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Forest-based industrial network: Case of the French timber market☆

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ABSTRACT

Following the literature on automation, we model the industrial network of the forest-based sector, with random demands, in the presence of supply contracts. The economic network is composed of upstream, instream and downstream agents. Through the resolution of the variational inequality model, we investigate the network equilibrium flows and compute the prices at which the former can be attained. With respect to other results on optimal pricing of timber and wood products in France, the model outputs show that forest resources are overvalued, while manufactured products are undervalued. At last, we explicitly state the equilibrium conditions in case of vertical integration between the upstream and instream agents.

1. Introduction

The supply chain network is a complex object, and finding the equilibrium flows, along the chain value, is one of the fundamental problems in industrial organization. A decentralized supply chain network is a structure that involves several decision makers within the chain value. The steady behavior of each decision maker can be separately characterized by a series of equilibrium conditions (Yang and Zhao, 2011). The natural mathematical expression for doing so lies in variational inequality, with distinguishable states and controls (Friesz et al., 2006; Friesz, 2010). Nagurney et al. (2002) first modeled the supply chain network equilibrium, and showed that it could be formulated as a variational inequality problem. Dong et al. (2004) and Yang and Zhao (2011) extended this approach to random demands with known probability distributions. Finally, Cojocaru et al. (2005), Yonghua et al. (2013) and Nagurney et al. (2014) provided a framework which allowed to study the cases with time-dependent variational inequalities.

The forest-based sector can be thought of as an industrial network composed of: forest owners and managers, who not only manage forests, but also commercialize timber; lumber manufacturers, also known as the first processing subsector, who transform timber into lumber and commercialize it to lumber remanufacturers; the latter being part of what is called the second processing subsector. With respect to this configuration, we can reasonably speak in terms of upstream, instream and downstream agents, all being connected through a vertical supply chain and forming a network. Because of the strain that hangs over the forest resources, the equilibrium of wood flows in the French forest-based sector is one of the major challenges faced by the industry players (Conseil National de l'Industrie, 2014; Sergent, 2010). This makes the study of equilibrium flows, that is, the network balance between supply and demand, even more suitable.

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In France, timber is sold through auction sales, over-the-counter sales and supply contracts, the latter being strongly implemented by the French National Forestry Office (ONF),[1] but also, to a lesser extent, by the private forest cooperatives. In the past, the French Forest Code used to stipulate that the sales be on standing timber and by auctions exclusively. The supply contracts have been developed since a 2001 legislative reform, which removed the derogatory nature of the over-the-counter sales. They provide for the provision of logs purchased in installments at several fixed dates; they can be annual or pluriannual, and cover the concepts of log volume, length, species, quality and price. Several objectives have been assigned to these long-term contracts (Dragicevic, 2015): to solve the issue of forest under-harvesting by planning fixed harvesting over several years; to allow access to the resource to the greatest number of manufacturers; and to better structure the segmented French forest-based sector. Before the paper by Barkaoui and Dragicevic (2016), in which the authors proved that Nash bargaining with social preferences could lead to the optimal log contracting, the literature has shown that the contract was a common and effective supply chain coordination mechanism (Cachon and Lariviere, 2005; Yang and Zhao, 2011).

Previous work introduced a network framework that highlighted the strategic advantages of horizontal mergers (Nagurney, 2009). Instead, we decide to focus on the equilibrium flows of a vertically integrated supply chain. Indeed, vertical integration occupies a central role in organizational economics. Williamson (2005) considers it to be the paradigm problem for explaining the distribution of firms and markets in modern economies. As such, the supply chain of a firm is owned by that firm, which reduces the number of intermediaries, and, in turn, cancels the transaction costs and solves the well-known double marginalization issue (Spengler, 1950). For example, Acemoglu et al. (2005) find that vertical integration is prevalent in countries with great contracting costs. With regard to the forest-based sector, Flückiger (2003) explains that, due to the lack of vertical integration, the forest-based sector suffers from the profitability shortfall. From the previous observation, Nordic countries have decided to move forward this industrial reconfiguration (Westholm et al., 2015).

Through the resolution of the variational inequality model, we investigate the network equilibrium flows and compute the prices at which the former can be reached. Compared with other results on optimal pricing of timber and wood products, the model outputs show that forest resources are overvalued, while manufactured products are undervalued. The analysis of the forest-based sector in a dynamic setting corroborates these results. In case of network disequilibrium, we find that the expected profits switch from increasing monotonic s-shaped functional forms to non-monotonic bell-shaped functional forms. At last, we explicitly state the equilibrium outcomes in case of vertical integration between the upstream and instream agents.

The remainder of the paper is as follows. In Section 2, we outline, through a variational inequality model, a forest-based network with random demands, and analyze how the presence of supply contracts impacts the equilibrium conditions. Sections 3 focuses on the network equilibrium in the presence of vertical integration. Section 4 extends the equilibrium analysis to the time-varying setting. Section 5 is devoted to illustrating simulation examples. We briefly discuss the model outputs and conclude in Section 6.

[1] The public agency is a decentralized industrial and commercial institution; it is also in charge of providing the services of general interest. As an important actor of the French forest-based sector, the strategy that it pursues is closely monitored by the manufacturing industry.

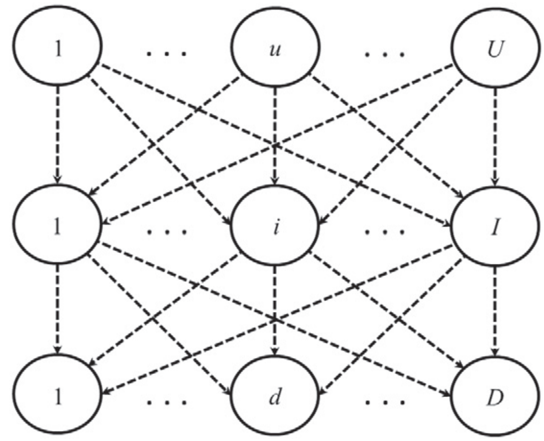

Fig. 1. Forest-based industrial network.

2. Model

Following the modeling works on automation (Setoodeh et al., 2012; Yang and Zhao, 2011), consider a three-layer forest-based industrial network, such as the one depicted in Fig. 1, composed of $u = 1,\dots,U$ upstream agents or timber producers, each of which owns $r_u = r_1,\dots,R_U$ resource units and provides them, in form of roundwood logs, to instream agents $i = 1,\dots,I$, like the sawmills. Instream agents then sell their lumber production to downstream agents $d = 1,\dots,D$ or remanufacturers.

In what follows, we denote a representative upstream agent by u, a representative instream agent by i and a representative downstream agent by d.

Let r_u and q_u be the resources owned by upstream agents and their timber productions respectively. The flow between upstream agent u and instream agent i is denoted by q_{ui}.[2] The following inequality stipulates that the total quantity of timber offered for sale to instream agents cannot exceed the total forest production or

$$\sum_{r_u=1_u}^{R_u}\sum_{u=1}^{U} q_u \geq \sum_{r_u=1_u}^{R_u}\sum_{u=1}^{U}\sum_{i=1}^{I} q_{ui} \tag{1}$$

$\forall r_u = 1,\dots,R_u, \forall u = 1,\dots,U, \forall i = 1,\dots,I.$

Consider $S_i(q_i)$ to be the expected sales of instream agent i with respect to its production level q_i

$$S_i(q_i) = \mathbb{E}\left[\min(q_i, M_d)\right] = q_i - \int_0^{q_i} P_i(x)dx \tag{2}$$

where M_d is the downstream demand – assumed equal to the final market demand –, P_i is the demand distribution function of instream agent i and p_i its density function. The distribution function is considered to be differentiable, strictly increasing and $P_i(0) = 0$. As well, its expectation equals $\mu_i = \mathbb{E}[M_d]$.

[2] Throughout the paper, when a transaction takes place, the flow is indexed by the agents at stake such as q_{ui} for u and i.