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Abstract

This paper performs a supply analysis of the Swiss forestry industry at the firm level. It explores the factors affecting quantity of supply, and determines the behavioural characteristics of the forestry firms. Supported by instrumental variables and several proxies, panel data methods are used in the regression analysis, allowing to distinguish several characteristics of firms in this strongly heterogeneous environment. Overall, results suggest that Swiss forestry firms are not acting as profit maximizers. This points towards the possibility that at least some of them could be modelled using a target revenue approach or similar models. Specifically, negative supply elasticities are estimated, with different magnitudes depending on firm characteristics such as ownership and on the econometric model used. Moreover, results indicate a concentration of market power among big forestry firms, which might be of special importance in the bargaining process with sawmills.

1 Introduction

Nowadays, it is well understood that forests are valuable at several levels. They fulfil a wide range of functions that compete with one another and each of them can be considered as the central one depending on external considerations and scale of values.

At the firm level and from an economic point of view, the function of wood production and its sale is, besides the subsidies, the unique source

[1] I'm grateful to my supervisor Mehdi Farsi for his help, effort and precious comments. I'm also grateful to the Swiss National Science Foundation and the National Research Program 66 "Resource Wood".

of revenues for foresters. It could therefore be considered as the most important. In any event, it is crucial for the financial viability of the firms and of the industry in general. It is also a must to enable the fulfilments of other obligations of forest maintenance, generally related to the multi-functionality of the forests and the non-economic functions.

The objective of this paper is to observe empirically the current situation and bring insights for further policy improvements. An econometric analysis in two steps is performed, highlighting the important factors affecting quantity of supply and allowing thereby to answer the important questions introduced below.

Among the main determinants of supply, price plays a central role. This paper therefore analyses supply with a special focus on it. On one side and as the first step, analysing the relation between price and quantity allows to test a first hypothesis: is the behaviour of Swiss forestry firms in accordance with the standard model of perfect competition? The Swiss forestry industry lies in such a complex environment, in terms of institutions and regulations, that competitiveness is expected to be largely rejected from the perspective of the wood supply[2].

As a matter of fact, strict profit-maximization behaviour is strongly suspected not to hold. Instead, others models, such as the target-revenue model, might better fit actual choices of forestry firms. Indeed the latter could be in line with the inter-temporality feature of this very specific industry, as well as with the numerous functions that are assigned to Swiss forests and foresters (in addition to timber harvesting). To test this hypothesis, the elasticity of supply is estimated using an econometric ana-

[2]Forest policies in Switzerland are largely focused on the many functions fulfilled by forests in addition to the production of wood. See Forest Policy 2020 (2013, FOEN) for more information

lysis modelling supplied quantity as a function of price and several different factors. A particular attention is given to the sign of the elasticity: a positive supply elasticity would mean that we cannot reject the competitive hypothesis, whereas a negative one would, in the current situation, reject it. Also, it is suspected that several characteristics of firms, such as ownership and the regions in which the firm operates, might indeed change the estimated elasticity of supply.

On the other side, and as a second step, the price level itself is of great interest. Although the forestry firms face an undeniable lack of flexibility in terms of harvesting decisions, mainly due to the numerous regulations in place, they are not necessarily devoid of any asset. Indeed, the main question here is to assess the level of market power held by forestry firms. The important transportation costs and the large amount of subsidies as well as the financial support from government constitute the main arguments for this suspicion. Hence, in this second part of the analysis, I model the formation of price in general as well as specifically estimate the level of market power among forestry firms. In this second econometric analysis, I therefore regress price on several factors such as a proxy for the economic environment, and two market power dimensions that are the size of firms and the amount of subsidies received.

This paper performs an econometric analysis in a complex environment. It contributes to the existing literature in several ways. First, to my best knowledge, no such study has been done in Switzerland. From an analytical point of view, this is even more important, given that the forestry sector is a highly particular and complex case. Second, the industry is currently going through a difficult time from a financial point of view[3], and this analysis will

[3]For more than two decades now, the forestry industry has incurred repeated losses. The gap between revenues and costs of the core activity has substantially increased over

hopefully help getting insights on how the structure of the industry could be improved. Last but not least, given that an important share of the Swiss forestry firms are publicly owned and that regulations are at the core of the industry, results concerning the behaviour of forestry firms with respect to price, as well as the formation of the latter and the market power, are highly policy relevant.

the period, with firms being generally unable to compensate it with non-core activities (FOEV, 2013. Annuaire La forêt et le bois, 2013).

2 Literature Review

The theory of forest economics is largely based on inter-temporal optimization, also known as the rotation age problem (see Faustmann (1849))[4]. The timber supply and management has first solely considered timber as a product and forest as a simple production area. Later this framework was extended with the introduction of amenity values, with Hartman (1976) as the first theoretical contributor, explicitly modelling the multi-functionality of forests.

Thompson et al. (1974) suggest the following as a strict definition of multi-functionality: "various uses can take place on closely intermingled tracts of land at the same time, or on the same land at different times, with the whole management area managed for multiple uses". In addition, they also present how the different functions of the forest are linked through a matrix of compatibility. It appears that most non-economic functions are fairly compatible with one another[5], whereas the economic one is highly conflicting all others.

In empirical analysis, all non-economic functions should at best be explicitly taken into account. However the main problem when modelling the multi-functionality of the forests is its high complexity; subsequently, the enormous data requirements in order to be able to grasp a substantial idea of facts is in practice unavailable. Some authors nonetheless venture to deepen and extend this empirical knowledge by applying a multi-functional framework, mainly in North America (see for instance Abt and Prestemon (2003); Pattanayak et al. (2000, 2003), Prestemon and Wear (1999); Swal-

[4] This is the first forestry theory, which is a simple profit maximization, given a growth function of forests, a constant price of wood, a harvest cost and a discount rate, as shown in equation (3) below. The solution to the problem is the rotation age, which is the age of trees at which they should be harvested.

[5] For example biodiversity, protection, recreational activities, water purification, etc.

low et al. (1990)). They identify non-economic functions in very different and heterogeneous ways. Proxies for amenity values range from the height of trees to inventory of standing forests. They also include the development of an index based on ecosystem and socio-demographic characteristics. This variety of choices highlights the difficulty to directly (or indirectly) observe non-economic functions. Such data with comparable level of detail are scarce in Switzerland, preventing similar analyses.

However, other relevant studies have focused on the analysis of wood production in this broad and general context (see for instance Polyakov et al. (2010); Adams et al. (1991); Berck (1979)). Using mainly translog models, the objective is most often to estimate price elasticities[6], as well as, for example, determine the differences in behaviour between public and private firms. In this regard, Pattanayak et al. (2000) find price elasticities ranging from 0.6 to 1.27, and a significant negative relation between skewness of inventory levels (as a proxy for non-economic function) and wood supply. They also summarized some other micro-econometric studies, for the overwhelming majority in North America, with all positive price elasticities but of very different magnitudes (from 0.2 to 7.7).

Although the subject is similar, the overall institutional and regulatory situation is very different in Switzerland and the forestry industries are indeed hardly comparable across countries and time, in terms of scale, but above all in terms of legislation and behaviour with respect to non-economic functions. For several reasons, it is believed that the Swiss forestry industry is not behaving competitively when considering wood supply. After analysing firm's costs, Bürgi and Pauli (2013) suggested that a negative relation

[6]The objective is shared by most of the above mentioned papers considering explicitly amenity values. See Wear and Parks (1994) and Kuuluvainen et al. (2003) for a broad and complete picture of the empirical techniques and alternatives with related critics.

with price is highly plausible (see also Bürgi et al. (2009)). Indeed, the strong dependency to subsidies, the financial support for the potential losses of public firms, the inter-temporal nature of the industry and the numerous regulations in terms of multi-functionality do not create incentives for an efficient management from an economic point of view.

For all these reasons, the assumption of negative elasticity of supply is a coherent and plausible one. This hypothesis implies from a theoretical point of view a backward-bending supply curve. Such supply behaviour has already been described several times in the analysis of the forestry industry, and even in other similar industries. Hyde (1980) and Binkley (1993) have both introduced this concept in the case of forest management, mainly from a theoretical point of view, as an extension of the rotation age problem of Faustmann (1849), although they presented two different and separated situations in which elasticity of supply can be theoretically negative and still in line with a profit-maximization behaviour. They show the importance of several factors affecting price elasticities, among others interest rates, costs, and expectation of foresters with respect to future price levels.

Before presenting those theories, some important concepts must be defined. First, the function $F(t)$ is the level of standing volume of wood (m^3) in the considered forest assuming an age of t for all trees in that forest (i.e. t years from the last harvest). Traditionally this function is (strictly) convex for low t and (strictly) concave for higher t, in order to reflect the real growth of trees, i.e. $\partial F(t)/\partial t$, being inverted u-shaped.

Based on this function, the (average) annual yield of wood (or, assuming a uniform age distribution from 0 to t, the wood supply $s(t)$) can be calculated as

$$s(t) = \frac{F(t)}{t} \tag{1}$$

which is obviously depending on the time t, or age of forest t, at which harvest will occur. Since $F(t)$ is first strictly convex and then strictly concave, it must be that $F(t)/t$ reaches one and only one maximum at some rotation age denoted t_{MSY}. This is known as the Maximum Sustainable Yield, or MSY. In this particular case, we have

$$F'(t_{MSY}) = \frac{F(t_{MSY})}{t_{MSY}} = s(t_{MSY}) \tag{2}$$

Then, for t smaller than t_{MSY}, it appears that $F'(t_{MSY})$ is bigger than the wood supply, and vice versa.

Turning to the theory itself, when maximizing its profit, the firm solves, as seen in Binkley (1993),

$$\max_t \pi(t) = -c + pF(t)e^{-rt} + \pi(t)e^{-rt} = \frac{-c + pF(t)e^{-rt}}{1 - e^{-rt}} \tag{3}$$

where $F(t)$ is defined above, $\pi(t)$ is the discounted profit of the firm at time 0 (to infinity), p the price of wood, c the harvesting and regeneration costs and r the discount rate. In equation 3, it is assumed that the forest is harvested at time 0 (which simplifies the calculations but does not change anything to the solution). This gives the following first order condition :

$$\frac{\partial F(t^*)/\partial t^*}{F(t^*) - c/p} = \frac{r}{1 - e^{-rt^*}} \Leftrightarrow p\frac{\partial F(t^*)}{\partial t^*} = r\frac{pF(t^*) - c}{1 - e^{-rt^*}} \tag{4}$$

t^* is the optimal rotation age, i.e. the age of trees when harvested, and is a function of p, r and c. Assuming constant c and r, we can estimate the elasticity of supply, denoted η and given in Binkley (1993) by

$$\eta = \frac{\partial s(t^*)}{\partial p} \cdot \frac{p}{s(t^*)} = \frac{\partial s(t^*)}{\partial t^*} \cdot \frac{\partial t^*}{\partial p} \cdot \frac{p}{s(t^*)} = \frac{\partial t^*}{\partial p} \cdot \left[F'(t^*) - \frac{F(t^*)}{t^*}\right] \cdot \frac{p}{F(t^*)} \tag{5}$$

$\dfrac{p}{F(t^*)}$ is obviously positive, and $\left[F'(t^*) - \dfrac{F(t^*)}{t^*}\right]$, depending on the optimal rotation level t^*, can be either positive (i.e. when the trees being harvested are younger than the MSY) or negative (i.e. when the trees being harvested are older than the MSY). $\dfrac{\partial t^*}{\partial p}$ is negative[7]; intuitively the higher the price, the less important the harvesting costs and therefore the shorter the rotation age. So it appears that $\left[F'(t^*) - \dfrac{F(t^*)}{t^*}\right]$ must be positive so that the elasticity of supply becomes theoretically negative (see Binkley (1993) for a thorough and more systematic explanation of the maximization solution and a complete development of the formula for the elasticity).

As seen above, this condition is possible only if the optimal rotation age is small, and more specifically smaller than the Maximum Sustainable Yield (MSY). In other words, the elasticity of supply is theoretically negative when the rotation age, i.e. age of trees when harvested, is sufficiently low compared to the MSY. Applied to the Swiss industry, this condition is far from being satisfied as the current rotation age seems to be largely beyond the MSY with many old and very old trees and forests. As more or less comparable examples, Sallnäs (1990) has estimated the MSY in Sweden for a pine forest to be at about 100 years and for a spruce forest (representing 44% of Swiss forests[8]) at about 60-70 years. In a different environment, Soares et al. (1995) have compared pine types in different regions in Portugal and found a MSY between 40 and 70 years. Posavec et al. (2011) have estimated an MSY for beech (representing 19% of Swiss forests[9]) at 85 years in Croatia. Natterer et al. (2004) also mention the old age of Swiss

[7]In fact, ${\partial t^*}/{\partial p}$ can potentially be positive in a very specific case where $F(t)$ is relatively small compared to ${\partial F(t^*)}/{\partial t^*}$, as it can be seen from equation 4. This appears when t^* is actually very small in absolute value. This would imply a large discount rate, far too high to be practically applicable and therefore ${\partial t^*}/{\partial p}$ can be safely considered to be negative in general.

[8]La forêt et le bois, 2013. OFEN.

[9]Idem.

forests by observing the Swiss situation as opposed to others European and comparable countries. Indeed, more than half of Swiss forests are older than 90 years (52.8%)[10]. It is clear that the MSY refers to the maximum age that a tree would reach when maximizing supply, the Swiss situation leads to the observation that forests are most likely harvested beyond this MSY. That is, assuming profit maximization among forestry firms, the theory and equation 5 tell us that such a behaviour should lead to a positive elasticity of supply in the case of the Swiss forestry industry.

To be complete Hyde (1980), on his side, shows another theoretical possibility leading to negative elasticity of supply in the case of profit maximization, which is however very hypothetical and barely applicable in practice. It appears that the expectation of prices in the medium to long term can determine the behaviour of firms. As a matter of fact, he shows that, assuming that a (real) price increase is part of a long-term growth rate, the optimal behaviour can indeed be the decrease of wood supply in order to benefit from the price increase and shifts the production to a future date.

It is important to note that other fields of research share many aspects of the forestry industry. Also, some models have been offered to explain the behaviour observed in such industries. As an example, target-revenue model is one of them, assuming a unit negative elasticity of supply, in order to ensure constant revenues. Direct applications of this model are numerous in other fields and include Griffin (1985) or Alhajji and Huettner (2000) in the context of OPEC behaviour; starting with Clark (1976) and followed by others such as, recently, Nguyen (2009) or Thuy and Flaaten (2013) with analyses in the context of the fishery industry. This latter industry is to many aspects comparable to the forestry industry: the inter-temporality

[10]National Forest Inventory 3, 2004-2006. WSL.

of management and the existence of non-economic functions exist in both cases. Empirical findings generally suggest that the fisheries show a stronger agreement with the target revenue model than the OPEC and oil supply in general, although empirical analysis do not fully support this framework.

3 Data

Data are drawn from the Federal Office for the Environment and the Swiss Forestry Statistics. They gather information on all Swiss forestry firms managing more than 50 hectares, which consist of around 2'000 firms. They respond annually and give basic information about their management, such as ownership, costs, revenues, land under management and wood production, among others.

Below are the descriptive statistics of the data set and an introduction to the Swiss forestry industry.

Swiss Forestry Statistics (SFS)

A total of 12'187 observations are available from 2004 to 2010. After cleaning the data and dropping firms with no production, cost or revenue, 10'822 observations remain. Table 1 presents the number of firms for each possible number of observations (i.e. years). It appears that most of the considered firms (1160 out of 1896) have observations for the whole period.

Table 1: Numbers of observations per firm (SFS)

# of observations (years)	1	2	3	4	5	6	7	Total
# of firms	124	90	122	119	130	151	1160	1896

In total, 1896 firms are considered that have, as mentioned above, a minimum area under management of 50 hectares. Whereas a large number of firms (more than a third of all Swiss forestry firms) are below this threshold, in terms of total area, these omissions represent a very small portion of total Swiss forests (around 2%), which means that the data can still be considered as covering the whole forestry industry.

3.1 The forestry sector

From the point of view of their structure, the forestry firms are highly fragmented with a large number of small and very-small firms. 53% of them manage less than 100 ha. On the other hand, less than 20% of the largest (above 500 ha) covers more than 70% of all Swiss forests. In general, firm size tends to increase for a few years now. This might be the consequence of the slow public awareness that this industry's fragmentation is problematic. Although the average of productive forest area per firm is increasing in all regions of Switzerland[11], there are still large differences among them: 442 in Jura, 132 ha in Plateau, and up to 795 ha in the Alps.[12]

The ownership is also of great importance. Firms are either owned by governments, cantons or smaller townships, public entities (e.g. army), bourgeoisie or private entities. In this analysis, ownership is divided into two main categories: public, or private. Bourgeoisie and private entities are considered private, mainly from an economic point of view, while the others are public. Although it is possible for the private entities to have political influence, the economic activity is separated, making them financially independent from public institutions (except from subsidies received by most firms). In this context, 49.1% of observations are private. But it is not evenly distributed over Switzerland. Table 2 presents the percentage of private firms for each region, as well as the medians of profit per hectare and production of wood per hectare. Medians are used instead of means to mitigate the effect of outliers.

It appears already that there exist some important differences between the private and public firms. For example, private firms are consistency

[11] Traditionally, Switzerland is divided into four regions that are (from North West to South East) the Jura, the Plateau, the Pre-Alps and the Alps (North and South).

[12] Annuaire La forêt et le bois, 2013.

Table 2: Distribution of ownership and medians of key variables

		Jura	Plateau	pre-Alps	Alps
Private share		25%	44%	70%	41%
Private	Area (ha)	406	138	173	553
	Profit/ha	1.5	45.6	35.8	-11.7
	m^3/ha	6.2	10.3	4.6	1.1
Public	Area (ha)	329	136	228	1101
	Profit/ha	-12.7	-121.7	-32.3	-44.4
	m^3/ha	5.8	9.1	7.0	2.4

outperforming the public in terms of profit per hectare in all regions (significantly, at the median)[13]. However, they are not producing more than public firms in all regions. Whereas it is the case in Jura and the Plateau, public firms produce on their side more in the pre-Alps and Alps. The first two regions are in general flatter, making them potentially easily accessible and thus more profitable than pre-Alps and Alps, where private firms seem to focus on minimizing costs rather than increasing revenues. As a matter of fact, when considering revenues and costs, private firms are not really earning higher revenues, but they are however able to better control costs. Finally, area under management for private and public firms (at the median) is also presented in table 2 in order to put the other figures into perspective. The Jura is the only region in which private firms are bigger at the median than public ones (statistically). In the pre-Alps and Alps, the inverse is true. It suggests therefore that the cost advantage from which private firms benefit is not related to size and economies of scale, and is to be found elsewhere.

[13]The differences are also significant when considering the mean, except in the Alps where they are not statistically different.

Like the structure of firms and as already suggested in table 2, the production of wood largely varies by regions. Table 3 shows how large the different regions are with respect to the wood harvested. The Alps, North and South, produce very small amount of wood with respect to their size, compared to Plateau which has in turn a very high production in relative terms. Jura and the pre-Alps, as for them, produce both slightly more than their forest shares.

Table 3: Distribution of forestlands and production

% of overall	Jura	Plateau	Pre-Alps	Alps
Forestlands	18%	18%	19%	45%
Production	22%	36%	24%	18%

The structure of Swiss forests heavily differs from one region to the other. Of course, this is surely a consequence of the heterogeneous environments. The forestry firms produce relatively more or less (per hectare) depending on their regions, and this might well be a consistent behaviour: forests are harder to reach and costs are therefore higher in the regions where the production of wood is smaller (e.g. Alps). This could then mean that harvesting in those regions is less due to economic reasons than for sustainability and in order to fulfil some other functions, such as biodiversity or protective ones (i.e. amenity function).

As a final word on overall wood production in Switzerland, table 4 shows the total production of raw wood in Switzerland every 3 years, from 2003 to 2012. In addition, the production per hectare and a price index of raw wood are presented as well.

Figures on production come from the respective annual reports of the FOEV (Federal Office for the Environment). The price index is based on price indices available for each type of wood[14] provided by the FSO (Federal Statistical Office) with new issuance every 4 months. The general index is created by weighting specific ones in each region separately, based on the percentage of each type of wood. The figures presented here are then the mean of the 3 prices available for each specific year. It is shown in real price (basis on December 2000).

Table 4: Wood production and prices over time

	2003	2006	2009	2012
Production (m^3, in thds)	5'100	5'700	4'880	4'660
Production (m^3/hectare)	4.19	4.58	3.89	3.70
Price index (CHF)	115.15	120.87	134.05	123.15

What we can see from this table is that production seems to be relatively decorrelated with prices. Although the latter has slightly increased over the 10-year period by a few percent, the production has meanwhile decreased by almost 10%. It is quite implausible that natural causes, such as the storm Lothar in 1999, have had strong impacts on the overall wood production during this period. The explanation is thus to be found somewhere else.

Finally, figures 1 and 2 display important sector relevant information on an aggregated level. In figure 1, we can see that over the period 2006-2010, exports of raw wood have substantially decreased, whereas imports have been fairly stable.

On the other side, it also appears that domestic demand, defined by the sum of domestic supply and net imports, slightly increased over the period 2004-2010 (figure 2). During the same period, prices have fairly increased

[14] The production of wood is divided into three main categories of wood: log-wood, sold to sawmills (around 55% of the overall wood production), industrial wood used to manufacture boards, paper and cardboard (around 10%), and energy wood, mostly burned to produce energy (around 35%).

with an index published by the Swiss Federal Statistical Office varying from 109.1 at the beginning of 2004 to 141.7 at the end of 2010 (basis=dec. 2000).

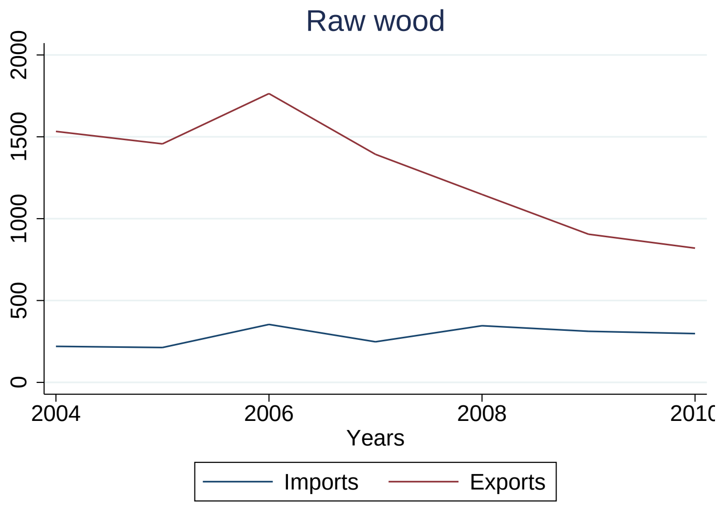

Figure 1: Economies of scale with respect to timber output.

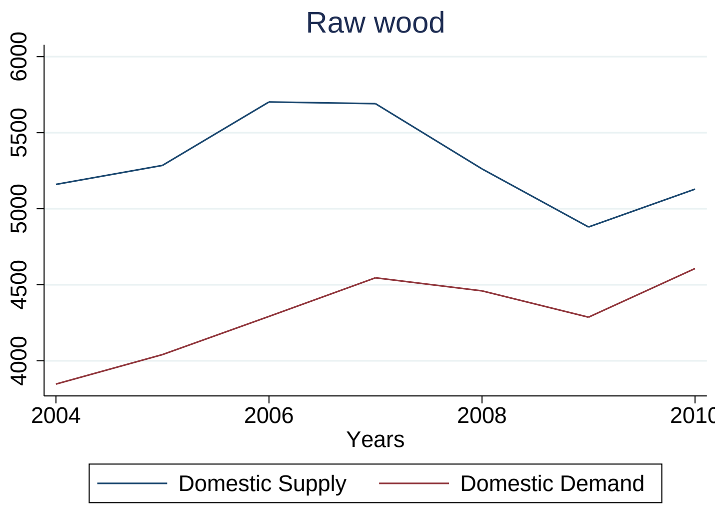

Figure 2: Economies of scale with respect to timber output.

4 Econometric approach and results

This section is divided in three different parts. First, the models with the related hypotheses to be tested are presented for both the supply analysis and the price formation. Second, the price variable is introduced, and potential shortcomings along with their solutions are discussed. Finally, the results are presented in a third part of the section.

4.1 Models and hypotheses

The econometric analysis involves both fixed or random-effects panel data models, as a way to deal efficiently with non-observed heterogeneity.

4.1.1 Supply analysis

The first part of the research aims to estimate a supply function as well as the elasticity of supply, and test specific hypotheses about the firms behaviour in the forestry industry. The first hypothesis I test is whether Swiss forestry firms do or do not behave in a profit maximization manner. From the previous descriptive analysis, there already to have suggestive evidences going in the direction of rejection of the profit maximization behaviour. If this hypothesis turns out to be true, it will have impacts in terms of the industry understanding, potentially both from a scientific and policy point of view.

As a second hypothesis, private and public firms are suspected to act differently. The former are expected to behave more closely to a competitive behaviour, whereas the latter are lacking incentives to act similarly, due for example to the financial support given by the legal authority owning the firm.

Moreover, if ownership plays an important role in the firm's behaviour, so should the regions. Switzerland is divided into four regions that show different characteristics in terms of altitudes, land features, accessibility, etc. Higher costs being borne in a mountainous region, it is expected for such firms to show a less competitive behaviour than the ones in a lowland area. This is due to the fact that their needs for liquidity and revenues are higher and they are therefore obliged to sell larger amount of wood in case of bad market conditions (see Bürgi and Pauli (2013)).

Also, and partly for the same reasons of costs, the last hypothesis in terms of firm's behaviour is that, in the case of forestry firms, size matters. As the latter increases, the relative costs diminishes through the economies of scale, allowing firms to behave more competitively. Moreover, bigger firms are suspected to be more concerned about financial results and give more importance to the economic function.

The supply function is defined as follows:

$$\begin{aligned} ln(Q_{f,t}) = \beta_{0,f} + \delta_t + \beta_1 \cdot ln(Price_{f,t}) + \beta_2 \cdot ln(Price_{f,t}) \times Region_r \\ + \beta_3 \cdot ln(Price_{f,t}) \times Region_r \times ln(area\ prod._{f,t}^{MC}) \\ + \beta_4 \cdot ln(Price_{f,t}) \times Region_r \times private \\ + \beta_5 \cdot ln(area\ prod._{f,t}) + \beta_6 \cdot ln(area\ non._{f,t}) \\ + \beta_7 \cdot \%Outsourcing_{f,t} + \beta_8 \cdot Subsidies_{f,t}/Costs_{f,t} \\ + \beta_9 \cdot \%Other\ costs_{f,t} + \epsilon_{f,t} \quad (6) \end{aligned}$$

where $Q_{f,t}$ is the total production of wood of firm f at time t, δ_t are time effects and $\beta_{0,f}$ fixed (or random) effects. $ln(Price_{f,t})$ are firm-specific wood prices. $ln(area\ prod._{f,t})$ and $ln(area\ non._{f,t})$ are logarithms of productive and non-productive hectares under management[15]. Interactions terms are also included in the regression analysis in order to allow the elasticity of supply to vary with respect to several characteristics of firms and test our hypotheses. As presented above, firm's size, through $ln(area\ prod._{f,t}^{MC})$ (MC standing for median-centered), is thought to be an important factor, along with ownership and regions. $Region_r$ are dummies for the four main regions in Switzerland, that are the Jura, Plateau, Pre-Alps and Alps. $\%Outsourcing_{f,t}$ denotes the % of outsourcing over total costs, and $Subsidies_{f,t}/Costs_{f,t}$ the coverage of subsidies over total costs. $\%Other\ costs_{f,t}$ denotes the % of administrative costs, and finally $\epsilon_{f,t}$ is the error term[16].

4.1.2 Price formation and market power

In a second step, the price formation and the market power of firms is estimated. In this part, the goal is to assess the level of market power held by forestry firms. The high transportation costs (creating generally small markets) suggest that there could exists some level of market power held by the forestry firms when selling wood to sawmills. Market power is generally closely related to size, hence the first hypothesis is that size has a positive influence on price.

Furthermore, all else equal, a higher amount of subsidies (in addition to the government supporting financial deficits) could also mean that the forestry firms are in general less dependent on revenues from wood. As a

[15]Productive areas are by definition all forests fulfilling any type of function, that is from economic to biodiversity or protection.

[16]Beside the results that are presented below, many regression analysis have been performed in order to challenge their conclusions: interaction terms with other variables, such as $\%Subsidies_{f,t}/Costs_{f,t}$, considered to potentially convey some market power, as well as interactions between price, years and regions. These models have only supported the conclusions presented below and are not presented here because of their inefficiency and for the sake of simplicity.

consequence, this could increase their potential market power, through the fact that a substantial share of their revenues is earned from non-economic activity (i.e. not related to wood sales). Firms with higher level of subsidies could then hold more bargaining power with respect to sawmills as they need less revenues, all else equal. This is thus our second hypothesis. In this context, the following regression model is used:

$$
\begin{aligned}
ln(Price_{f,t}) = \alpha_{0,f} + \alpha_1 \cdot ln(Index_{r,t}) + \alpha_2 \cdot Log_{f,t} + \alpha_3 \cdot ln(Demand_t^{raw}) \\
+ \alpha_4 \cdot ln(Imports_t^{semi}) + \alpha_5 \cdot ln(area\ prod._{f,t}^{MC,R}) \\
+ \alpha_6 \cdot Subsidies_{f,t}/Costs_{f,t} + \alpha_7 \cdot Private + \mu_{f,t} \quad (7)
\end{aligned}
$$

where $ln(Index_t)$ is a regional price index[17], being considered to be a good measure of the overall economic situation. $Log_{f,t}$ is the % of log produced in each firm, and is an important input as log-wood is substantially higher than other types of wood. Although the structure of the tree is independent of the foresters, the different environments faced by firms have a significant influence (for example on wood species), which then has a clear importance for prices. $ln(Demand_t^{raw})$ and $ln(Imports_t^{semi})$ denotes the logarithm of raw wood national demand (= national supply − exports + import) and imports of semi-finished products in Switzerland, respectively. $\mu_{f,t}$ finally denotes the error terms.

4.2 Price and endogeneity

Before considering the analysis, some remarks concerning wood price must be made. The true wood price P^* being not observable at the firm level, a proxy is used, which is simply given by

[17] This is the same index presented in table 4 of section 3.

$$Price_{f,t} = \frac{Revenues_{f,t}}{Quantity_{f,t}} \tag{8}$$

where $Revenues_{f,t}$ are defined by the revenues coming from wood sales and $Quantity_{f,t}$ the amount of m^3 harvested during the same period (year). Equivalently, one can write

$$ln(Price_{f,t}) = ln(Revenues_{f,t}) - ln(Quantity_{f,t}). \tag{9}$$

As a first comment, the aggregation of different types of wood in equation 6, and again in the price variable presented above, is potentially a source of errors, and is somehow questionable. But this is supported by the fact that, as mentioned before, types of wood are not separately produced, i.e. one cannot choose to produce only one type of wood (e.g. logwood), ignoring the two other types (e.g. industrial and energy wood). They come from the structure of the tree, and cannot be affected, although it is clear that hardwood, softwood and the different environments show different characteristics in terms of wood types distribution. Nonetheless, the data do not enable separation of wood types in the subsequent analysis. Still, it is considered, based on the previous remark, to be representative and exempt of major issue.

However, a second concern can be raised with more problematic implications. Taking the logarithm, a simple mechanical problem arises as the dependent variable $ln(Q_{f,t})$ appears on the right-hand side of equation 6 (with a negative sign). Along with this simple mechanism, some measurement error cannot be excluded at first sight. There is thus a potential endogeneity problem, warranting the use of instrumental variables in this context.

Finally, another reason exists to suspect endogeneity, which is the potential market power that could be held by forestry firms. This is further discussed and tested in section 4.3.2. Finally, the simultaneous relation between price and quantity in these relatively small geographical markets is a further potential argument. Nonetheless, whereas there could have unanticipated changes in quantity of supply, due for example to a natural hazard, which could then affect price, the period considered is exempt of major storms or any other events that could have lead to such a scenario.

The instrumental variables models along with results are presented in Appendix A. The difficulty to find proper exogenous instruments is an important matter further discussed. Also, the results, even though they leave very small doubt on the sign of the elasticity of supply in the forestry industry, are not sufficiently robust to draw specific conclusion about the absolute value of the elasticity. Moreover, regression with price indices are also presented in order to strengthen the conclusions.

4.3 Results

4.3.1 Supply analysis

In this section, the main determinants of supply in the context of forestry industry are presented, and the elasticity of supply as well as the differences existing between different firms are estimated.

Tables 5 presents the results of different fixed-effects models, using the Swiss Forestry Statistics. Model 1 is a panel data regression model with no interaction terms. Models 2 and 3 include interaction terms in two separated regressions. Model 2 focuses on the firm's characteristics, including regional and ownership dummies and a size proxy. Model 3 focuses on year interactions in order to determine whether the firm's behaviour has changed over time. The results show homogeneous estimates and elasticity of supply that are fairly constant over time, strengthening the findings and supporting the fact that there has been no significant natural event that could have disrupted the wood market.

The first important observation obviously concerns the price effect, and more precisely the elasticity of supply. It appears that, as expected, it is significantly negative for all models irrespective of the specification[18].

This observation strongly rejects the assumption of competitive behaviour and profit maximisation with respect to wood supply. In short, the results show a behaviour that is going in the opposite directions of profit-maximization from a theoretical point of view (as seen in section 2), given the previous discussion excluding the possibility of observing simultaneously a negative elasticity and a profit maximization behaviour. Not only uncorrelated with the market, the elasticity of supply is negative, supporting the proposition brought by Bürgi and Pauli (2013) of negative relation between price and quantity.

Model 2 is estimated in order to better understand the potential mechanisms of price and quantity determination, and get an insight on how firm's characteristics affect their behaviour. Focusing on their elasticity of supply, it appears that, following our hypotheses, the behaviour varies across firms, and more specifically that some characteristics have an impact on their elasticity.

[18]In addition to the econometric analysis of Appendix A in order to dispel any doubts on the estimations, the same models have also been applied to the Swiss Forestry Pilot Network (TBN/REP). On a voluntary basis, forestry firms can join this network and provide detailed information about their costs, revenues, employment and production (among others), through an accounting tool. Around 200 firms are part of it on a yearly basis. The estimations show very similar results. The Swiss Forestry Statistics have thus been chosen because they cover the whole forestry industry.

Table 5: Supply analysis

Variables	Model 1	Model 2	Model 3
$ln(Price_{f,t})$	-0.304***	-0.216***	-0.248***
$ln(Price_{f,t}) \times Plateau$		-0.032	
$ln(Price_{f,t}) \times Pre\text{-}Alps$		-0.160**	
$ln(Price_{f,t}) \times Alps$		-0.265***	
$ln(Price_{f,t}) \times private$	0.066***		
$ln(Price_{f,t}) \times Jura \times private$		-0.003	
$ln(Price_{f,t}) \times Plateau \times private$		-0.009	
$ln(Price_{f,t}) \times Pre\text{-}Alps \times private$		0.161***	
$ln(Price_{f,t}) \times Alps \times private$		0.195***	
$ln(Price_{f,t}) \times ln(area\ prod^{MC}_{f,t})$	0.086***		
$ln(Price_{f,t}) \times Jura \times ln(area\ prod^{MC}_{f,t})$		0.001	
$ln(Price_{f,t}) \times Plateau \times ln(area\ prod^{MC}_{f,t})$		0.034	
$ln(Price_{f,t}) \times Pre\text{-}Alps \times ln(area\ prod^{MC}_{f,t})$		0.046	
$ln(Price_{f,t}) \times Alps \times ln(area\ prod^{MC}_{f,t})$		0.150***	
$ln(Price_{f,t}) \times 2004$			-0.084***
$ln(Price_{f,t}) \times 2005$			0.008
$ln(Price_{f,t}) \times 2006$			-0.051
$ln(Price_{f,t}) \times 2007$			-0.008
$ln(Price_{f,t}) \times 2008$			0.026
$ln(Price_{f,t}) \times 2009$			0.012
$ln(area\ prod_{f,t})$	0.540***	0.669***	0.848***
$ln(area\ non_{f,t})$	0.009	0.015	0.010
$Subsidies_{f,t}/Costs_{f,t}$	-0.051	-0.052	-0.044
$\%Outsourcing_{f,t}$	0.261***	0.257***	0.253***
$\%Other\ costs_{f,t}$	-0.356***	-0.360***	-0.350***
2004	-0.060***	-0.053**	0.230*
2005	-0.081***	-0.075***	-0.100
2006	0.029	0.032	0.209
2007	0.073***	0.069***	0.106
2008	0.013	0.011	-0.076
2009	-0.005	-0.004	-0.046
Constant	5.532***	4.751***	3.774***

*, **, *** : $p<0.1$, 0.05, 0.01

First, region is an important aspect that makes firms behave differently. As expected, (public) firms in a rougher environment, such as in mountainous areas (e.g. the Alps) have a lower elasticity of supply, all else equal.

Second, the private firms are in general more competitive than public ones in these difficult regions, with differences of 0.185 and 0.209 for the pre-Alps and Alps. The reason might come from the fact that public firms have their deficits covered by authorities, which does not give them financial incentives in order to keep the head above water, in contrast to private firms. Moreover, their sensitivity to non-economic functions, and the pressure exerted by population might be generally bigger as well. However, when comparing private firms across regions, their elasticities of supply do not significantly vary from one region to another. This suggests that the behaviour of private firms is coherent and similar all over the country from this perspective. Still, as presented in section 3, it is clear that the levels of wood production and many other aspects are widely different.

Table 6 shows the elasticity of supply for specific characteristics of firms, that are ownership and regions, and finally summaries this discussion.

Table 6: Elasticity of supply

	Jura	Plateau	pre-Alps	Alps
Private	-0.219	-0.257	-0.215	-0.286
Public	-0.216	-0.248	-0.376	-0.481

Finally, the interaction between $ln(Price_{f,t})$ and $ln(area\ prod^{MC}_{f,t})$ is significantly positive and shows an estimate of 0.150 for the Alps, whereas there is no significance for the other regions. As firm's size increases in the Alps, its behaviour shifts towards a more competitive one. Whether this comes from larger economies of scale in the Alps, making costs reductions larger when size increases, or because of an increased concern for economic function, is hard to tell. Figure 3 shows for the Alps the elasticity of supply at different quantiles of the size distribution. At the lower end, some of the smaller firms might even follow a target-revenue model, although most of them are undoubtedly above this specific level.

The observation of a negative price estimate is of course expected based on preliminary hypothesis. It is however again important to note that from a theoretical point of view, these negative price elasticities do not directly bring to the conclusion that forestry firms are not acting as profit-maximizers. Indeed, as presented in Binkley (1993) and Hyde (1980), the dynamics of harvesting over time and the inter-temporal optimization are important and cannot be ignored. Assuming that a price increase is thought to be part of a long-term increase (i.e. the real price is growing over time) and is not considered as a one-time shock, the optimal production level might indeed be decreasing, and hence could agree with observations. In other words, price expectations are decisive from a theoretical point of view.

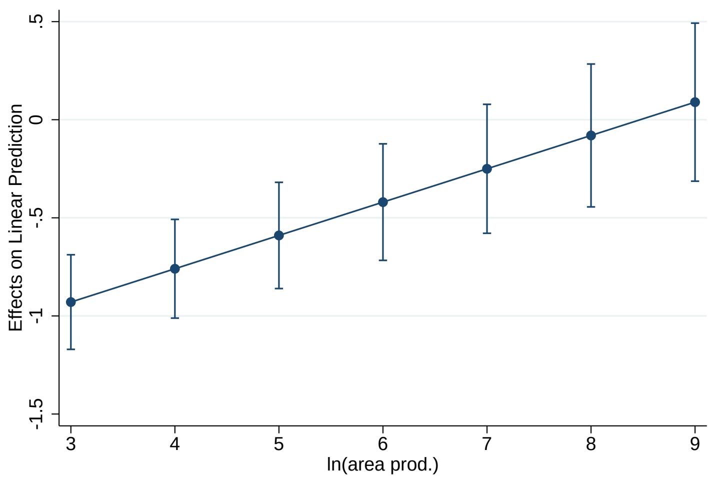

Figure 3: Elasticities of supply at different level of $ln(area\ prod_{f,t})$ with 95% confidence interval (Alps).

However, as a matter of fact, there exists a substantial accumulation of suggestive evidences leading to the conclusion that forestry firms are not profit maximizers and that the industry is not competitive.

As a first argument, if theory indeed allows the possibility that profit-maximization behaviour leads to a negative elasticity of supply, it is under the assumption that foresters view price increase as part of a long-term rate. This would have the effect of lengthening the optimal rotation period and therefore decrease harvesting. Year interactions clearly show the fact that elasticity of supply are consistently negative. Given these results, this would theoretically imply that not only price but also the rate of price increase is consistently changing over time, leading the forestry firms to consistently decrease or increase their production in order to continuously adapt the rotation period based on the new price rate expectation. This is a hardly plausible hypothesis with very little empirical credibility.

Other evidences exist suggesting non-profit maximization behaviour. The current distribution of forest age, which is far from optimal from a production point of view, is one of them. Forests are in general largely skewed towards old and very old trees and their growth are therefore sub-optimal. But even in this situation of rather small standing forest growth, firms are not fully harvesting the potential of wood from the Swiss forests. Every year, standing wood is growing by around 1.6 millions m^3 due to a lack of harvest, as mentioned in section 1.

In addition, no financial incentives exist for public forestry firms to seek profits. Their deficits are covered by public authorities. Traditionally, the latter is generally inclined to compare current year with previous ones. That means that rather than having to achieve a positive operating result, reaching previous year profit (respectively deficit) is mostly sufficient to stay out of trouble.

Finally, the multi-functionality of the forests is undeniable. In Switzerland regulations create a significant pressure on firms through, for example, the Forest Policy 2020, focusing simultaneously on several functions that are mostly not related to the economic activity of selling wood[19]. It is clear that the current political decisions in terms of multi-functionality of the forests with goals for the next 10 to 25 years has contributed to the current situation. Whereas no judgement is made on the current policies, this analysis highlights the frictions existing in the forestry industry in terms of wood supply. Although the firms could be willing to harvest more wood, the restrictions and the related costs are an obstacle for the firms, making wood harvesting unprofitable to them from an overall perspective.

Moreover, there exist emotional aspects linked to the population, which values forests for their recreational activities, but also the forest *per se*. Although the Swiss forests are currently underexploited, only 22% of Swiss people think that it should indeed be more intensively managed[20]. This creates a certain pressure, especially on public firms that must act accordingly and therefore preserve too much forests from what would be optimal from an economic point of view.

As a matter of fact, the negative price elasticity can be explained by the current overall situation in terms of multi-functionality of the forests, along with the different respective regulations. As shown, it seems that forestry firms are not eager to maximize their profits. On the other hand,

[19]In 2011, the Forest Policy 2020 was introduced with 11 objectives to be fulfilled until 2020, as part of a more general and long-term vision (2030). This vision focuses on the durability of the forests existence, their main functions (protective, economic and ecological) as well as on the value-added chain of the whole wood market (from the tree to the final products).

[20]Based on a survey on socio-cultural aspects of forest monitoring in Switzerland (WaMos, OFEV, 2010).

achieving other objectives related to regulations, such as the objectives of the Forest Policy 2020 as well as internal rules, prevails over the financial health of the firm. Forestry firms are responsible and accountable for the forests as well as the fulfilments of its functions, and the population is surely not willing to see them harvested and managed without any consideration to their non-economic functions.

Non-economic functions, and their implicit values, are important factors that affect the production of wood, either through regulations or public pressure. In any case, the high implicit value of the non-economic functions makes the wood production less profitable from an overall perspective. This means that in an extreme case, the quantity of timber harvested could even be considered either a by-product of another function's maintenance, or the consequence of a need for external revenues. That is, the economic activity *per se* is set aside by the multi-functionality of forests.

Of course, it does not mean that the current situation is inappropriate or inefficient from an economic perspective. It has the benefit of making the wood production greener than in many other places, as non-economic considerations in general are properly taken into account. The environmental cost is therefore fairly low. Unfortunately this is not reflected economically in prices. It should somehow be transferred into the market, ideally through a price difference with respect to what could be called less green wood. Whereas it will hardly be the case in practice, the use of direct subsidies for the wood production (per m^3 sold) could be an appropriate alternative.

All these explanations for the current behaviour of the firms should however not be an excuse to avoid finding potential improvements. The very high costs compared to revenues (for which Switzerland is a special case in the forestry industry as opposed to other European countries) is an issue that should be addressed. However, there are no evidence of any real incentives for a significant improvement in terms of cost efficiency. The different analyses done in this context confirm that there are indeed costs problems (Bürgi and Pauli (2013) and Krähenbühl (2014)).

Putting it all together, the findings are coherent. The true elasticity of supply is hard to assess as all models are predicting different levels. The negative sign, however, is on the other hand unambiguous. The previous arguments and considerations have thus all lead to the conclusion that forestry firms are actually not profit-maximizers. As a matter of fact, there undoubtedly exist other considerations that are of bigger importance than the economic function in the forestry industry. The many restrictions influencing the forestry firms inevitably worsen the financial situation and diminish the overall profit of the industry. Nevertheless, it is also a fact that the benefits of these restrictions in terms of non-economic functions are considerable. At the end, the price to pay in terms of efficiency and more generally in terms of profitability of the firms might be small compared to the related benefit.

4.3.2 Price formation and market power

In this part, the objective is to assess the level of market power held by forestry firms. It is a fact that it is a highly fragmented industry, and is therefore at first sight not a good candidate for holding large market power. However, due to high transportation costs (relative to wood prices), markets get generally small. This means that forestry firms can then easily hold some bargaining power with respect to sawmills.

Specifically, the determinants of price are estimated and some hypotheses concerning market power are tested. That is, it is expected that size could have an positive effect on price, which would suggest the existence of market power. Moreover, the revenue side is also to be considered. Subsidies are large and constitute a substantial portion of firm's revenues. In this context, the dependency of firms to external revenues (from wood sales) is potentially smaller, giving them a certain bargaining power in their transactions with sawmills.

For convenience, the regression model (equation 7) is again presented below:

$$
\begin{aligned}
ln(Price_{f,t}) = \alpha_{0,f} + \alpha_1 \cdot ln(Index_{r,t}) + \alpha_2 \cdot Log_{f,t} + \alpha_3 \cdot ln(Demand_t^{raw}) \\
+ \alpha_4 \cdot ln(Imports_t^{semi}) + \alpha_5 \cdot ln(area\ prod._{f,t}^{MC,R}) \\
+ \alpha_6 \cdot Subsidies_{f,t}/Costs_{f,t} + \alpha_7 \cdot Private + \mu_{f,t}
\end{aligned}
$$

Here is a brief explanation of the reasons for which these variables have been added to the equation. The first ones control respectively for economic environment ($ln(Index_{r,t})$) and the type of wood sold ($Log_{f,t}$). Also, $ln(Demand_t^{raw})$ and $ln(Imports_t^{semi})$ are introduced to further consider economic environment, as well as the demand side of the national market. Then, the proxy for the firm's size, $ln(area\ prod._{f,t}^{MC,R})$, is considered as a proxy for potential market power. Note that in this analysis, the variable is median-centered for each region. Locally, forestry firms might potentially have a bargaining power in their relation with sawmills due to, as noted above, the high transportation costs. The larger the firm, the more influence it might have, obviously. As a second measure to test for the market power, the coverage of costs by subsidies is used, denoted $Subsidies_{f,t}/Costs_{f,t}$. The higher the subsidies, the lower the need for the firms to produce and sell large amount of wood, and therefore the higher their bargaining power.

Tables 7 presents the results of the panel data models. The method is denoted by (CRE) for correlated random-effects. Note that because there are several variables that are only varying through time, year dummies had to be excluded from the model.

The first two variables considered are $ln(Index_{r,t})$ and $Log_{f,t}$, controlling for the economic environment and the type of wood harvested of the region. Both variables are always positive and significant, which was highly expected. The estimate of $ln(Index_{r,t})$ shows that prices are indeed partly following the market price. The estimate of $Log_{f,t}$, which is the most expensive type of wood, has obviously a positive influence on the average price at which forestry firms sell their wood.

Also, the national demand and the imports of semi-finished products show mostly expected results. First, the demand for raw wood has a negative but non-significant effect on price. However, in such price-quantity relation and even more in such specific industry, the causality, if any, is not straightforward.

In terms of imports of semi-finished products, the estimate shows a significant impact on prices. This was indeed expected, as higher imports mean all else equal a higher demand for such products as well as raw material (in this case, raw wood).

Models 2 and 4 are similar to models 1 and 3, respectively, besides the fact that year dummies were added in the formers. Therefore, national demand and imports are excluded from the model (both variables have only one observation per year).

Table 7: Price formation and market power

Variables	Model 1 (CRE)	Model 2 (CRE)	Model 3 (CRE)	Model 4 (CRE)
$ln(Index_{r,t})$	0.812***	1.152***	0.810***	1.034***
$ln(Demand_t^{raw})$	-0.358*		-0.322	
$ln(Imports_t^{semi})$	0.240**		0.239**	
$\%Log_{f,t}$	0.345***	0.344***	0.344***	0.343***
Private	-0.561	-0.000	-0.000	-0.000
$Subsidies_{f,t}/Costs_{f,t}$	-0.209***	-0.207***		
$Sub_{f,t}/Costs_{f,t} \times Private$	-0.007	-0.009		
$Jura \times \%Sub_{f,t}/Costs_{f,t}$			-0.273***	-0.271***
$Plateau \times \%Sub_{f,t}/Costs_{f,t}$			-0.167***	-0.167***
$Pre\text{-}Alps \times \%Sub_{f,t}/Costs_{f,t}$			-0.143***	-0.143***
$Alps \times \%Sub_{f,t}/Costs_{f,t}$			-0.438***	-0.436***
$ln(area_{f,t}^{MC,M})$	0.103***	0.103***		
$ln(area_{f,t}^{MC,M}) \times Private$	0.051**	0.051**		
$Jura \times ln(area_{f,t}^{MC,M})$			0.067***	0.067***
$Plateau \times ln(area_{f,t}^{MC,M})$			0.111***	0.111***
$Pre\text{-}Alps \times ln(area_{f,t}^{MC,M})$			0.141***	0.141***
$Alps \times ln(area_{f,t}^{MC,M})$			0.171***	0.171***
Plateau	0.107***	0.098***	0.251	0.257
Pre-Alps	-0.199***	-0.231***	-0.331	-0.323
Alps	-0.413***	-0.462***	-1.157	-1.294
2004		0.137		0.096
2005		0.122		0.085
2006		0.075*		0.056
2007		0.038**		0.037**
2008		0.026		0.030
2009		0.018		0.014
Constant	1.120	-1.417	0.745	-1.028

$Subsidies_{f,t}$ and $ln(area\ prod_{f,t}^{MC,R})$ are shortened by $Sub_{f,t}$ and $ln(area_{f,t}^{MC,R})$.
*, **, *** : p<0.1, 0.05, 0.01

Whereas a positive relation between subsidies and price would have suggested that firms could use their market power more extensively by increasing prices, it seems not to be the case. Quite the contrary, as a negative relation exists, from -0.207 to -0.209, suggesting that, all else equal, a higher amount of subsidies allows firms to fight less in the negotiation and accept a lower price, because a higher part of their revenues is guaranteed. Therefore, even if it could give them some leverage in the negotiation phase, they do not use it at all, for some reasons. Firstly, they could potentially prefer to secure the external part of their revenues coming from wood sales. Or, secondly, it might also come from an indirect effect. Subsidies are given to forestry firms for specific mandates. Therefore, a higher percentage obviously means that a larger portion of the work done by firms comes from and for external mandates. In those cases, it might be that wood production is only a by-product and not an end in itself, and thus sold cheaper.

The second part of the market power hypothesis is focused on size. Whereas the same models using fixed-effects would not reveal any market power, it is not the case when using (correlated) random-effects. It is important here to note that $ln(area\ prod_{f,t})$ is mostly varying across firms and thus its effect mainly falls into the fixed terms, which is why it is considered that random-effects are here of greater value[21]. Indeed, the estimate of the size proxy is positive and significant when random effects are used instead of fixed effects.

Models 1 and 2 focus on the differences existing between public and private firms. We can see from the results that whereas private firms are not able to sell their wood at a higher price and that subsidies has the same

[21] Although Hausman test suggests that fixed-effects should be used, estimations with correlated random-effects are in general in full accordance with fixed-effects models: the main differences lies in the size proxy.

negative effect than public ones, there is a considerable difference lying in the effect of size. Indeed, the interaction between private and $ln(area_{f,t}^{MC,R})$ is positive and significant, at 0.051, giving a total size effect for private firms at 0.154, substantially higher than for public ones (0.103). This means that bigger private firms are benefiting from a higher level of market power, and therefore can sell their wood at a higher price.

In models 3 and 4, this market power due to size is subdivided into the four regions of Switzerland already introduced above. For some reasons, big firms in the Jura seem to be the ones holding the least market power at 0.067, compared to elsewhere in the country, although all regions have positive estimates. On other side, the pre-Alps and Alps are the regions in which size has the biggest effect, with 0.141 and 0.171, respectively.

In short, this part of the analysis has focused on the price formation and more specifically on the market power held by forestry firms. Two hypotheses were tested. Whereas subsidies do not show any evidence of market power, the size has on its side the expected positive effect on price. From the empirical estimations, it seems to be higher in mountainous area (i.e. rougher environment), and held to a greater extent by private firms.

5 Conclusion

This paper's first objective was to model wood supply in the Swiss forestry industry and to understand its main drivers. Panel data models were used in the regression analysis, along with instrumental variables to obtain robust results.

Among the most important hypotheses, the profit-maximization behaviour of the forestry firms is strongly rejected by the empirical analysis and several suggestive evidences. Negative elasticity of supply is supported by all models. Moreover, the current forest age distribution is largely skewed towards old trees and therefore far from the optimal condition from an economic point of view. The possible explanations for the lack of competitive behaviour are numerous and might include a problem of ownership, and more specifically the lack of incentives for better financial management, especially for public firms. Also, the multi-functionality of the forests, along with the current general opinion of the population against a more intensive exploitation, might also be partly responsible for this situation. Whereas the industry is surely financially and economically inefficient, this paper does not explicitly consider the whole spectrum of non-economic functions that must be taken into account when estimating and assessing the level of efficiency of the industry.

Whereas the overall conclusions are robust, the exact level of elasticity of supply is difficult to estimate based on the empirical analysis and the available data. Nonetheless, it still does not prevent from rejecting the hypothesis of profit-maximization and competitive behaviour. However, alternative models potentially explaining the behaviour of forestry firms, such as the target-revenue model, are difficult to test in these circumstances. Moreover, some other findings are still unexplained, such as several differences existing across regions in the supply function as well as the price formation and would surely require some further work.

In a second step, the analysis has focused on the formation of price in the Swiss market and specifically the existence of market power held by forestry firms with respect to sawmills in the price negotiation. Empirical evidences suggest that, if subsidies do not have the expected effect on price, the size of firms positively influences the price and therefore implies the existence of market power in the industry. Moreover, it appears that private firms are holding, or simple using, a significantly bigger level of power with respect to public ones. Also, it is in the roughest natural environments that are found the highest differences between small and big firms, that is in the pre-Alps and Alps.

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6 Appendix A

In order to corroborate the results presented in section 4 using the price proxy that could be called into question, two alternative specifications are used. First, instrumental variables are used in order to deal with potential endogeneity of price introduced in section 4.2.

Second, the price variable is substituted by the price index used in the price formation analysis. It is obviously exogenous, and the only potential shortcoming is its small number of observations (one per region per year).

Focusing on instrumental variables and table A.1, the instruments were chosen to be only a mix of two indices. It appears that with the exception of one regression showing non-significant price estimate, the others are all significantly negative. It has been hard to find proper instruments passing the Sargan test, and the sensitivity of the results to them is strong. Whereas it can safely reject the existence of strong endogeneity bias (at least in the positive direction that would have changed the conclusions of competitiveness), the variability of the estimates is too high to draw any further conclusion[22].

Turning to panel data model using price index and table A.2, we can clearly see that irrespective of the index, the sign is always negative, although the magnitude of the estimate changes quite dramatically[23].

Based on these findings, although the magnitude of the elasticity of supply estimated in tables A.1 and A.2 do not coincide with the results shown in table 5, the sign is unambiguous and it implies that the hypothesis of profit-maximization can be safely ruled out. However, it is clear that the question remains on the exact magnitude of the elasticity of supply.

[22] Out of the numerous instruments and specification used, only one turned out to be positive, significant and not rejected by the Sargan test. In light with all the preceding evidences, it is considered to be a type II error.

[23] The last index of energy wood is not shown here for simplicity. Its estimates are non-significant.

Table A.1: Instrumental variables

Variables	Model 1 (FE)	Model 2 (FE)	Model 3 (RE)	Model 4 (RE)	Model 5 (RE)
$ln(\hat{Price})$	-1.232***	-1.206***	-1.264***	-1.187***	-1.229***
$ln(area\ prod_{f,t})$	0.848***	0.848***	1.153***	1.143***	1.149***
$ln(area\ non_{f,t})$	0.011	0.011	-0.053***	-0.053***	-0.052***
$Sub_{f,t}/Costs_{f,t}$	-0.203***	-0.199***	-0.237***	-0.222***	-0.230***
$\%Outsourcing_{f,t}$	0.245***	0.245***	0.164***	0.164***	0.165***
$\%Othercosts_{f,t}$	-0.404***	-0.403***	0.447***	0.454***	0.436***
Private			-0.356***	-0.353***	-0.354***
2004	-0.218***	-0.214***	-0.214***	-0.201***	-0.208***
2005	-0.240***	-0.235***	-0.248***	-0.234***	-0.242***
2006	-0.026	-0.024	-0.034	-0.029	-0.032
2007	0.146***	0.144***	0.149***	0.144***	0.147***
2008	0.099**	0.097***	0.098***	0.092**	0.096***
2009	-0.017	-0.016	-0.011	-0.010	-0.011
Plateau			0.572***	0.563***	0.569***
Pre-Alps			-0.265***	-0.258***	-0.262***
Alps			-1.877***	-1.850***	-1.866***
Constant	7.220***	7.128***	6.229***	6.009***	6.127***
J-test (p-value)	0.125	0.321	0.060	0.627	0.821

*, **, *** : p<0.1, 0.05, 0.01

Table A.2: Price Indices

Variables	Model 1 (FE)	Model 2 (FE)	Model 3 (FE)	Model 4 (RE)	Model 5 (RE)	Model 6 (RE)
$ln(Price\ Index_t)$	-1.224***			-1.105***		
$ln(Price\ Log_t)$		-2.677***			-2.645***	
$ln(Price\ Indus._t)$			-0.531**			-0.429**
$ln(area\ prod_{f,t})$	0.826***	0.810***	0.836***	0.990***	0.989***	0.991***
$ln(area\ non_{f,t})$	0.016	0.019	0.015	-0.034***	-0.033***	-0.034***
$Sub_{f,t}/Costs_{f,t}$	0.007	0.005	0.009	0.016	0.014	0.018
$\%Outsourcing_{f,t}$	0.254***	0.255***	0.256***	0.219***	0.219***	0.219***
$\%Other\ costs_{f,t}$	-0.336***	-0.338***	-0.336***	0.119*	0.117*	0.119*
Private				-0.307***	-0.307***	-0.307***
2004	-0.361***	-0.784***	-0.313**	-0.321***	-0.770***	-0.248**
2005	-0.366***	-0.769***	-0.323***	-0.334***	-0.761***	-0.266**
2006	-0.116**	-0.367***	-0.000	-0.102*	-0.364***	0.008
2007	0.068***	0.104***	0.094***	0.069***	0.105***	0.089***
2008	0.040	0.117***	0.030	0.037	0.117***	0.025
2009	-0.039	-0.094***	-0.017	-0.031	-0.088***	-0.009
Plateau				0.490***	0.600***	0.408***
Pre-Alps				-0.022	0.018	-0.166***
Alps				-1.313***	-1.206***	-1.511***
Constant	8.424***	15.415***	5.265***	7.383***	14.609***	4.458***

*, **, *** : p<0.1, 0.05, 0.01