaluate their supply or their demand. The system is optimized, and a matrix of bilateral exchanges is calculated in each round.

Progress of first round

To start with, the sellers must provide a list - valid for the duration of the sale - of the types of woodchips they wish to sell. Depending on the classification of their woodchips and their ability to grade the species, they will have the choice of offering woodchips of high density, low density and jack pine. A sawmill may offer more than one woodchip type only if it is able to grade its trees and woodchips. A seller who does not grade his woodchips will be able to offer only one of the three types of woodchips corresponding to his "average" woodchip type.

The buyers take part in a single market bringing together the three types of woodchips. They must, however, specify the minimum and maximum proportions of each type of woodchips they wish to obtain. For instance, a buyer whose recipes require no more than 30% high density woodchips, a minimum of 70% low density woodchips and no jack pine chips will specify accordingly the proportions he is seeking in the recipe table:

Recipe table

Woodchip type	Minimum percentage	Maximum percentage
Low density	70	100
High density	0	30
Jack pine	0	0
Total:	**70**	**130**

Since the value of each woodchip type is not necessarily the same, a seller may offer, for a given price, different quantities of each type of woodchips, provided he apportions his offer to the three different markets.

For the buyers, the situation is different. What matters to them is the total quantity, average price and composition (proportion of each woodchip type in the total quantity purchased) of the woodchips. So the demand is grouped together within a single market, and buyers are permitted to specify the proportions they want. The average price, but also the price of each woodchip type purchased as well as the quantity obtained will be disclosed in each round. The buyers will then be able to reduce or increase the quantities requested and the proportions announced in light of this information.

1. Submission of buyers' bids

Each buyer must provide a demand schedule, that is, a series of pairs (price, quantity) each indicating the number of woodchip units desired and the corresponding price. These are the prices that have been defined as paper mill acquisition prices: what a buyer is prepared to pay to procure a given quantity of woodchips corresponding to his technical requirements. Paper mill acquisition prices therefore include transportation costs, regardless of who actually pays for them.

To complete his demand schedule, a buyer must first ask himself the following question: how many woodchip units would I be prepared to buy if the price were set at x, y, and so on? Normally, the lower the price is, the larger are the quantities requested. In answering this question, the buyer establishes a relationship between the price and the quantity requested, and it is this relationship which enables him to draw his *private demand curve*. The demand schedule must be designed from this *private demand curve*. In fact, the buyer must disclose a number of points, (price, quantity) pairs, that will form his demand schedule and from which his *disclosed demand curve* will be constructed.

A buyer's demand schedule consists of a list of prices arranged in descending order, with which requested quantities are associated, necessarily in ascending order.

A demand schedule will always be accompanied by a recipe table enabling buyers to specify the desired proportions of each woodchip type. Each buyer must therefore complete his recipe table, respecting the following constraints:
(1) Minimum ≤ Maximum for each woodchip type
(2) Sum of minimums ≤ 100%
(3) Sum of maximums ≥ 100%.

The demand schedule and recipe table represent buyers' first-round «bid». In fact, each buyer discloses a certain number of points which will form his disclosed demand curve and his requirements as to woodchip types. The series formed by the demand schedule and the recipe table accompanying it will typically take the following form:

Table 4: Demand schedule and recipe table

Unit price	**Total quantity** (in thousand units)
130	10
125	20
120	30
115	35
110	40
108	45
107	48

Woodchip type	Minimum percentage	Maximum percentage
Low density	50	70
High density	20	50
Jack pine	0	20
Total:	**70**	**140**

The demand schedule is interpreted as follows:

- at a price above $130, the buyer asks for quantity nil; by convention, and without the buyer having to specify it, the system will create the (price, quantity) pair (131, 0) to incorporate the information disclosed by the buyer whereby $130 is the maximum price at which he is prepared to purchase;
- at a price of $130, the buyer asks for 10,000 units;
- at a price between $125 and $130, the buyer asks for a quantity between 10,000 and 20,000 units;
- at a price of $125, the buyer asks for 20,000 units;
- at a price between $120 and $125, the buyer asks for a quantity between 20,000 and 30,000 units; and so on for the subsequent prices;
- at a price below $107, the buyer always asks for 48,000 units -- this represents as it were his maximum demand. By convention, and without the buyer having to specify it, the system will create the (price, quantity) pair (0, 48,001) to incorporate the information disclosed by the buyer whereby a price below $107 will have no significant impact on the quantity he asks for.

To fill in the spaces in the demand schedule established by the buyer, the system draw straight lines.

The recipe table is interpreted as follows:

- the total quantity of woodchips desired must contain no less than 50% low density woodchips;
- the total quantity of woodchips desired must contain no more than 70% low density woodchips;
- the total quantity of woodchips desired must contain no less than 20% high density woodchips;
- the total quantity of woodchips desired must contain no more than 50% high density woodchips;
- the total quantity of woodchips desired must contain no more than 20% jack pine woodchips.

2. Submission of sellers' bids

At the same time, the sellers provide their supply schedules, or bids. A seller offering more than one woodchip type must submit an equivalent number of supply schedules. Like the buyers, a seller, to complete his supply schedule, must first ask himself the following question: how many woodchip units would I be prepared to sell if the price was set at x, y, and so on? Normally, the lower the price is, the smaller the quantities offered will be. In answering this question, the seller establishes a relationship between the price and the quantity offered, and it is this relationship which enables him to draw his *private supply curve*. The supply schedule must be designed from this *private supply curve*. In fact, the seller must disclose a certain number of points, (price, quantity) pairs, which will form his supply schedule and from which his *disclosed supply curve* will be constructed.

A seller's supply schedule consists of a list of prices in ascending order with which quantities offered are associated, necessarily in ascending order.

The sellers provide their supply schedules for *reference* woodchips. The sellers therefore disclose a certain number of points which will form their disclosed supply curves. A supply schedule provided by a seller will take the following form:

Table 5: Supply schedule

Unit price	**Total quantity** (in thousand units)
80	5
85	7
90	8
95	9
100	10

This supply schedule is interpreted as follows:

- at a price below $80, the seller offers nothing; by convention, and without the seller having to specify it, the system will create the (price, quantity) pair (79, 0) to incorporate the information disclosed by the seller whereby $80 is the minimum price at which he is prepared to sell;
- at a price of $80, the seller offers 5,000 units;
- at a price between $80 and $85, the seller offers between 5,000 and 7,000 units;
- at a price of $85, the seller offers 7,000 units;
- at a price between $85 and $90, the seller offers between 7,000 and 8,000 units; and so on for the subsequent prices;
- at a price above $100, the seller always offers 10,000 units -- this is as it were his production capacity. By convention, and without the seller having to specify it, the system will create the (price, quantity) pair (a, 10,001), where *a* is an arbitrarily high price, to incorporate the information disclosed by the seller whereby raising the price above $100 will have no significant impact on the quantity he offers.

To fill in the spaces between the points on the seller's supply schedule, the system draws straight lines.

The first-round bid submission phase can end when all bids (demand and supply schedules) have been received, or at a pre-determined time.

3. Optimization

The system calculates optimal allocations (prices and quantities) -- those which maximize the efficiency of the market[3] -- from all the demand and supply schedules provided by the players,

[3] For a more comprehensive discussion of the characteristics of the allocations calculated by the system, see Appendix 2: Optimization module.

including the buyers' recipe tables. This information is placed against the transportation matrix and the technical matrix. Once the optimization process is completed, the system generates the bilateral exchange matrix (matrix of optimal quantities) stemming from the bids. For a given market, the matrix will typically have the following shape:

Table 6: Bilateral exchange matrix

	A_1	A_2	…	A_j	…	A_m
V_1	q_{11}	q_{12}				
V_2	q_{21}	q_{22}				
…						
V_i				q_{ij}		
…						
V_n						

Each q_{ij} indicates the total quantity of woodchips that will be exchanged between buyer A_j and seller V_i if no one expresses a desire to modify his bid. At the end of the optimization process, each player receives only the information concerning him. The seller receives separate quantity and equilibrium prices for each woodchip type offered. The buyer also receives a price and equilibrium quantity for each woodchip type, in addition to the weighted average of prices and the sum of the quantities he has obtained. It is from the latter information that he will be able to alter his bid.

In view of transportation costs, the selling price and purchase price for a particular type of woodchips are not equal, and are generally different for all market players. *Readers interested in the mathematics of this problem are referred to Appendix 2 of this paper.*

For instance, for buyers whose preferences we established in Table 4, the unit equilibrium price could be $115 for a given market. At a price of $115, our buyer obtains the 35,000 woodchip units requested. Of course, for the equilibrium price set by the optimization process to be exactly the same as the price for which the buyer has defined a requested quantity is a matter of chance. Let us take a more realistic example, namely an equilibrium price set at $112.50. The quantity asked for and obtained is then determined according to the straight line automatically drawn by the system between the (price, quantity) pairs (110, 40) and (115, 35). As the equilibrium price exactly divides the price interval in two (for simplicity of explanation), the quantity that will be attributed to the buyer will correspond to 37,500 woodchip units. Table 7 gives an idea of what the information provided to the buyer by the system could be. A new (price, quantity) pair has been added to it to indicate the price and the equilibrium quantity in this particular case.

Tableau 7: Information received by the buyer after the first round

Unit price	**Total quantity** (in thousand units)
130	10
125	20
120	30
115	35
112.50	*37.5*
110	40
108	45
107	48

Type	**Quantity**	**Price**
Low density	18.75	114.50
High density	11.25	110.83
Jack pine	7.5	110
Total	**37.5**	**112.5**

Supposing that for the supplier the equilibrium price is $92.50, then the quantity offered and potentially sold by this supplier will be 8,500 woodchip units. Table 8 illustrates the information obtained by this supplier, including the new pair added to the new equilibrium price.

Table 8: Information received by the seller after the first round

Unit price	**Total quantity** (in thousand units)
80	5
85	7
90	8
92.50	8.5
95	9
100	10

Note that the price announced to the buyer will not be the same as the one announced to the sellers. For instance, if two sawmills supply the same paper mill with woodchips, the offers it will make to each of them will be different. In fact, the sawmill farther away will receive a lower offer, since transportation costs are higher in its case. Conversely, if a sawmill sells woodchips to two paper mills, the paper mill farther away will have to pay more.

Progress of subsequent rounds

Once the first-round allocations are known, buyers and sellers may be interested in altering their bids. Upon the announcement of the start of the second round, the players are authorized to alter their demand or supply schedules. The buyers may also alter their recipe tables. A round may end at a pre-set time or when all bids have been received. It could also end if no change in bids has been recorded within a pre-set period.

Following the bidding period for each round, the system calculates a new matrix for prices and optimal quantities. Each player receives the new information concerning him and then decides whether to alter his bid in the following round. The process continues, with one round following another so long as any players wish to alter their bids. It ends when there is no more activity on the market when the allocations (prices, quantities) are announced. Such an adjustment process allows each participant to obtain the quantities desired even if initially the participant does not know how much he must bid to obtain those quantities.

1. Changes to buyers' bids according to the eligibility rule

In an auction process involving successive rounds such as this one, it may be beneficial to establish *eligibility rules* whose function is to give impetus to the market. These are, in fact, rules which prompt participants to bid in line with their true preferences as early as possible and to be active in the market.

Let us take a moment to look at the eligibility rule for buyers. It would be reasonable to envisage a rule where a buyer wishing to raise his bid (to ask for more at certain prices) would have to do so in the next round, subject to not being able to do so in subsequent rounds. Such a rule would avoid having players merely watch the market for too long before intervening, thus unduly dragging out the sale phase.

Let us first establish two general restrictions on changes in bids from one round to the next:

1- *A player may only raise his bid.*
2- Nevertheless, *his bid is limited by a «maximum eligibility quantity».*

The first restriction implies that a player may only increase the quantities bid upon initially. He may in fact raise them, but the new quantities may not exceed the maximum eligibility quantity. This quantity is initially set on the basis of the maximum quantity bid upon in the first round.

For a buyer for whom Table 7 represents the first (first-round) bid, the maximum eligibility quantity is set at 48, for all prices. In subsequent rounds, the maximum eligibility quantity at the equilibrium price will be modified, and will correspond to the new quantity bid upon at this price. In addition, the maximum eligibility quantities for prices above the equilibrium price will correspond to the lesser of the quantity bid upon at the equilibrium price (after the change) and the current maximum eligibility quantity.

A buyer may also modify his recipe table. Two restrictions also apply to these changes:

1- *The new minimum must be smaller than or equal to the former minimum corresponding to the same woodchip type.*
2- *The new maximum must be greater than or equal to the corresponding former maximum.*

Thus, the previous allocations can always be realized, that is, they still comply with the new minimum and maximum proportions requested.

Thus, let us suppose that our representative buyer wishes to alter his bid in light of the allocation he receives after the first round. He may do so by raising the quantity he asks for at the equilibrium price ($112.50), by lowering the minimum proportions and/or by raising the maximum proportions in the recipe table. He could decide to alter his bid in this way for the following round (which we shall call Round 2):

Table 9: Demand schedule bid in Round 2 and recipe table

Unit price	**Total quantity** (in thousand units)	**Maximum eligibility quantity**
130	10	43
125	20	43
120	30	43
115	35	43
112.50	*43*	*43*
110	40	48
108	45	48
107	48	48

Woodchip type	Minimum percentage	Maximum percentage
Low density	40	70
High density	20	50
Jack pine	0	20
Total:	**60**	**140**

Our buyer has therefore decided to raise his bid at the equilibrium price ($112.50) by 5,500 units, bringing his total quantity asked for to 43,000, and to lower the minimum proportion of low density woodchips to 40%. It is important to note that he could have bid up to a total quantity of 48,000 - his larger quantity initially requested.

The maximum eligibility quantity is then 43 for all prices above than or equal to $112.50. By choosing to bid a quantity of 43 at $112.50, the buyer will lose the chance to purchase more than 43 units unless the price falls again. At prices below $112.50, the maximum eligibility quantity remains unchanged.

The demand curve therefore now includes the (price, quantity) pair (112.50, 43). The buyer could also have raised his quantity bid upon to any price whatsoever, provided he complied with the maximum eligibility quantity for each price. In order to comply with the restriction stated above, whereby demand curves necessarily have a negative slope, the system automatically eliminates pairs which are out of sequence, such as the (110, 40) pair.

Let us suppose that instead of changing the quantities at the equilibrium price, the participant changes his quantity bid upon at $115 to 44. Now the demand curve will no longer have a negative slope, but the system will accept the bid anyway and will adjust the quantity requested at the equilibrium price. We will then obtain, by construction, a total quantity requested and a maximum eligibility quantity at $112.50 (and at the price above $112.50) of 46.

Let us return to the case where the buyer revises his quantity at the equilibrium price and sets it at 43, and let us suppose that after Round 2 the price rises to $117. The new information received by the buyer is as follows:

Table 10: Information received after Round 2

Unit price	**Total quantity** (in thousand units)	**Maximum eligibility quantity**
130	10	43
125	20	43
120	30	43
117	*33*	*43*
115	35	43
112.50	43	43
108	45	48
107	48	48

Type	**Quantity**	**Price**
Low density	13.2	120.50
High density	13.2	116
Jack pine	6.6	112
Total	**33**	**117**

Our buyer now obtains 33,000 units (rather than 37,500 after Round 1). If he then considers that the quantity he is obtaining on the market is insufficient, he may raise his bid at the new equilibrium price or at any other price up to his maximum eligibility quantity. Let us suppose that he decides to take advantage of this opportunity and raise his bid at the equilibrium price by 2,000 units, bringing his bid up to 35,000 units, and that he decides not to change his recipe table at all. Table 10 shows this buyer's bid in Round 3:

Table 11: Demand schedule bid in Round 3 and recipe table

Unit price	**Total quantity** (in thousand units)	**Maximum eligibility quantity**
130	10	35
125	20	35
120	30	35
117	35	35
115	35	43
112.50	43	43
108	45	48
107	48	48

Woodchip type	Minimum percentage	Maximum percentage
Low density	40	70
High density	20	50
Jack pine	0	20
Total:	**60**	**140**

The $115 line is automatically eliminated by the system so that the demand curve remains downward. Note that the system favours the higher of the two prices corresponding to a total quantity of 35.

Let us now look finally at the last figure possible. Let us suppose that after Round 3 the equilibrium price has fallen back down to $108, because supply, for instance, has risen more than demand. The maximum eligibility quantity corresponding to this price is 48,000 units. Owing to this price drop, the buyer could decide to raise his quantities bid at the new equilibrium price ($108) with a view to Round 4. He will then define a new (price, quantity) pair, for instance (108, 46). Table 11 shows our buyer's bid in Round 4:

Table 12: Demand schedule bid in Round 4

Unit price	**Total quantity** (in thousand units)	**Maximum eligibility quantity**
130	10	35
125	20	35
120	30	35
117	35	35
112.50	43	43
108	*46*	*46*
107	48	48

Note that the new maximum eligibility quantity associated with the equilibrium price (46,000) has no effect upon maximum eligibility quantities at higher prices. This is so because the buyer, when the price was $117, did not feel it necessary to bid more than 35,000 units. There is no valid reason for this to have changed. If the equilibrium price were to climb back over $117, the maximum quantity the buyer could bid would still be 35,000 units. *Thus, the maximum eligibility quantity for a given equilibrium price is always lower than or equal to the maximum eligibility quantities of prices below it.* This latter example illustrates precisely the function of an eligibility rule: to prompt the fastest possible convergence of bids toward players' true preferences.

2. Changes to sellers' bids in accordance with the eligibility rule

The eligibility rule applies to buyers in the same way that it does to sellers, but in reverse. It applies separately to each woodchip type offered.

Let us look again at the example of the allocation received by the seller after the first round, and let us suppose that he wishes to alter his bid by raising the quantity offered to 9.5:

Table 13: Supply schedule bid in Round 2

Unit price	**Total quantity** (in thousand units)	**Maximum eligibility quantity**
80	5	9.5
85	7	9.5
90	8	9.5
92.50	*9.5*	*9.5*
95	9	10
100	10	10

The maximum eligibility quantity therefore becomes 9.5 for all prices *below* or equal to $92.50. Note that the maximum eligibility quantity for a given equilibrium price is always less than or equal to the maximum eligibility quantities of prices *above* it.

Also, to comply with the restriction whereby supply curves necessarily have a *positive* slope, the system automatically eliminates the (95, 9) pair, which is now out of sequence.

2- Operation of the long-term compensatory market

Current practices in the present woodchip market are primarily based upon long-term agreements, that is, agreements whose application extends for one year or more. Long-term contracts between sawmills and paper mills primarily cater to paper mills' need for steady provisioning. Any market mechanism for woodchips will have to take this fact into account.

A long-term contract is a promise made by a sawmill to a paper mill to deliver a certain quantity of woodchips at a certain price, according to a given schedule. As we mentioned earlier, it is essential for the prices negotiated to appear in long-term contracts so they can be incorporated into the OPM's exchange optimization process.

To ensure consistency between the long-term market and the medium-term market (OPM), some adjustments to current trade practices will be necessary. These adjustments stem from the pursuit of two sometimes competing objectives, namely, efficiency and continuity. While continuity and market stability require the maintenance of long-term agreements, market efficiency calls for them to be somewhat relaxed.

We propose that the long-term market be governed by *compensatory contracts*. Under a compensatory contract system, long-term agreements concern financial flows alone, as opposed to actual flows (actual physical exchanges of woodchips). A long-term compensatory contract between a sawmill and a paper mill will typically take the form of a guaranteed price for a given quantity of woodchips and will therefore have to specify a guaranteed price and quantity for periods corresponding to the intervals between OPM sessions. For instance, if the OPM opens up every month, a quantity and a price will have to be negotiated for each month.

This long-term market is similar to existing futures markets. On a futures market, such as Chicago for instance, futures contracts are negotiated for a given quantity of a commodity. Players who exchange a commodity on the futures market generally have no intention of going ahead with the "physical" transaction stipulated in their contract. Their only interest is in the financial flows. On the long-term compensatory contract market for woodchips involved here, as on any other futures market, the paper mills and sawmills will be able to protect themselves against any unfavourable movement in the price of woodchips, while the actual exchanges are nevertheless still determined by the OPM.

Compensatory contracts will be negotiable according to customary trade practices or, again, it will be possible to enhance the flexibility of the long-term market by setting up negotiations assisted by electronic tools similar to those developed for the OPM. A long-term compensatory contract will not be able to deal with more than one type of woodchips (high density, low density or jack pine). It may be worded in terms of sawmill selling price, paper mill acquisition price, or both together.

Real flows, that is, exchanges of woodchips, are determined for each month (hypothetically) upon the closure of the OPM. Let us consider, for instance, the case of sawmill i and paper mill j, bound by an annual compensatory contract, and let us suppose that for a UTC of 10 and a QAF of 0, they negotiated during the first month of the year 100 amt of woodchips at a *sawmill selling price* (Pv) of $100/amt equivalent to a *paper mill acquisition price* (Pa) of $110/amt. Both facilities participate in the OPM, which then determines actual flows. At an OPM session, supply and demand for all facilities in the industry are compiled, and the market is optimized so as to determine the bilateral exchanges which will take place during the month. At the end of the session, the paper mill obtains a certain quantity of woodchips for which it will have to pay a price determined by the optimization module, and the sawmill receives the mandate to deliver a certain quantity of woodchips for which it will be paid a given amount.

The compensation mechanism is therefore a sort of guarantee, for anyone receiving an unfavourable price on the OPM will be compensated by his partner. For example: if the selling price is $95/amt, sawmill i will receive $500 in compensation, at the rate of $5 for each 100 amt pre-negotiated. Conversely, if the price is $115/amt, paper mill j will receive $5 in compensation for each 100 amt negotiated. This compensation is regardless of whether or not sawmill i delivers to paper mill j. Note that paper mill j's purchase price must not be more than $10 (UTC between i and j) higher than the selling price obtained by sawmill i, otherwise paper mill j would find it advantageous to purchase its woodchips from sawmill i and would re-establish the differential at $10. Thus, the paper mill will have to compensate sawmill i only if it receives a purchase price below the $110/amt negotiated. Similarly, sawmill i will not compensate paper mill j unless it receives a selling price higher than the $100/amt negotiated.

Note that regardless of the quantity actually exchanged by either party, the amount paid in compensation is calculated on the basis of the quantity negotiated (the quantity appearing in the contract). Note also that only long-term contracts negotiated in the form of compensatory contracts, as established above, will be included in the OPM compensation mechanism. Very long-term agreements which specify no price are quite simply not taken into consideration by the OPM.

In more general terms, we propose the following rules, where $P_{ij}*$ is the price negotiated at the paper mill and $Q_{ij}*$ the quantity negotiated.

(1) If $Pa_j \leq P_{ij}* \leq (Pv_i)r_{ij} + t_{ij} + s_{ij}$, that is, if the price negotiated by compensatory contract lies between the paper mill acquisition price and the sawmill selling price as established by the OPM, then no compensation is paid.[4] Here, no compensation is necessary, since each party receives at least as good a price as that negotiated in the long-term contract. Note that it is possible to have $Pa_j < (Pv_i)r_{ij} + t_{ij} + s_{ij}$, if the OPM determines that it is not mutually beneficial for i to deliver to j.

(2) If $P_{ij}* \leq Pa_j \leq (Pv_i)r_{ij} + t_{ij} + s_{ij}$, that is, if the price negotiated by compensatory contract proves to be lower than the paper mill acquisition price and the sawmill selling price as determined by the OPM, then compensation equal to $(Pa_j - P_{ij}*)\ Q_{ij}*$ is paid by the seller to the buyer. Here, the buyer must be compensated because the OPM price is higher than the negotiated price. The seller may pay this compensation because, for his part, he receives a beneficial price.

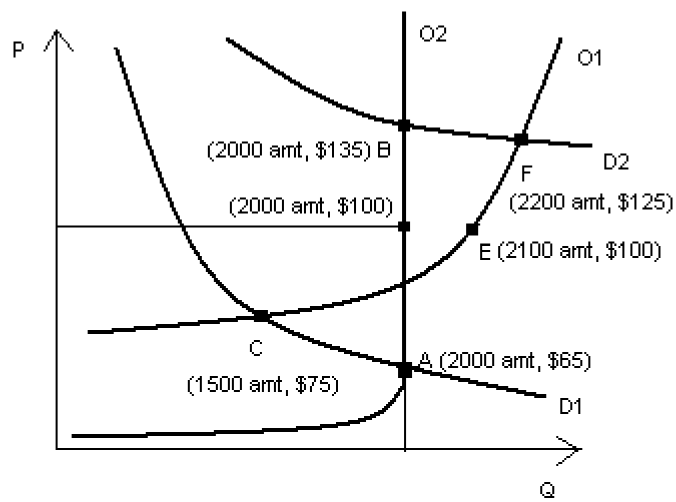
[4] The mathematical formula $(Pv_i)r_{ij} + t_{ij} + s_{ij}$ corresponds to the sum of the sawmill selling price (weighted by the multiplicative QAF where defined), the UTC and the additive QAF (where defined), established between sawmill i and paper mill j. On this topic, see Appendix 2: Optimization module.

(3) If $P_{ij}* \geq (Pv_i)r_{ij} + t_{ij} + s_{ij} \geq Pa_j$, that is, if the price negotiated by compensatory contract proves to be higher than the paper mill acquisition price and the sawmill selling price as determined by the OPM, then compensation equal to $(P_{ij}* - ((Pv_i)r_{ij} + t_{ij} + s_{ij})) Q_{ij}*$ is paid by the buyer to the seller. Here, it is the seller who must be compensated because the OPM grants him a lower price than the price guaranteed to him by the contract. Since the paper mill obtains on the OPM a price below the negotiated price, it can afford to pay the compensation.

Note that the above-mentioned compensation rules guarantee each party at least the equivalent of what was negotiated in the long-term contracts.

Let us consider, for instance, the case where a seller has negotiated a long-term contract with a buyer guaranteeing him a price of $100/amt for 2000 amt. Let us suppose that the seller's true supply curve (corresponding to actual costs per additional unit) is given by Offer O1.

Figure 1



In this example, the sawmill would agree to sell 2100 amt at the price of $100/amt (point E).

If the sawmill submits offer O2 to the OPM, it ensures that the status quo is maintained. In fact, whether its partner's demand passes through Point A (Demand D1) or Point B (Demand D2), the equilibrium quantity remains 2000 amt. In one case the price is $65, and in the other $135, but this does not much matter, since the compensation rules guarantee that the net price for the sawmill will remain $100, as negotiated.

The sawmill could do better than Offer O2 by submitting, for instance, its true supply curve. If its partner's demand passes through Point C (1500, 75), the sawmill will sell fewer woodchips. The net price of its 1500 amt of woodchips will be $100/amt and, moreover, the sawmill will receive $25 ($100 - $75) in compensation for the 500 amt negotiated in addition, but not sold. For the sawmill, this situation is beneficial, since normally the sawmill was to deliver an additional 500 amt, for each of which it would receive only $75 extra, or less than its production costs. If the buyer's demand passes through Point F, the sawmill is also a winner. It sells 2000 amt at $100 each, but also an additional 200 amt at $125, or a price higher than its production cost.

Thus, the OPM compensation rule and renegotiation mechanism offer a procedure guaranteeing:

- each player at least the equivalent of what is negotiated in the long-term contract;
- all agents the opportunity, where appropriate, of discovering and realizing profits from the exchange which had not been realized.

3- Operation of the spot market

The spot, or short-term, market is an instrument which enables sawmills to liquidate their surpluses and paper mills to acquire an additional quantity of woodchips as they need it. A cap will, however, be set based on the maximum percentage of quantities purchased or offered on the Optimized Periodic Market, in order to keep the largest possible quantity of woodchips available and thus ensure the efficiency of the OPM. The woodchips exchanged on the spot market must be delivered during the period between the last OPM session and the next one.

This market may, just like the OPM, operate by means of an electronic auction system. In that case, a BBS is installed, through which each participant initiates an auction to sell or buy woodchips. An offer to purchase or to sell specifies the woodchip type, the floor or cap price, the quantity, the type of auction used, and the date and time of the start and end of the sale, while a bid must specify a price and a quantity. The technical requirements, UTC and QAF disclosed during the latest session of the OPM are considered as being the same and will be used to make the conversion between sawmill selling prices and paper mill acquisition prices.

The market may also be anonymous or nominal, that is, the offers to sell or purchase might or might not be identified, as well as the winning bids. In an anonymous market, participants do not know the bidders' identity. All information, namely, UTC and QAF, is conveyed through a filter. For instance, for an offer to sell, the price displayed is the paper mill acquisition price, transportation and QAF included. For an offer to purchase, the price displayed will be the sawmill selling price, transportation and QAF excluded.

The spot market is a decentralized market. Several auctions may therefore take place at once. Nonetheless, all the sales could occur, as with the OPM, in a common virtual site where all spot market auctions would be announced.

Several types of auctions may be used. The market could offer participants submitting an offer to sell or purchase the possibility of choosing the type of auction they wish to use. The market must, however, be clear and clearly specify the rules for each type of auction along with bid priority rules.

Here is an example of the mechanism that could be used. It involves simultaneous multi-unit open discriminant auctions. These auctions are called simultaneous multi-unit because several units of the same commodity, specifically woodchips, are sold or purchased at once. The sales are also described as open since the bids are made public as and when they are made, unlike the closed auction where no information is given to participants until the bidding period is over. Also, in an open auction, participants may modify their bids as they wish, depending on other participants' bids. Finally, the last characteristic concerns the price paid by the winner or winners. An auction is said to be discriminant or first-price when the winners pay the amounts of their bids. Conversely, an auction is said to be non-discriminant or second-price when the winners pay only the amount of the highest bid rejected or the lowest bid accepted.

Onsale, the largest, most complex site offering merchandise for auction on the Web, uses algorithms for discriminant and non-discriminant simultaneous open auctions. The auctions may last from several minutes to several days. *Priority rules* for ranking bids (price, quantity and time rules, etc.)

are set, as is an *end-of-auction rule*. For an offer to sell, bids are first ranked in descending order of price, then of quantity, and finally in chronological order (from the oldest to the most recent). For an offer to purchase, bids are first ranked in ascending order of price, then in descending order of quantity, and finally in chronological order (from the oldest to the most recent). Also, the sale terminates if no bid has been received five minutes before a pre-set time, otherwise it continues and ends five minutes after the last bid is received. The winners are those who make the best offers (highest selling price in the case of a sawmill, lowest purchase price in the case of a paper mill). The quantities are apportioned among the winners in order of priority. It may therefore happen that a winner does not receive the quantity he requested, but a lower quantity corresponding to the residual quantity of the offer to sell or purchase.

Let us now look in more concrete terms at how the spot market operates, depending on whether it is nominal or anonymous.

Nominal spot market

Offer to purchase

Let us suppose that paper mill j wishes to make an offer to purchase. It then completes a form in order to provide the necessary information, namely, the maximum price it is prepared to pay (paper mill acquisition price), quantity requested, woodchip type desired, auction type, and date and time of end of auction. An auction is then organized among interested sawmills.

Let us suppose that sawmill i wishes to take part. It will then have access to the information in the offer to purchase and will know the identity of the paper mill that provided it. It will also be able to know the condition of the market, that is, winning bids to date (price, quantity, and date and time of bid) as well as the identity of the winners. Bids are ranked in order of priority as described above (ascending Pa).

Since the identity of the paper mill is disclosed, the sawmill knows the UTC and QAF associated with this paper mill. It can then easily convert the purchase price announced by the paper mill into a selling price by means of the following formula:

$$(1) \quad Pa_j = Pv_i + t_{ij} + s_{ij} .$$

It can also easily calculate the selling price it must offer to beat rival bids. Let us suppose that Pa1 is the purchase price of the winning bid. The selling price which sawmill i has to offer to beat this bid will therefore be as follows:

$$(2) \quad Pv_i < Pa1 - t_{ij} - s_{ij} .$$

Offer to sell

Let us now suppose that sawmill i wishes to make an offer to sell. Like a paper mill in the case of an offer to purchase, it must complete a form to provide the information necessary for the sale, namely, the minimum price it is prepared to accept (sawmill selling price), quantity offered, woodchip type, auction type, and date and time of end of auction. An auction is then organized among interested paper mills.

Let us suppose that paper mill j wishes to take part. Like the sawmill in the case of an offer to purchase, it will then have access to the information in the offer to sell and will know the identity of the sawmill which provided it. It will also be able to know the condition of the market, that is, winning bids to date (price, quantity and date and time of bid) as well as the identity of the winners. This time, bids are ranked in order of priority (descending Pv).

Still using the same form (Form 1), the announced selling price can easily be converted by the paper mill into a purchase price. Similarly, the purchase price which paper mill j must offer to be able to beat the existing bid is calculated as follows:

$$Pa_j > Pv1 + t_{ij} + s_{ij}$$

where Pv1 is the selling price of the winning bid.

Anonymous spot market

In the anonymous market, the identity of the paper mill or sawmill which initiates an auction, as well as the identity of participants in the sale, remains secret, since prices are disclosed through a filter which preserves each party's anonymity.

Offer to purchase

Paper mill j wishing to make an offer to purchase must provide the same information as in the nominal market, except of course for its identity. In this case, however, the maximum price set by the paper mill is automatically converted into a selling price using the following formula:

$$Pv_i = Pa_j - t_{ij} - s_{ij}$$

where Pa_j is the maximum purchase price announced in the offer to purchase.

The amount of the winning bids is also automatically converted into a selling price, which the sawmill may interpret directly as the price to beat. For instance, let us suppose that sawmill k made the best bid (offered the lowest purchase price to paper mill j), then the selling price disclosed to sawmill i (Pv1) will be calculated as follows:

$$Pv1 = Pa1 - t_{ij} - s_{ij}$$

where $Pa1 = Pv_k + t_{kj} + s_{kj}$.

Offer to sell

Let us suppose that sawmill i makes an offer to sell. Once again, the information provided by the sawmill is the same as in the nominal market. As for offers to purchase, it is the information disclosed to the paper mills that is different. The identity of the sawmill making the offer to sell is not disclosed to the paper mills, and the minimum amount of the offer to sell is automatically converted into a purchase price for the paper mills in order to preserve the sawmill's anonymity. In fact, for paper mill j, the minimum purchase price disclosed is:

$$Pa_j = Pv_i + t_{ij} + s_{ij}$$

where Pv_i is the minimum selling price announced in the offer to sell.

The amount of the winning bids is also automatically converted into purchase prices which the paper mill can interpret directly as the prices to beat. For instance, let us suppose that paper mill n made the best bid (it offered the highest selling price to sawmill i), then the purchase price disclosed to paper mill j, Pa1, will be calculated as follows:

$$Pa1 = Pv1 + t_{ij} + s_{ij}$$

where $Pv1 = Pa_n - t_{in} - s_{in}$.

Let us now illustrate this with an example. Let us suppose that sawmill i has surplus woodchips to sell. It then makes an offer to sell on the anonymous spot market. Let us suppose that the offer to sell concerns 10 amt of low density woodchips offered at a minimum price Pv_i = \$100/amt. Two paper mills are interested in these woodchips. The first, paper mill j, is located very close to sawmill i, whence t_{ij} = \$10/amt and its technical requirements correspond to s_{ij} = +\$5/amt. The second, paper mill k, is located farther away from sawmill i, but its technical requirements are not as high, whence t_{ik} = \$25/amt and s_{ik} = -\$5/amt. Let us suppose that paper mill j wishes to make a bid. It must offer at least:

$$Pa_j = Pv_i + t_{ij} + s_{ij} = 100 + 10 + 5 = \$115/\text{amt}.$$

Let us suppose it offers \$120/amt for the 10 amt of woodchips offered by sawmill i. Sawmill i will then receive a selling price equal to:

$$Pv1 = Pa_j - t_{ij} - s_{ij} = 120 - 10 - 5 = \$105/\text{amt}.$$

Paper mill k which also wishes to make a bid is then in the following situation. It initially had to offer at least:

$$Pa_k = Pv_i + t_{ik} + s_{ik} = 100 + 25 - 5 = \$120/\text{amt}.$$

Since paper mill j has already made an offer, paper mill k now has to make an offer higher than:

$$Pa_k = Pv1 + t_{ik} + s_{ik} = 105 + 25 - 5 = \$125/\text{amt}.$$

Let us suppose that at the end of the auction, paper mill j offers \$120/amt for 5 amt of woodchips and paper mill k offers \$122/amt for 10 amt of woodchips. The selling prices obtained by sawmill i are therefore \$105/amt for paper mill j and \$122 - 25 + 5 = \$102/amt. Paper mill j whose offer is the higher will therefore receive the 5 amt of woodchips it asked for, whereas paper mill k, whose offer is lower, will obtain the residual quantities, namely 5 amt.

Part III: Frequently asked questions (FAQ)

- How will the transition between the current market and the smart market for woodchips take place? What will happen to existing long-term contracts?

There will be a training period before the market is set up. During that period, participants will become familiar with the system at specially organized briefings where they will be able to learn how to develop strategies and to evaluate the impact of the information provided by the different market players on prices and quantities exchanged.

Then, when the smart market for woodchips replaces the existing market, it will be possible to replace existing long-term contracts by compensatory contracts exchanged on the long-term market. Existing long-term contracts can also translate into agreements on quality adjustment factors. All solutions are possible. The industry will have to consult together and make its own decision as to which solution to adopt.

- Are special relationships between a paper mill and a sawmill still possible?

Yes, it is still possible for paper mills and sawmills to maintain special relationships. The long-term contract market allows participants who so desire to maintain long-term relationships between themselves and even to create new ones. Similarly, in Phase 3 of the pre-sale, paper mills and sawmills can negotiate quality adjustment factors (QAF). Thus, a paper mill may maintain special relations with one or more sawmills so that they offer it a better QAF. A sawmill may also offer a better QAF to one or more specific paper mills with which it maintains good relations. The purpose of all this is to promote exchanges between them.

- What is the relationship between the price of lumber and the price of woodchips on the smart market for woodchips?

When the price of lumber is high, then the sawmills operate at maximum capacity and produce more woodchips. The supply of woodchips is therefore momentarily increased, and if demand remains steady, the price of woodchips on the OPM may be expected to drop. Conversely, if the price of lumber is low, the sawmills will produce fewer woodchips, and if demand remains steady, this will generate a rise in the price of woodchips on the OPM. The price will therefore adjust itself in order to equalize supply and demand. These adjustments are normal and necessary for the industry to operate efficiently. That is why it is important for the price-setting mechanism to be flexible.

- How can the OPM guarantee an allocation at least as beneficial for all participants as the one specified in long-term contracts?

The compensation mechanism for long-term contracts proposed under the OPM has been designed so that the exchanges determined at the end of an OPM session are always at least as beneficial for everyone as the terms of the contracts. A relatively technical explanation of the mechanism is given in Section 2 (long-term compensatory market) of Part II of this paper, along with examples.

The essential idea is that, if a participant wishes, he can be sure to obtain at least the equivalent of the pre-negotiated contract, that is, there is a strategy which guarantees, regardless of the state of the market, at least the status quo. It can, nevertheless, be shown that this strategy is not the optimal strategy for participants. There are strategies which are always at least as good (and in most cases superior).

The OPM therefore enables participants, both sellers and buyers, to enhance their profit with respect to long-term agreements. Where do these profits come from? How is it possible for everyone to benefit from the system?

Let us not forget that the OPM seeks to maximize the profits of the industry as a whole. If the pre-negotiated quantities do not correspond to the optimal quantities, it is possible to seek additional profits. If the pre-negotiated exchange flows do not correspond to the flows whereby transportation costs are brought down, other profits are possible. The OPM identifies these profits and redistributes them to participants.

- Currently, a certain quantity of unsold woodchips remains on the ground. Will a smart market resolve the problem of woodchip piles, or surpluses?

Recorded woodchip surpluses are, at least in part, the outcome of the rigidity which currently characterizes the woodchip market. This rigidity stems from the fact that the exchanges are governed by long-term agreements whose renegotiation is generally detrimental to one of the parties. In the present situation, a sawmill which invites its partners to buy more woodchips is likely to see the price negotiated in the long-term contract renegotiated downward, and he will have no guarantee that it will rise again once the surpluses have been eliminated. So, it is not very profitable for sawmills to market their woodchip surpluses.

The OPM proposes a kind of objective tool for renegotiating long-term contracts. The long-term compensatory contract market is designed so that the parties are not prevented from dealing with other partners if additional profits can thus be realized. If it is in the interest of one of the parties, or both, not to carry out the terms of a compensatory contract and to deal with a third party, the OPM points this out and pays the compensation provided for so that both parties achieve at least the profit level corresponding to the terms of the contract.

The OPM guarantees the price negotiated in the long-term contract for the equivalent of the quantities pre-negotiated. The OPM enables a sawmill to sell any additional quantity at a new equilibrium price. This additional quantity will be sold on the market to the buyer offering the highest price, reflecting transportation costs and technical requirements. Later, if the surpluses are absorbed, the OPM will set new prices on the basis of supply and demand at the time, while guaranteeing prices negotiated for the long term. The incentives provided for by the OPM are therefore different from the present system's and favour temporary market readjustments.

The proposed market mechanism was therefore designed to limit the accumulation of surpluses and avoid having the woodchips end up on the ground. The objective of the proposed mechanism is to prevent potential woodchip surpluses. A sawmill which must supply the paper mill with which it is bound by a long-term contract with a quantity of woodchips lower than its forecast output can attempt to sell its surplus woodchips on the OPM. The OPM enables the seller to know exactly the quantity of woodchips he must deliver during the period covered: the seller is then in a position to better plan his production and thus avoid the accumulation of unwanted woodchips. Finally, if long-term contracts, the OPM and better planning have not eliminated all surpluses, the seller can always attempt to sell his woodchips on the spot market.

Another solution that could be envisaged to resolve the problem of "woodchip piles" would be to open up a specific market. In fact, certain paper mills, for various reasons, sometimes wish to purchase less "fresh" woodchips. This proposal limits the types of woodchips exchanged on the market to three, but the industry could very well consider "woodchips on the ground" as a valid type of woodchips (on the same basis as high density, low density and jack pine). This solution does not, however, guarantee that the woodchips will sell better, since they are damaged and demand for this type of woodchips is very low.

Finally, one could potentially envisage OPM sessions open to foreign facilities. Exports could then be seen as another type of solution to the problem of "woodchip piles". In a period of abundant production, prices tend downward. These low prices would have the impact of attracting foreign buyers to the Quebec market. This additional demand would mean surpluses could be sold off while the product price was to some extent sustained.

- What will happen between Optimized Periodic Market sessions if a sawmill wishes to sell certain quantities of woodchips or a paper mill wishes to buy an additional quantity of woodchips?

There will be the spot market, so paper mills and sawmills will be able to buy or sell a certain percentage of their woodchips. This percentage will act as a cap to ensure the necessary density for the Optimized Periodic Market to operate properly. The spot market allows participants to adapt to unforeseen conditions which can arise during that period.

- Is collusion between participants possible? How can it be avoided?

There are laws against this type of activity. Beyond this legal protection, we believe the opportunities for collusion in such a system are very slight. In fact, during the sale stage, as the market is anonymous, it is very difficult to comply and ensure compliance with agreements previously reached with other participants. Participants have only a few minutes to say whether they have received the quantity desired, and if not, which quantity they want. Nor have they any guarantee that the others will respect their commitments and they will not be able to find out after the sale whether or not the others have cheated. In these conditions, collusion between participants is highly unlikely, and indeed virtually impossible.

- Does the system permit a form of discrimination, and if so, which?

Paper mills and sawmills can indeed practise a form of discrimination toward one another, but this discrimination can only be "positive".

A paper mill can favour a sawmill by announcing a very low or even zero unit transportation cost (UTC) between it and the sawmill. An integrated paper mill, for instance, could act in that way in order to favour its own sawmill, but since this strategy has no impact on the market price, it would most often be depriving itself of purchasing opportunities that it might be presented with. If the exchange between a paper mill and a sawmill is optimal, then the OPM will determine it. Otherwise, the OPM will find a more advantageous exchange for the integrated facility. If on the other hand a paper mill wishes not to do business with a specific sawmill, the only way for it to exclude it is to lower the UTC between it and all the other sawmills. This measure is possible, but proves very costly for the paper mills.

As to the sawmills, they can treat a paper mill favourably not only by lowering the UTC between themselves and the paper mill, but also by setting a quality adjustment factor (QAF) that will favour the paper mill. In the same way as for paper mills, a sawmill wishing to treat one paper mill in particular unfavourably must lower the UTC and QAF of all the other paper mills. In other words, it must treat the other paper mills more favourably. Once again, this strategy, while possible, is unlikely, given the high costs associated with it.

- When is the market anonymous?

Step 1, the pre-sale, is not anonymous. In fact, when the technical requirements are announced in Phase 1 of the pre-sale, each sawmill becomes aware of the technical requirements of each paper mill. Similarly, in Phase 2 of the pre-sale, the sawmills in turn announce the quality adjustment factors (QAF). The paper mills learn in Phase 3 the QAF of each sawmill in response to their technical requirements. In Phase 3, the information contained in the transportation matrix is also disclosed to the sellers, buyers and potential carriers, so that the auction can be carried out.

It is in Step 2 that the market becomes anonymous. Participants disclose their supply and demand schedules and receive the equilibrium prices and quantities. Throughout this process, the participants do not know with whom they will exchange their woodchips. It is only in Step 3, the after-sale, that the bilateral relations between the participants are disclosed.

- What happens in the event of default by a paper mill or a sawmill?

The penalties in the event of non-compliance with a paper mill's woodchip quality requirements were announced during Phase 1 of the pre-sale. When a sawmill does not meet its commitment toward a paper mill, it must compensate it in the manner previously established by the industry. Similarly, a paper mill not meeting its commitments toward one or more sawmills must compensate them.

Cases of force majeure (such as mill closures for fire, strikes, etc.) should also be the subject of discussions and eventually agreement among paper mills and sawmills as to the means to penalize those very facilities which are in default.

- Will all woodchips be sold on the smart market for woodchips?

For it to be really efficient, the smart market for woodchips should ideally include all fir, spruce, pine and larch woodchips manufactured in Quebec. This is a desirable, but not an essential condition.

- How should the frequency of the optimized market be set?

The frequency of the optimized market has been set at one month. It could, however, be set at a shorter or longer interval. It is important that the frequency chosen not be too long so that, during that time, participants can plan their supply and demand. Adjustments are, however, always possible on the spot market. A longer interval makes it possible to lower the costs associated with using the smart market system. It also helps ensure provisioning over a longer period, but this advantage already exists in the longer-term compensatory contract market.

- Is any carrier whatsoever entitled to participate in the auction on unit transportation costs (UTC) which takes place during Phase 3 of the pre-sale?

It is possible, if the industry wishes, to limit participation in the UTC auction to accredited carriers. The latter could obtain accreditation if they meet certain criteria previously chosen through discussion and an agreement within the industry. This measure could prevent certain undesirable carriers from interfering in the market.

- Who pays for the system?

A system like the smart market for woodchips requires a certain initial investment. Such an investment is needed in order to put in place the necessary technology (communication networks, computers, smart market software, etc.) and should come from the main stakeholders in the industry.

Subsequently, the costs of using such a system are minimal when set against the total value of the goods exchanged through the system. They are of the order of tenths of percentage points. For instance, the annual costs of using the electronic pork auction (EÉP) accounted in 1994 for a mere 0.3191% of the total value of all the hogs sold to slaughterhouses using this system.

- Is the number of woodchip types limited to three? Could other types of woodchips potentially be traded on the OPM?

For the purposes of this proposal, we have chosen to divide woodchips into three types: high density, low density and jack pine. But it is possible to envisage other types of woodchips: planings, sawdust, softwood chips, woodchips on the ground, etc. The software designed to support the OPM is generic: changes can easily be made to it when necessary.

- Will large integrated facilities be able to manipulate the market more easily than they can at present?

As soon as it is a question of pulling the strings in a given market, large players are better placed than small ones. This is all the more true when integrated facilities are in a position to intervene on both the supply of and demand for a product. The presence of major players is part of the present situation in the woodchip market, and it will remain so in a smart market. But it is clear that the introduction of such a market mechanism will have the effect of stimulating competition and thus to some extent reducing the influence of the larger players. Indeed, the system was built so as to ensure that participation is beneficial to all parties, large and small.

It is important to realize that market manipulation ultimately favours either those generating the demand or those generating the supply. Integrated facilities (paper mills with their own sawmills) are by definition generators of both demand and supply on the woodchip market. Rarely are they major net buyers or sellers. Whether it is a question of raising or lowering the price, the interest of a player who buys almost as much as he sells on the market, or vice versa, is quite clearly very limited.

- How will a sawmill which considers that it does not have the means to forward the merchandise to one paper mill in particular be able to set about avoiding having the OPM force it to do so?

Let us consider the example of a paper mill which wishes to receive its woodchips only by rail. How can a sawmill which is not adequately equipped to deliver by this transportation mode convey this information to the OPM? The OPM does not ask participants to specify their preferred transportation mode. Only cost is important from the viewpoint of optimization of exchanges. On the other hand, if a sawmill, for instance, does not wish to deliver by rail, it will be able to announce an initial UTC which is arbitrarily high for paper mills requiring delivery by train. If the UTC between a sawmill and a paper mill is very high, optimization of exchanges by the OPM will mean that these facilities do not deal with each other.

In Phase 3 of the pre-sale, paper mills or carriers may announce on one segment a lower UTC than was initially announced by a sawmill. By bidding a lower UTC, a paper mill then undertakes to handle the transportation and pay for it on the segment in question. Exchanges between this paper mill and this sawmill then become possible, but the sawmill does not have to concern itself with transportation of the output.

Appendix 1: Glossary

Buyer: purchasing unit (pulp and paper mill) with given requirements and a given location. Each pulp and paper mill owned by a paper company constitutes a discrete buyer.

Carrier: Any agent who is neither a buyer nor a seller and who agrees to handle the transportation of woodchips over certain segments.

Compensatory contract: Contract concerning a single type of woodchips guaranteeing both parties compensation to the «loser» on the quantities negotiated if the price differs from the negotiated price. The compensatory contract therefore takes the form of a guaranteed price for a given quantity of woodchips and concerns financial flow rather than the actual flow of woodchips.

Paper mill acquisition price (Pa): Unit price paid by the paper mill, including transportation costs.

Quality adjustment factor (QAF): Indicator calculated and supplied by sellers to allow for cost variations stemming from the production of woodchips not meeting the previously defined reference quality. The proposed mechanism provides for two types of quality adjustment factors: a sawmill may use an additive and/or multiplicative QAF.

For instance, a sawmill assigns an additive QAF of 0 to a unit of reference woodchips. If it costs a sawmill more to produce a woodchip unit of superior quality to the industry standard, it will assign this quality of woodchips an additive QAF higher than 0 (+ 5, for instance). Conversely, an additive QAF of - 4 will refer to woodchips intended for a buyer whose technical requirements are lower than the industry standard. While more than one interpretation of such an indicator may be imagined (cf. Appendix 2), we shall restrict ourselves here to the most intuitive. A sawmill which assigns an additive QAF of + 5 to a quality of woodchips reveals that it is asking a premium of $5 per unit of woodchips, compared with reference woodchips, for producing this type of woodchips. At the same time, if the unit production cost of reference woodchips for a given sawmill is $70, but it considers that it can meet a given buyer's requirements with respect to woodchip quality at a lower cost, for instance $60 per unit, it will assign to this quality of woodchips an additive QAF of - 10.

A sawmill also assigns a multiplicative QAF of 1 to a unit of reference woodchips. For a unit of woodchips whose production cost is higher, it will assign a multiplicative QAF higher than 1 (1.2, for instance). The interpretation of this coefficient is that to produce 1 amt of superior quality costs the equivalent of 1.2 amt of reference woodchips.

Clearly, how sawmills determine their QAF will often depend more on a subjective interpretation of their production costs than on their actual costs. In this sense, a QAF may be interpreted as a premium (positive or negative) charged by a sawmill to a paper mill whose requirements differ from reference woodchips.

Reference woodchips: Woodchips meeting technical requirements deemed to correspond to a reference standard recognized by the industry. No firm is obliged to produce reference woodchips, and each firm may define its own woodchip quality requirements.

Sawmill selling price (Pv): Unit price received by the sawmill, excluding transportation costs.

Seller: Unit (sawmill) with a specific location. Each sawmill owned by a paper company constitutes a discrete seller.

Technical matrix: Table presenting QAF established by each seller to meet each buyer's technical requirements.

Technical requirements: Listing of each buyer's requirements with respect to woodchip quality (moisture content, size, and other characteristics, excluding species type). In particular, the listings will have to specify daily needs and the penalties imposed on sellers in the event of non-compliance with quality requirements and daily needs. These requirements apply to all sawmills, regardless of source or species type of the woodchips offered.

Transportation matrix: Table presenting the UTC between each buyer and each seller.

Type of woodchips: We have defined three types of woodchips, by species, namely, low density chips, high density chips, and jack pine chips.

Unit: One anyhdrous (metric) tonne (amt) of woodchips.

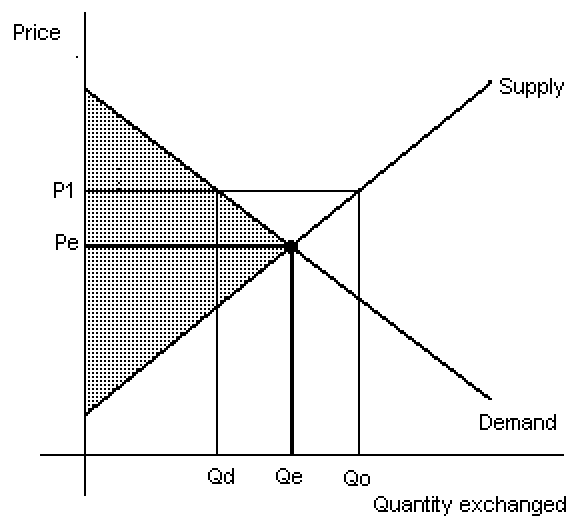
Unit transportation cost (UTC): Cost of transporting one unit on a given segment, ie., between a sawmill and a paper mill (between a seller and a buyer). By construction, UTC is the difference between the paper mill acquisition price and the sawmill selling price.

Appendix 2: Optimization module

The prices and quantities exchanged as a result of optimization of the system are those which maximize the industry's overall profits in the three markets at once, given the supply and demand curves disclosed, and in light of the technical requirements and transportation costs. The process of auctions in successive rounds enables the players to refine their preferences, their supply and their demand. At the end of the process, since the players no longer wish to alter their bids, it is reasonable to believe that the supply and demand disclosed are the "true" supply and demand curves. They therefore make it possible to set prices corresponding to quantities which maximize the efficiency of the market and the profits of each facility.

The equilibrium prices generated by the system present the characteristic of being those which maximize the industry's efficiency. To convince ourselves of this, let us look at the diagram below, which represents a competitive market to which we could compare the woodchip market. The maximum overall profit, in this figure, corresponds to the shaded area to the left of the equilibrium price, between the supply and demand curves.

Figure 2: Competitive balance



It is possible to reinterpret the problem of setting equilibrium prices and quantities as a mathematical problem of optimization. Let us define utility function U(q), expressing buyers' profit for a given quantity q exchanged, by the area beneath the buyers' demand curve. This utility function is strictly concave and differentiable. Let us define a given cost function C(q) by the area beneath the sellers' supply curve. This cost function is convex and differentiable.

On a market, the overall profit is equal to the difference between buyers' profits and costs. The optimization problem we must solve to maximize overall profits on the market may be expressed as follows:

$$(1) \qquad \underset{q}{Max} U(q) - C(q)$$

In this optimal solution, the marginal desire to pay is equal to the marginal cost of producing. The equilibrium price is set at the following value:

$$(2) \qquad U'(q) = C'(q) = p$$

Let us now look again at the analysis, introducing into it constant unit transportation costs t. The overall profit is now maximized at the quantity where the desire to pay is equal to the sum of the marginal production cost and the unit transportation cost. The problem to be maximized becomes:

$$(3) \qquad \underset{q}{Max} U(q) - C(q) - tq$$

Optimally, we have:

$$(4) \qquad U'(q) = C'(q) + t = p$$

The problem we have to solve is evidently more complex, but the logic remains similar. We have to introduce transportation costs, technical requirements and recipe constraints. Mathematically, the problem of allocation is presented as a problem of maximization under constraints, and with each solution we may associate equilibrium prices.

A solution from the optimization program specifies a value for each q_{ij}^k, namely, the quantity of type k woodchips delivered by sawmill i to paper mill j. We maximize:

$$\max_{q_{ij}^k} \sum_j U_j \left(\sum_i \sum_k q_{ij}^k\right) - \sum_i \sum_k \left(C_i^k \left(\sum_j q_{ij}^k \; r_{ij}\right) + \sum_j s_{ij} q_{ij}^k\right) - \sum_i \sum_j \sum_k t_{ij} q_{ij}^k$$

(5) subject to the constraints

$$m_j^k \left(\sum_k \sum_i q_{ij}^k\right) \le \left(\sum_i q_{ij}^k\right) \le M_j^k \left(\sum_k \sum_i q_{ij}^k\right) \qquad \forall j,k$$

$$q_{ij}^k \ge 0 \qquad \forall i,j,k$$

where s_{ij} and r_{ij} correspond respectively to the additive and multiplicative QAF, t_{ij} corresponds to the UTC between the seller and purchaser j, and m_j^k and M_j^k correspond respectively to the minimum and maximum proportions of type k woodchips in purchaser j's recipe.

From the optimality conditions, we can construct equilibrium prices. For buyer j, the optimization module specifies purchase price Pa_j^k for each woodchip type k and an average price Pa_j. For seller i, we obtain selling prices Pv_i^k for each woodchip type. Using these prices, it is easier to understand and interpret the optimization program's optimality conditions.

First we have:

$$(6)\ \ Pa_j = U'_j(\sum_i \sum_k q_{ij}^k)$$

If $\sum_i \sum_k q_{ij}^k$ is the total quantity purchased by firm j at the optimum, the average price paid by j corresponds to the price associated with this quantity on demand function j. Similarly, if $\sum_j q_{ij}^k r_{ij}$ is the quantity sold by sawmill i of type k (quantity weighted by multiplicative QAF), the selling price for the reference quality is given by:

$$(7)\ \ Pv_i^k = C_i'^k(\sum_j q_{ij}^k r_{ij})$$

that is, the price associated with this quantity on supply function i. If sawmill i delivers type k woodchips to paper mill j, the latter will have to pay for its woodchips as follows:

$$(8)\ \ Pa_j^k = (Pv_i^k r_{ij}) + s_{ij} + t_{ij} \text{ if } q_{ij}^k > 0.$$

that is, the price adjusted for QAF and transportation costs. The paper mill will pay this price to all sawmills that will deliver type k woodchips to it. We should add that if sawmill i does not deliver type k woodchips at the optimum to paper mill j, we will have:

$$(9)\ \ Pa_j^k \le (Pv_i^k r_{ij}) + s_{ij} + t_{ij} \text{ if } q_{ij}^k = 0.$$

Obviously, the average price paid by paper mill j must meet the following condition:

$$(10)\ \ Pa_j(\sum_k \sum_i q_{ij}^k) = \sum_k Pa_j^k(\sum_i q_{ij}^k)$$

Note that if $Pa_j^k < Pa_j$, type k woodchips are less expensive than the others; if it is deemed optimal to purchase other types of woodchips anyway, this is because paper mill j has already reached the maximum proportion of type k woodchips allowed. If type k woodchips are the cheapest, the paper mill will use the maximum proportion of them.

(11) If Pa_j^k is the lowest price, then $\sum_i q_{ij}^k = M_j^k(\sum_k \sum_i q_{ij}^k)$.

Conversely, if type k woodchips are the most expensive, the paper mill will use the minimum proportion of them.

(12) If Pa_j^k is the highest price, then $\sum_i q_{ij}^k = m_j^k(\sum_k \sum_i q_{ij}^k)$.

In both these cases, the paper mill could profitably cut its costs by being more flexible in its recipe requirements.

Conditions (6) through (12) summarize the overall conditions for market optimality. The solution thus obtained maximizes problem (5) and yields equilibrium prices. The quantities obtained are those which maximize the profits of the industry as a whole, in light of transportation costs and technical requirements. The prices obtained correspond to the equilibrium prices in a competitive market. Given these prices, the quantities obtained or sold correspond exactly to the quantities requested or offered. Note also that the market is balanced because the difference between the amounts collected from buyers and the amounts paid to sellers exactly matches the negotiated transportation costs.