

ESSAYS ON THE SUPPLY SIDE OF RAW WOOD

PhD thesis submitted to the Faculty of Economics and Business

Institute of Economic Research

University of Neuchâtel

For the degree of PhD in Economics

by

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Defended on November 28th, 2018

IMPRIMATUR POUR LA THÈSE

Essays on the supply side of raw wood

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Neuchâtel, le 11 février 2019



Le doyen

Mehdi Farsi

Acknowledgments

First of all, I would like to thank my supervisor, Professor Mehdi Farsi, for his dedication, time and patience during these years. His very valuable comments helped me immeasurably. I am also thankful for the teaching opportunities he gave me.

I am thankful to the entire team working on the NRP 66 Program, composed of Professors Milad Zarin and Andrea Baranzini, Alexander Mack, David Maradan, Nicolas Borzykowski and especially to Professor Alain Schönenberger for his help and constructive discussions. I'm also grateful to Professors Milad Zarin, Oliver Thees and Massimo Filippini who have kindly accepted to serve in my dissertation Committee. I particularly acknowledge them for their precious time.

I thank the Swiss National Science Foundation and the NRP 66 Program for the funding of this research, as well as the University of Neuchâtel which provided me with an ideal working environment.

I am thankful to all my colleagues and friends at the Institute for Research in Economics, especially Sandra Klinke who had the difficult task to share the same office during many years, as well as Caspar Sauter, Luciano Lopez, Alexandra Kis, Benjamin Tissot-Daguette, Ivan Tilov, Cécile Hediger, Joséphine Leuba and Leila Schwab with whom I shared unproductive yet so essential time.

I would also like to thank all my invaluable friends, particularly Jean-Marc, Olivier E., Jody, Olivier S., Joachim, Romain, Quentin, Yohan and all the members of the great "Section Neuchâteloise de la Société Suisse des Étudiants de Zofingue"; and especially my heartfelt gratitude to Coraline, for her unconditional support and understanding, for which I am deeply thankful.

Finally, I am very grateful to my family, my parents, my sister Stéphanie, my brother Gabriel and to Virginie for their huge love and support.

Summary

The Swiss forestry industry is a complex environment including aspects of both public and private sectors. As a consequence, pure public sector economics cannot be fully applied in this context as forestry firms are in the private market of selling raw wood; it turns out to be an important part of their job and most of their revenues. At the same time, it is not possible to only consider the private market of raw wood as they also provide numerous public and non-marketable services which play a crucial role for our society. These services include, among others, road maintenance, protection of infrastructure and population against avalanches or landslides, biodiversity preservation or recreational activities.

The general motivation of this thesis is the analysis of the behaviour and the performance of the Swiss forestry sector, which provides both private and public services ("hybrid" sector). Practically, the objective is to develop and apply a methodology to describe the structure of the supply side of the forestry industry, which is an interesting example of a hybrid sector, but certainly not the only one; utility or education, for example, share very similar characteristics. The applicability of the methods presented in this thesis goes well beyond the sole field of forestry economics, in any sector involving a mix of public and private services.

The thesis is composed of three different chapters complementing each other in the analysis of the Swiss forestry sector. The motivation of the first chapter is to better understand the cost structure of the forestry firms and get insight on their cost performance and how to increase it. The use of economies of scale and the effect of outsourcing are paramount in this analysis. With the forestry sector being highly fragmented with many small firms operating in this capital intensive environment, I present some evidence that cost reductions are possible through an increase of firms' size. Collaboration and outsourcing are potential alternatives as well. The second chapter focuses on and tests the hypothesis that forestry firms are profit maximizers regarding raw wood. Many evidences suggest that the sector faces strong lack of efficiency, at least from a sole economic point of view. In addition, the existence of market power is tested using two main drivers: the size of firm, and the level of subsidies. While the profit maximization hypothesis is strongly rejected by the estimations, the market power could exist in some specific circumstances, with size as the main driver. Finally, the last analysis of this dissertation gives the multifunctionality of forests a central role, as it has been an important aspect of forest management in Switzerland for a very long time. In this context, the foremost motivation is to explicitly take it into account and assess the value of the different public services from the firms'

perspective. Protection appears to be the only binding public service, which, to be some extent, can be explained by its economic and regulatory importance, compared to the others.

This dissertation is an exploratory work. Specific methodologies and specifications have been developed and applied. Other applied methodologies are known in some other economic fields but have been only scarcely, if any, applied to the forestry industry.

Keywords: raw wood, forest economics, forest functions, multifunctionality, performance, public services, public economics, non-linear modelling, cost functions, supply functions, economies of scale, shadow prices.

Résumé

L'industrie forestière suisse est un environnement complexe comprenant autant des aspects du secteur public que du secteur privé. Ainsi, l'économie publique au sens strict du terme ne peut pas pleinement s'appliquer dans ce contexte car les entreprises forestières coupent et vendent du bois brut sur le marché privé; cela s'avère d'ailleurs être une partie importante de leur travail et forme une part significative de leurs revenus. En même temps, il n'est pas possible de considérer uniquement le marché privé du bois brut, car l'industrie forestière fournit également de nombreux services publics et non commercialisables qui jouent un rôle crucial pour notre société. Ces services incluent, entre autres, l'entretien des routes, la protection des infrastructures et de la population contre les avalanches ou les glissements de terrain, la préservation de la biodiversité et les activités de loisirs.

L'objectif principal de ce travail est d'analyser le comportement et la performance du secteur forestier suisse, qui fournit à la fois des services publics et privés (secteur "hybride"). Pratiquement, l'objectif est d'élaborer et d'appliquer une méthodologie permettant de décrire la structure de l'offre du secteur forestier, qui est un exemple de secteur hybride, mais certainement pas le seul; le secteur de l'électricité ou celui de l'éducation, par exemple, partagent des caractéristiques très similaires. L'applicabilité des méthodes présentées dans cette thèse va donc bien au-delà du seul domaine de l'économie forestière, et ce dans tout secteur impliquant une combinaison de services publics et privés.

La thèse est composée de trois chapitres qui se complètent dans l'analyse du secteur forestier suisse. L'objectif du premier chapitre est de mieux comprendre la structure de coûts des entreprises forestières et d'obtenir un aperçu de leur performance en matière de coûts et sur la manière de l'accroître. L'utilisation d'économies d'échelle et l'effet de la sous-traitance sont primordiaux dans cette analyse. Le secteur forestier étant très fragmenté et de nombreuses petites entreprises opérant dans cet environnement à forte intensité de capital, je présente certaines preuves selon lesquelles des réductions de coûts sont possibles grâce à une augmentation de la taille des entreprises. La collaboration et la sous-traitance sont également des alternatives potentielles. Le deuxième chapitre se concentre sur et vérifie l'hypothèse selon laquelle les entreprises forestières maximisent leurs profits. De nombreuses évidences suggèrent que le secteur est confronté à un fort manque d'efficacité, du moins du seul point de vue économique. En outre, l'existence d'un pouvoir de marché est testée à l'aide de deux facteurs principaux: la taille de l'entreprise et le niveau des subventions. Alors que l'hypothèse de maximisation du profit est fortement rejetée par les estimations, le pouvoir de

marché pourrait exister dans certaines circonstances spécifiques, la taille étant le principal facteur. Enfin, la dernière analyse de cette thèse attribue un rôle central à la multifonctionnalité des forêts, qui constitue depuis très longtemps un aspect important de la gestion des forêts en Suisse. Dans ce contexte, la motivation première est de la prendre explicitement en compte et d'évaluer la valeur des différents services publics du point de vue des entreprises. La protection apparaît comme le seul service public contraignant, ce qui s'explique dans une certaine mesure par son importance économique et réglementaire vis-à-vis des autres.

Cette thèse est un travail exploratoire. Certaines méthodologies spécifiques ont été développées et appliquées ; d'autres sont connues et appliquées dans d'autres domaines économiques mais n'ont été utilisées que très peu, voire pas, à l'industrie forestière.

Mots clés: bois brut, économie forestière, fonctions de la forêt, multifonctionnalité, performance, services publics, économie publique, modèle non-linéaire, fonction de coûts, fonction d'offre, économies d'échelle, prix fictif.

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*"It's when forests stop breathing
that man bids farewell."*

Anthony T. Hincks

1 Introduction

Everyone in Switzerland had the chance to stroll at least once on a dirt road while enjoying the fresh air of the forest. Most people take this for granted. However, among many others, this service is guaranteed by the forestry industry and its forestry firms which maintain, operate and harvest about a third of the country covered by forests.

Beside their core activity of wood production (a marketable good), these firms fulfil several obligations for a large variety of public (and mostly non-marketable) services. Provided by forests, these ones play a crucial role for the industry, costing often much and allowing hardly any revenue (beside subsidies). In addition, they require a lot of specific attention from forestry firms while restricting their flexibility in terms of their forest management choices.

It is no wonder that all these functions and services provided by the forestry industry are often in conflict and in all cases influence each other. The combination between marketable goods and (non-marketable) public services makes the forestry industry a particular case of special interest for an economic analysis. It is not a unique and isolated industry with such characteristics or constraints. Numerous other hybrid examples (facing both aspects of the private and public sectors) exist, such as hospitals, universities or utilities.

The consequences of these intermingled functions and the underlying mechanisms associated with strategic choices of firms and the impact on performance, are all important aspects to better comprehend how the forestry industry works.

This dissertation attempts to bring a contribution to the understanding of the mechanisms driving the forestry industry, analysing its behaviour as well as giving indications of its performance. In addition, the methodology used in this dissertation is designed to be applicable to any hybrid sector.

1.1 Contributions and research questions

The value of Swiss forests is undeniable. Wood can be harvested and used as a marketable good. However, the standing trees themselves are also extremely valuable, largely beyond a stock of wood waiting for harvest¹. Forests fulfill numerous functions from water purification to protection, along with recreational activities for the population. It is also a great shelter for life and biodiversity. However, its industry has for several decades recorded recurrent and significant losses. It seems that there has been a significant downtrend with no sign of reversal². This observation is troublesome and raises many questions that should be answered to help the industry keep its head above water. These considerations are crucial for this thesis and bring a first concrete motivation.

Whereas wood production is the major source of revenues for forestry firms, it is not their sole activity. In its Forest Policy 2020, the Swiss government has formulated 5 objectives considered of major importance: exhaustion of the wood harvesting potential, climate change mitigation and adaptation, protection function, biodiversity conservation and improvement and finally forest area conservation. It appears that only one of those objectives targets the wood production function. For the remaining ones, the attention is focused on the public services. They are costly and do not generate directly much revenues for the forestry industry. As an external support, subsidies are meant to compensate and pay for the work and the public services provided. However, some voices from the industry are rising to argue that the current level does not even pay for the direct costs of these services, partly due to the wood price continually decreasing. It

¹See for example: Federal Act on the Reduction of CO₂ Emissions, 2011. In addition to its use as a source of energy considered to be carbon-neutral, wood is also explicitly cited as a potential carbon sink.

²The gap between revenues and costs of the core activity has substantially increased over the period, with firms being generally unable to compensate it with non-core activities (FOEV, 2017. *Annuaire La forêt et le bois*, 2017).

is then not even needed to mention the opportunity costs of those services. As mentioned earlier, all functions of forests greatly influence each other and it is not surprising that the public ones have a great impact on the major source of revenues, the wood production.

The Swiss forestry industry is composed of a large variety of firms in terms of size, ownership, environment or constraints. The fragmentation of the industry is an important matter as many firms are very small, with fewer relatively large ones. Most of them are owned by the public sector, acting therefore with specific objectives, potentially different from the private ones. They also differ in terms of environment and types of forest under management; as a result, growth rate of trees, accessibility, regulations and underlying functions of forests vary widely from one firm to another, with regions, altitude or landscape.

The industry lies between private goods on one side, with the production of wood and its sale, and the public services on the other side, with numerous public functions that forests must fulfil and which are not marketable, yet extremely valuable for society. This creates a hybrid sector which needs a special methodology for its analysis.

The general research topic of this dissertation is the analysis of the behaviour and the performance of an industry facing both aspects of the private and public services. First, an estimation of performance is carried out, and more precisely of cost performance (chapter 3). Cost aspects are related to the overall structure of the industry; this means that performance metrics such as economies of scale could allow to reach a better design for the industry without altering either the behaviour or the outputs (in overall terms) of forestry firms. Then the behaviour in the market is analysed through two chapters. Analyses are conducted both on the (non-)competitive behaviour of forestry firms (chapter 4), as well as the impacts and the evaluation of the multifunctionality of the forests (chapter 5).

First, the classical economic models are applied to the Swiss forestry industry for some insightful observations: in terms of costs (chapter 3), assuming therefore optimal outputs for the analysis, with insights for potential cost reductions alternatives; then, in terms of supply (chapter 4), for a preliminary behavioural approach challenging strategic choices as well as analysing the level of market power (as another performance indicator of the market).

Second, an analysis is performed integrating the multifunctionality aspect of the industry, and more specifically with the estimation of shadow prices of public functions (defined as a proxy for the implicit value of a non-marketable service, either willingly by forestry firms or through external forces). This is an explicit integration of the constraints faced by forestry firms but typical to any hybrid market and practically neglected by classical methods (chapter 5).

Chapter 3 : Costs Analysis and Economies of Scale

This chapter attempts to bring some understandings of the cost structure of the forestry industry in Switzerland. First, it describes the factors and main drivers affecting costs in this industry. Second, it creates a basis to get insights in order to increase the cost efficiency of the forestry firms and potentially help put an end to almost three decades of recurring deficits. Such information are crucial to policy makers in order to further understand the challenges faced by the industry alongside with its potential solutions.

While there has been several technical efficiency analyses in the case of the Swiss forestry industry (Mack (2009) or Schönenberger et al. (2009)), there was no such cost analysis, and considering its financial difficulty, the analysis is in this regard already an important output. The economies of scale are estimated and discussed with the perspective of the multifunctional environment of forests. With the Swiss forestry industry highly fragmented into many small and very

small firms, this point is crucial as it is believed to be of significant importance in the cost structure of the forestry industry and its efficiency. As an alternative, a special emphasis is also put on outsourcing which is believed to be another important factor of efficiency. The decision to outsource is a technological transfer from one firm to the other. Therefore, it is *per se* not good, but it is assumed that the firms outsourcing their work to third parties do it in an attempt to improve their cost efficiency, because the alternative of doing it themselves would be worse. Of course, it is not the best solution from a general perspective, as it increases administration costs, but it still can, at still in short and medium terms, be a good and practical measure, which is easily implemented.

Moreover, the methodology is recognized as a minor but interesting additional contribution. Not only does it consider a multi-output framework, the specification is also based on a completely separated non-linear approach, taking therefore full advantage of the data, with a more flexible specification than any linear ones. The structural methods used in this chapter involve several recent econometric novelties, that have very rarely if at all been applied in such empirical analysis. Still closely related to theory, this methodology is applicable to costs analysis well beyond forestry economics. It also enables to make important estimations such as economies of scale by taking heterogeneity and strategies of firms into account which, to my knowledge, has never been done in this economic field.

Are there structural inefficiencies that could be reduced?

The Swiss forestry industry has been in current deficits for the last two decades. If understanding the reasons is crucial, finding solutions to this issue is at least as important. As mentioned, the focus in this chapter is on one major structural aspect: the economies of scale. Indeed, the fragmentation of the industry is a

potential reason for the recurrent deficits and the economies of scale might be a solution to increase cost efficiency and therefore reduce losses. According to several authors³, economies of scale have often been an important factor in the efficiency of the forestry industries worldwide.

Late history has also brought evidences that it indeed plays a significant role, with market forces pushing towards efficiency. As a matter of fact, strong economies of scale certainly explain why, for example, in the middle of the 20th century, the number of sawmills in the United States have been almost divided by ten in a couple of decades (Granskog, 1978). The Swiss forestry industry being characterized by numerous small firms, this point is of significant importance. In Switzerland, Mack (2009) and Schönenberger and Mack (2009) have found that economies of scale are indeed significant. In this context, we will re-explore this field and bring further evidence by taking a different approach. In particular, more precise measures of economies of scale will be estimated, taking into account specific features that were not considered in previous studies. These include strategic behaviours and heterogeneity across firms (by taking into account specific characteristics of firms) which is believed to be a strong factor affecting economies of scale and consequently theoretical optimal size.

Results show that there exist significant economies of scale in the forestry industry. In other words, there is a substantial potential for cost reduction through mergers and collaborations between firms. Findings might have several impacts. Policy makers can profit from such analysis in order to create incentives in precise directions and knowing that the current goal of helping forestry firms merge can indeed be profitable in the long run. And if not through direct merger of firms, which could be difficult to apply in practice, collaboration with provision of equipment, infrastructure or simply work coordination can also be helpful in

³Among them Sutton (1973), Granskog (1978), Grebner and Amacher (2000), Mack (2009) or Lantz (2003).

the overall objective to reduce costs without jeopardizing the services provided by forestry firms. Other means used to achieve the same goal of decreasing losses while increasing efficiency are explored in the second research question.

Are there any other options available to firms in order to save costs?

In a harsh economic environment, new alternatives should be explored to find appropriate solutions. Following the previous question about cost efficiency, outsourcing is one potential alternative. For small firms that have not reached a critical size to allow for considerable investments, and which cannot merge or collaborate with others for some reasons, it might very well be the most efficient way. Indeed, it can be viewed as a transfer of technology from the forestry firm outsourcing activities to the specialized firm mandated. The firms outsourcing part of their activities to more efficient firms are then mechanically more efficient as well, even though they are not doing any improvement by themselves. As a matter of fact, results support that outsourcing as a strategy holds significant potential for cost reductions (through the technological transfer from one firm, the forestry firm, to another, the specialized firm). In this highly fragmented industry with a significant lack of synergies, these findings are important and encourage to further investigate this topic, given the importance of costs in this industry and the great potential lying under economies of scale.

Other strategies are also available, which should be explored. For example the ancillary services, additional paid services which are not part of traditional activities of forestry firms, such as extra recreational activities, or sales of manufactured goods made from wood. The amount of such services have largely increased over the last three decades. It might as well be a mean to try to increase profits of the non-core activities in order to compensate for the losses of the core activities, if thought to be inexorable.

Chapter 4 : Supply Analysis and Market Power

Wood supply has been widely studied. Starting with Faustmann (1849), modelling the decision making process of harvesting is definitely an important subject and an interesting optimization problem with many possible constraints and uncertainties. Most often, authors have tried to estimate what the optimal level of wood production is given certain realistic characteristics or by incorporating new specifications (risks of diseases or fire, non-uniform distribution of forest ages, etc.), while often neglecting non-wood functions (Samuelson (1976); Hyde (1980); Ussivuori and Kuuluvainen (2005)).

This chapter is a first application of industrial organization challenging fundamental assumptions of the theoretical economic models. The Swiss forestry industry enables a thorough analysis with pertinent and extensive data. This chapter attempts to contribute to the wood supply analysis in a reduced form and at two different levels.

First, it starts by exploring the factors affecting quantity supplied and determining the behaviour and the main drivers of the forestry firms. Overall, it is a interesting case study because of the very heterogeneous characteristics it shows, in terms of environment, ownership, size, forest type, etc. These allow to control more easily for the specificities of each entity. Firm-specific price elasticities are estimated thanks to the regression analysis; characteristics such as ownership or sizes are controlled for. Specifically, the assumption of profit maximization (and as a consequence perfect competition) is highly questioned, and related tests are performed. Alternatively, targeted revenues, as opposed to profit maximization, could be a credible goal aimed by the forestry firms.

What is the overall level of competitiveness of the industry?

In order to better understand the overall situation of the Swiss forestry industry, it is legitimate to ask some questions about the managerial objective of the firms. For all mixed services sectors as well, this is crucial as it relates to the fundamental assumptions of underlying economic theory. More specifically, we want to know which objectives Swiss forestry firms pursue.

The first task is naturally to know whether or not forestry firms are profit maximizers. More specifically, the first part of the analysis focuses on the supply response to a price change (price elasticity of supply). The first hypothesis of no (or negative) response from forestry firms to any price change tests a necessary (but not sufficient) condition for profit-maximization. In other words, if the first hypothesis cannot be rejected, the relation between quantity and price would therefore not be positive and the forestry industry cannot be maximizing profits. This then could lead to think that the goal pursued is different, and maybe closer to a target-revenue behaviour. This kind of behaviour, with the objective to reach a certain level of revenues (therefore selling less when prices are higher), can be theoretically sound for public markets with considerable fixed costs, especially when sales can be easily postponed or when there is substantial market power. It has been extensively studied in the case of oil and OPEC. Teece (1982), Griffin (1985) or more recently Smith (2005) are good examples and indeed apply interesting methods that could be useful for some hybrid industries. In the case of the Swiss forestry industry, Bürgi and Pauli (2013) and Bürgi et al. (2009) have already suggested that firms could show such a behaviour (or at the very least in contradiction with profit maximization behaviour), mainly as a result of large fixed costs.

Even though the two industries of oil and wood are different in many ways, there are reasons to believe that the same objective of target-revenue applies here

as well. Most forestry firms are public firms and heavily subsidized. Their costs being relatively invariant for a specific year, the revenues they have to achieve is potentially well-known. They have basically no incentives to go beyond that point, even more with the current difficult financial situation and the uncertainty of future periods in terms of prices. Moreover, the production can easily be postponed to the following years. This encourages them to reduce production and keep high wood inventory, which is fully in line with observations of the current situation of Swiss forests, as shown in Natterer et al. (2004).

As a matter of fact, the results show that the hypothesis of competitive market can be safely rejected. It is however important to note that the alternative might not be an inefficient behaviour. It could also be that, because of either external restrictions such as regulations or simply specific non-wood objectives, the forestry firms are not seeking any optimum for their production of wood but are looking for other objectives, and therefore are simply not profit-maximizers.

This supply analysis also provides an empirical justification of the suspicion presented by Bürgi et al. (2009) and Bürgi and Pauli (2013). Thompson et al. (1974) indirectly presented a theoretical approach suggesting a similar conclusion. Their work, showing that the function of wood production is in direct opposition to many if not all other functions fulfilled by forests, has a direct consequence: as long as a forestry firm values (or is constrained by law) and provides public (and non-wood) services, the optimal level of wood production (from the sole wood production point of view) is essentially unachievable.

What are the drivers of the wood price formation and is there evidence of market power?

In parallel to the first analysis of supply and the competitive behaviour of firms, the price itself is also closely examined, for a better understanding of its

formation and consequently of a potential market power. Bergman (1993) has raised similar questions in Sweden for the pulp and paper industry, and results have shown some evidence of variable oligopsony power. In the Swiss forestry industry tradition and handshakes dominate; important transportation costs and the significant amount of subsidies are other non-negligible aspects of this market. Moreover, the sawmills being confronted to a very harsh economic environment, these all bring some suspicions that forestry firms might, in some cases, hold a certain level of market power. The chosen methodology enables to answer several questions about the price formation. Is there evidence of market power? And if any, what are the main drivers of this power and how important is it?

By giving a very close attention to the price formation, this chapter brings a significant contribution to an industry characterized by high transactions and transportation costs. The particular question of price formation was rarely asked in the case of forestry industry. Although with a slightly different approach, Bergman (1993) also analyses the level of market power in the case of the pulp and paper industry. With a deeper understanding of the formation of prices, one can better understand the process driving the whole wood market.

Specifically, two main hypotheses are tested through the estimation of an econometric model describing the formation of price. The first concerns the size as a source of market power, which is fairly usual in this type of analysis. Second, the level of subsidies which might also help influence the price of wood. Everything else being equal, the higher the level of subsidies, the less dependent are the forestry firms from wood revenues which could give them a certain flexibility on the market, and as a direct consequence some market power.

The results suggest that market power seem to exist in the forestry industry. Indeed, higher prices generally come with bigger firms. On the other hand, the second hypothesis about the subsidies did not find any empirical evidence.

Nevertheless, it must be noted that the level of market power is fairly low and concentrated within private firms, which might just be harsher on price when dealing wood in the market.

Chapter 5 : Analysis of behaviour in a multifunctional context

The multifunctionality has been an important aspect of the Swiss forestry industry since the prohibition of clear-cutting at the end of the XIXth century in order to promote a more environmental-friendly management⁴. Nowadays, firms face many constraints with many services they have to provide in their daily businesses: protection, biodiversity⁵, water purification, road maintenance, and so on. The extensive list of public services provided by forests is long and includes almost invaluable ones. This chapter is an attempt to explicitly account for them and assesses how these public functions affect the forestry firms from an economic and financial standpoint.

In practice and particularly in the forestry industries, the explicit consideration of the multifunctionality indeed has often been an issue; partial available data force researchers to demonstrate an extensive level of creativity for the creation of various proxies for the non-wood value of forests. They include the height of trees, the inventory of standing forests or the creation of an index based on ecosystem and socio-demographic characteristics (Abt and Prestemon (2003); Pattanayak et al. (2000, 2003); Prestemon and Wear (1999) or Swallow et al. (1990)). In particular, the North American industry has been widely studied compared to other parts of the world. While there are still some issues, avail-

⁴Press release from May 29, 2001, OFEV. "125 ans de loi forestière: un succès durable".

⁵The concept of biodiversity services here is used in this dissertation as the conservation of species diversity and of all ecosystems, as mentioned in the Forest Policy 2020. Millenium assessment (2005) defines biodiversity as "the foundation of ecosystem services". The discussion here focuses on the biodiversity conservation and consciously ignores the ecosystem services provided, that is "the benefits people obtain from ecosystem" (Millenium assessment (2005). Including the latter would be, in terms of analysis and especially data, impossible is therefore let for further researches.

able data for the Swiss industry allow a new and more detailed analysis of the forestry industry with the objective of better understanding the behaviour of firms in a multifunctional environment full of constraints.

Looking at similar studies, there is, first of all, Baardsen (2003) who used econometric methods in the context of the Norwegian sawmilling industry to estimate shadow prices and the short-run supply and demand of wood. However, this paper does not explicitly study the behaviour of firms and the causes and impacts of constraints. This chapter uses a very similar approach in terms of methodology in the context of the Swiss supply of raw wood. These methods have to my best knowledge never been used directly and explicitly to understand the behaviour of forestry firms while taking the constraint of non-wood functions into account.

On the other hand, the question of the impacts of constraints on firm's behaviour and policies has however already been raised in several contexts of the forestry industry. Nonetheless, most researches use aggregated data for the whole industry and it thus leads to generalized results with no possible precise observations. Górriz-Mifsud et al. (2016) is a good example of such studies, with an evaluation of ecosystem services in Mediterranean forests.

While neither the methodology nor the research question is new in the existing literature, the combination of the two has never, to my best knowledge, been done in the context of forestry industry before, which could therefore bring new perspectives. As a result, it appears that state-of-the-art methods have never been applied in the context of the behavioural constraints imposed at the firm level by multifunctionality of the forests. This last part of the dissertation attempts to fill this gap. Moreover, this type of hybrid industry, in between private and public sectors, can be met in very different markets nowadays (utilities, transport, health care), making this type of analyses widely applicable.

How do Swiss forestry firms manage multifunctionality with numerous public and non-marketable services?

Turning to more specific contributions, the first focus of this chapter is to understand how forestry firms behave in the context of the numerous public functions. In other words, the first objective is to find out whether or not these services have a binding effect on firms and to estimate their intrinsic value empirically. To help tackling this wide question, this chapter presents an econometric analysis using a restricted revenue function in order to assess the implicit value of different public and non-marketable functions. Using such methods, specific shadow prices are estimated for each function, period and firm. Using these estimations, it is then possible to characterize the impact of each of the different functions and evaluate the firms' choices or, similarly, how each of these functions weigh in the general management of the forestry industry. Moreover, by assuming revenue maximization, the structure of the forestry firms can be modelled in line with the rejection of the profit maximization assumption. This new approach allows for more sophisticated models, and the mechanisms of the wood market can therefore be better understood. To my knowledge, such an analysis has never been performed in Switzerland.

Based on this specification, shadow prices are estimated, representing the public and non-wood services imposed (internally or externally) on forestry firms. Three non-marketable (or non-wood related) functions are available for the estimation based on data: protection, recreation and biodiversity.

The results show that protection is the most important public service in terms of implicit value for the industry. At the same time, both the biodiversity and the recreation functions do not give significant shadow prices.

Are the implicit values of the public services in line with current policy and willingness-to-pay of Swiss population?

The Forest Policy 2020, project put in place in 2011, establishes concrete objectives to be achieved by 2020, as part of a long-term program to 2030 with several goals. Whereas economic viability of the forestry industry is one of them, the others focus mainly on forest existence itself and its derived public and non-marketable functions, such as biodiversity or ecology. In summary, the policy "support[s] the consistent but sustainable utilization of wood from domestic forests and the resource efficient use of the raw material wood".⁶

With such policies in place, it could be assumed that forestry firms are more concerned with non-wood related functions than the wood production itself. Current policies encourage firms towards an increasing level of fauna and flora biodiversity, protection of soils and forestlands, and many other functions, often in direct conflict with economic efficiency (as already mentioned by Thompson et al. (1974)). Moreover, Swiss population have expressed their clear preferences (by stating their willingness-to-pay) for biodiversity and protection over the wood production and recreation functions (Borzykowski et al., 2015).

It is then interesting to confront the current policy, formulated to guarantee a sustainable forest management, with the results of this chapter and those of Borzykowski et al. (2015, 2017). Without being perfect matches or allowing irrefutable conclusions, it surely can give an interesting overview of the current situation of the Swiss forestry industry. The Swiss government strongly values the existence of forests beyond the sole wood production and, to some extent, there is evidence that the Swiss population shares this opinion. Therefore, there seems to be a consensus on the demand side. In order to assess whether or not the constraints faced by forestry firms are in line with the willingness of Swiss

⁶FOEN, 2008. The wood resource policy.

population, no formal test is performed. However, as public services are not compatible with respect to the wood harvesting function (see Thompson et al. (1974) for more detailed explanations), comparing the estimated shadow prices can give insights as which of the functions is binding and which one is therefore not influencing the forestry industry. Focusing on protection, without a doubt the most important function in terms of policy enforcement, the estimation of the related shadow price is, as expected, significant. However, it appears that it is the only significant shadow price. Turning to the biodiversity function, its implicit value is insignificant for the forestry firms, meaning that no impact of this function was found. This might be the sign of a contradiction between the demand and supply sides and definitely the starting point for further investigations. Finally, the same observation applies to the recreational activities, with the perspective that it is not considered, neither for the government nor the Swiss population, as a priority.

The dissertation is structured as follows. After a general description of the wood market in Switzerland and its forestry industry (chapter 2), the three main analyses of the dissertation are presented through three chapters. Chapters 3 and 4 present the two classical economic approaches, respectively the supply and the costs analyses. Then the analysis of revenues and behaviour (chapter 5) precedes the conclusion of the dissertation (chapter 6).

2 The Swiss Forestry Industry

2.1 Swiss wood sector

The wood market has several specific characteristics. In addition to the production of wood, their core economic activity, forestry firms have a role of providing public services from which they do not directly benefit. These services include recreational activities, but also other functions such as protection, biodiversity, and so on and so forth. A complete analysis of wood should therefore consider this multifunctionality of the forests. Switzerland is indeed active in this field by considering many functions of the forests in its policies⁷.

When looking a bit further in the wood supply chain, the wood products are very heterogeneous in their uses, competing with each other, to some extent, for the same input, i.e. raw wood. Irrespective of the wood species considered, the wood any firm can harvest falls in one of the three following product categories: log, industrial wood, and energy wood.

The first category, log, represents the largest part of the wood production. It regroups the most expensive and the highest quality of wood, which is then transformed into sawn wood for the production of many different products and uses: construction, furniture, outdoor uses, etc. All these sub-categories can then, of course, be subdivided again.

Industrial wood, on the other hand, is mainly used to produce pulp wood and cellulose, which are then transformed into paper and cardboard. However, it is also used for other completely separated productions such as clothing of some low quality furniture.

Finally, energy wood, which can sometimes be assimilated to the wastes of trees, is the least expensive but the most flexible product in terms of input re-

⁷For more information, see Federal Office for the Environment (FOEN), 2008. Wood Resource Policy Strategy, Objectives and Action Plan for the Resource Wood.

quirements. It is generally produced from the remaining wood that cannot be used elsewhere. This type of wood is finally burned for heat and energy purposes. Over the last decade, the interest for this type of energy source alternative has grown constantly. As a consequence, its utilization has significantly increased over that period. Greenhouse gas reductions policies and the nuclear power phase-out are among the main triggers.⁸

2.1.1 Swiss forests

In 2012, 30% of land in Switzerland was covered by forests. This represents around 1.25 million hectares. The regions with the highest forest density are Jura and Southern Alps with 49%. On the other side, the lowest density are found in Mittelland and Northern Alps, both with 23%.

Since the first National Forestry Inventory (NFI) in 1983-1985, forest land in Switzerland has slightly increased in total. Table 1 presents the number of hectares from the four NFIs that were conducted in Switzerland over the last 30 years. Differences between regions are however relatively important. Jura, Mittelland and Pre-alps have been rather stable over the time period, with very minor increase in forestland, if any. On the contrary, the Alps (both North and South) went through a significant increase of their forestland. One reason for this specific observation might be economic, as most unused lands are found in the Alps, where forests can expand naturally without competing with other land uses that could be more profitable economically. However, the flat part of Switzerland, with lower altitude and better accessibility of lands in general, is largely more suitable for the forestry industry, because of its higher productivity (a tree grows more rapidly in lower altitude than in mountains), and lower harvesting and management costs. This leads to a stronger exploitation of the forests in the

⁸FOEV, 2012. *Annuaire La forêt et le bois*, p. 119-121.

Jura, Mittelland and Pre-alps, and a less intensive one in the Alps.

Table 1: Evolution of forest area (thousand of ha)

Region	IFN 1	IFN 2	IFN 3	IFN 4
	1983-1985	1993-1995	2004-2006	2009-2011
Jura	195	201	202	202
Mittelland	228	227	231	233
* Prealps	217	220	228	231
Alps	382	415	435	460
Alps (South)	165	171	183	185
Switzerland	1'186	1'234	1'279	1'311

*Including bushy forests.

In terms of volume, there were approximately 422 mio m³ of "living" wood in the forest from the last inventory (2009-2011). The annual growth (before logging) is approximately of 10 million m³ per year. Compared to this annual growth, around 8.4 million m³ are either harvested by the forestry industry or die naturally. However, there are some important differences across regions: for example, in Mittelland, the net growth is actually negative, with harvesting and natural death exceeding the natural growth by 15%, whereas in the Alps both phenomena reach only 58% of the natural growth. It is even more extreme when we know that the natural growth in the former regions are slightly higher than 12 m³/ha and less than 6 m³/ha in the Alps. Assuming that the death rate is fairly similar, this means that logging is a lot more intense in Mittelland than in the Alps, which seems to reflect the harvesting conditions, as already mentioned above: it is more difficult and costly to harvest the same volume in the Alps than in any other region in Switzerland.

Table 2 shows the distribution of stock of wood in the different regions of

Table 2: Evolution of wood stock (m³/ha)

Region	IFN 1	IFN 2	IFN 3	IFN 4*
	1983-1985	1993-1995	2004-2006	2009-2011
Jura	328	365	377	392
Mittelland	409	440	410	398
Prealps	417	469	464	489
Alps	292	318	321	335
Alps (South)	176	219	241	259
Switzerland	333	366**	364	376**

* These figures come from: <http://www.lfi.ch>.

** FOEV "Annuaire" (2012, p. 25) gives 360 and 369.

Switzerland and for different periods of time. With the exception of Mittelland, all regions have increased their stocks during the last 30 years. This observation suggests a certain level of under-exploitation of the resources. We will come back to this point by bringing some possible explanations in the following sections. The figures are derived directly from the respective National Forestry Inventories. Note that several sources might give slightly different numbers. Figures included in tables 1 and 2 are based on estimations of the inventories and are therefore subject to confidence intervals.

These two tables bring some interesting facts about the heterogeneity of the regions in terms of harvesting and management conditions. This implicitly results from the distribution of the wood production in the different regions.

As mentioned before, natural growth differs dramatically between Mittelland and the Alps. Similarly, wood production is significantly skewed towards the plain regions, and mainly Mittelland. Indeed, whereas it accounts for less than 20% of forestlands in Switzerland, the production in this region exceeds 35% of Swiss production. On the contrary, the Alps (both North and South) account

for around 45% of the overall forest area, but produce less than 20% of the Swiss wood.⁹

As a matter of fact, the four main regions dividing Switzerland are very heterogeneous in terms of forest environments and structures, as well as from the point of view of the forestry industry. These differences will appear more clearly in the following pages.

Consumption

In 2009, the Federal Office for the Environment published a report on the final consumption of wood products in Switzerland. Here is a short summary of the main figures and conclusions.

The final consumption is divided into the following 8 subcategories: construction, outdoor use, furniture and indoor use, packaging, finite-products, do-it-yourself, paper/cardboard and wood energy. The last two categories have not been considered in the report although some data are available from the Federal Office for the Environment (FOEN).

However, it is important to keep in mind that these two categories actually represent a major part of total consumption of wood products in Switzerland. Total consumption of the first six categories considered in the report amounts to 2.903 million m³ in 2009, whereas for the same period, consumption of wood energy and paper/cardboard products was 4.348 million m³ and 2.613 million m³ (for 2010), respectively. Information about paper and cardboard consumption in 2009 is not available, possibly due to recent changes in the collection of data and the introduction of a new flow model of the wood market in 2010. It is important here to note that these figures come from different sources, and are therefore not perfectly comparable. They are only presented for the general magnitudes of the

⁹FOEV, 2012. *Annuaire La forêt et le bois*, p. 31.

sectors in the market, which is still significant.

Moreover, the paper and cardboard sector, even though not the biggest category in terms of consumption, is by far the most important one when imports and exports are considered: in 2009, imports and exports, including recycled paper, represented 43.6% and 52.8% of total wood and wood products imports and exports in m³. In terms of value, the proportions are even larger, to 55.3% and 71.8%, respectively. This is obvious as paper and cardboard are among the most expensive finished products per unit of volume. More figures are available in section 2.1.2.

2.1.2 Supply chain

For a couple of years now, the Federal Office for the Environment presents a chart of the wood supply chain in Switzerland in its annual report on the forest and wood¹⁰.

The wood production chain can be subdivided into three main and schematic "levels", which are shown in the figure 1. Round (or more generally raw) wood, directly coming from the forestry firms, semi-finished or intermediary products after being processed by sawmills, and finished products which are finally consumed.

At each of these stages, several markets exist, partly independent and partly interconnected and dependent on international environments.

Figure 1 shows a simplified version of the chart appearing in the 2012 report (FOEV, 2012), representing the wood market and the relations between its different industries.

Despite its simplicity, it shows some important characteristics of the different markets through the wood production chain. The percentages shown in the

¹⁰Most recently: FOEV, 2012. *Annuaire La forêt et le bois*. Also available in German.

figure represent rough proportions (in terms of volume) of wood injected into each "output" arrow. The situation might be constantly changing but orders of magnitude are here more important than precise figures.

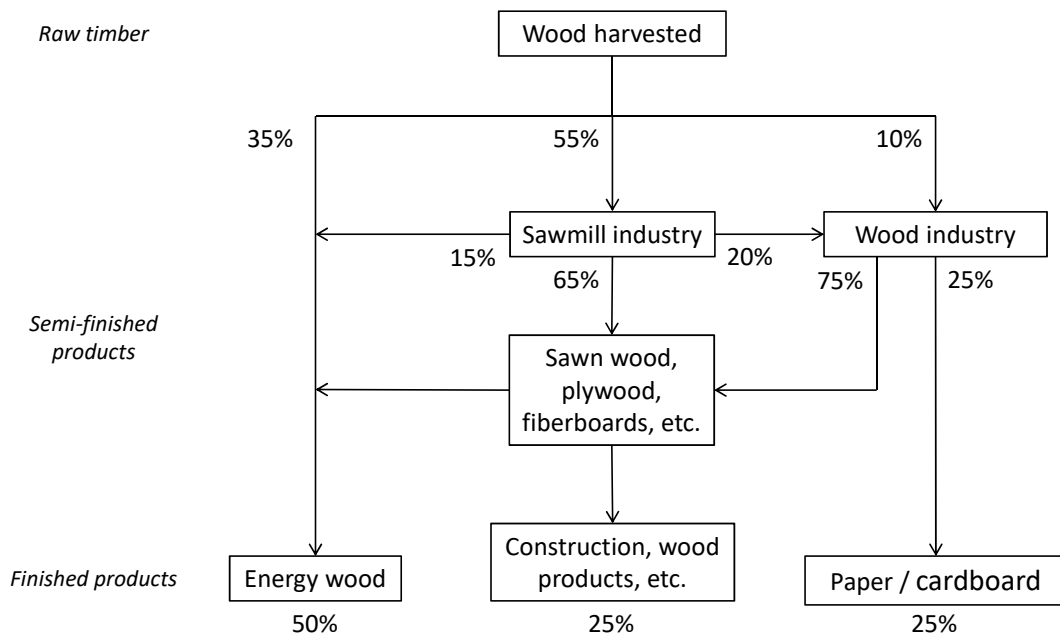


Figure 1: Wood Supply Chain. All figures in % are based on compact m^3 .

When referring to the first level of production (and basically to any other level as well), raw wood can be divided, horizontally, into three categories: energy wood, sawn wood (and related) and industrial wood. These categories are clearly separated in figure 1 by the three vertical production chains.

The first category, energy wood, is the least valuable as wastes of both other products transformation is mostly redirected into this category. In the general context of increased interest for the environment and the consequent increase in the use of greenhouse gas and especially CO₂ neutral energy sources, the wood, most often considered as carbon-neutral¹¹ is increasingly more valued as a means

¹¹The fact that it is considered carbon-neutral can be questionable, though it is undeniably cleaner than many other energy sources (in other words, wood as a energy source could be viewed to be carbon-neutral relative to other sources). By growing, the wood captures CO₂ that is then

of reducing greenhouse gas emissions. A direct consequence is a higher price that creates incentives to produce more energy wood (as a matter of fact any type of wood can basically be transformed into energy wood).

An underlying concern to this recent change in the interest for energy wood is its consequences on the other markets, and the frictions that could be created. However, some studies have shown that competition intensity is still relatively low. See for example Nagubadi and Zhang (2006), Olsson (2011) and Olsson and Lundmark (2011).

For more information on relations between wood markets and figures on the different industries, the interested reader can refer directly to the chart from the annual report on Swiss wood and forest (FOEV, 2012). It gives important insights on the magnitude of each market, and also, among others, on how dependent those markets are on international environments through imports and exports. Additional remarks and observations on specific industries will be made below under the respective markets considered.

released when burned for heat, making it neutral from that point of view. But this ignores transportation and manufacturing of wood, which can be costly from an environmental point of view. See Johnson (2009) for more information.

2.2 The forestry industry

The Swiss forestry industry is owned mainly by the public sector, with 894,000 ha representing 71% of overall forest areas in Switzerland, while the private sector owns the remaining 29% (363,000 ha)¹². Along with many other characteristics that we have considered above and will consider below, the distribution of ownership over the main Swiss regions is very heterogeneous. Generally speaking, presumably less productive regions such as Prealps and Alps (due to harder environmental conditions) present a higher proportion of public firms, whereas presumably more productive (and more profitable) regions contain more private firms. Among the most important cantons in terms of forest hectares, forests in Bern (Mitelland) are managed almost equally between public and private forestry firms, whereas in Graubünden or Valais (Alps), it is extreme with around 90% of forests managed by public firms. It can then be logically asked whether those differences are related to the significantly non-uniform productivity and efficiency of the different forestlands, and related costs of management and harvesting¹³.

Knowing this, it is then easier to put into perspective some other statistics that could be otherwise misleading. For example, the fact that, although private firms account for 29% of forestlands in Switzerland, they produced 35% of overall wood production in Switzerland.¹⁴ A somewhat simplistic conclusion would be that private firms are indeed more efficient and productive than public ones, all other things being equal. But precisely, all other things are not equal, as private ownership is more highly represented in more productive regions, implying that if we assume equal efficiency between private and public firms, the latter should anyway produce a higher proportion of total wood production, given their relatively better environments and conditions. A more extended and thorough

¹²FOEV, 2012. *Annuaire La forêt et le bois*, p. 9.

¹³Idem, p. 11.

¹⁴Idem, p. 30.

analysis is therefore needed to clarify this point.

Structure

The forestry industry is composed of more than two thousand forestry firms, which corresponds to a small average size. Indeed, the multitude of small and very small firms is an important point; an efficient management is far less financially attractive to very small forest managers whose earnings from harvesting are almost negligible (problem of "marginality"). Therefore, economically efficient behaviour (i.e. profit maximizing firm) is consequently not the rule for these firms, with financial considerations being too small to be a sufficient incentive. Whereas this issue is more important for private owners who are largely more fragmented, small public forestlands owners still have the problem that efficient management might require knowledge that is too costly (in terms of opportunity) to be accessible. At first sight, these issues might be part of the mechanism leading to the inefficiency of wood supply in Switzerland.

Figure 2 shows the distribution of forestry firms in Switzerland¹⁵. Even though the large majority of firms are very small (in terms of forestlands under management), one can see that it does not represent much of the total Swiss forests, which puts the above discussion into perspective. The optimal size might depend on the environment and characteristics of the forests under management, Farsi (2013) and Mack (2013) both found empirically optimal size that are well above 500 ha, and even possibly above 2000 ha. Considering these figures, we can still conclude that firm size is indeed an issue and potential improvements are considerable.

Profitability

Since the beginning of the 1990s, the industry has suffered from recurrent

¹⁵Source: Swiss Forestry Statistics

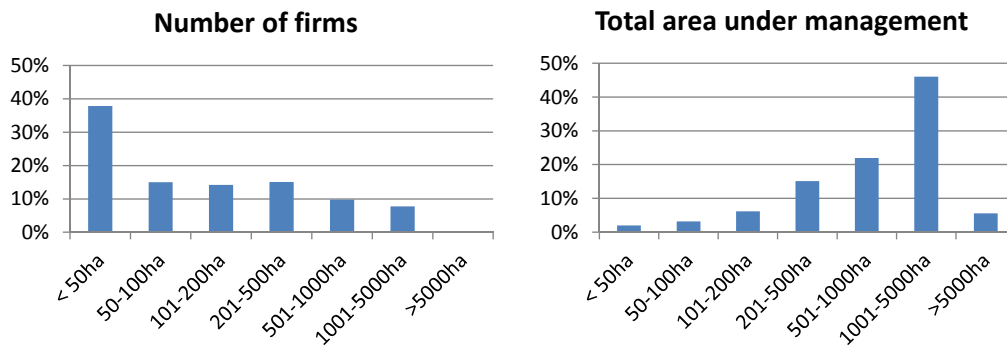


Figure 2: Distribution of firm size in Switzerland

deficits that have been generalized to the large majority of firms. They are therefore heavily subsidised by governments, at different levels. This failure to keep a prosperous and profitable industry raises many questions and credible solutions should be brought to the table.

This observation is even more disturbing when we know that some of the neighbouring countries of Switzerland, that are to some extent comparable ones, hold very efficient forestry industries, whereas the Swiss firms persistently fail to earn profits in general, and with an even worse situation when considering their core activities only.

Natterer et al. (2004) pointed out the fact that the forest structure in Switzerland is far from optimal and largely skewed towards old forests, creating an excess stock of old trees (ranging from 60 to 150 years, and beyond). The authors present the opposite example of Scandinavian countries where "revolution" never exceeds 50 to 60 years. Even though the conditions are different and a direct comparison would not make much sense, it is clear that the structure of the forestry industry in Switzerland is largely different from other countries, and might already be part of the explanation for the deficit problem. This observation also explains the increase of living stocks in almost all regions in Switzerland, as seen in section 2.1.1.

As mentioned before, the industry has for now almost three decades incurred repeated losses, highlighting some important structural problems. When considering overall activities, the situation has slightly improved since 2000. This is shown in figure 3, which summarizes the last 40 years of financial performance of the Swiss forestry industry. The first (main) graph shows the revenues and expenses of the whole industry, whereas core and non-core activities are shown separately below¹⁶. The non-core activities includes all goods and services provided by forestry firms that are not directly related to the harvesting activities or forest management. They include Christmas trees sales, manufacture and sale of wood-products such as tables or benches as well as services for other forest owners or the community, such as woodworking for public or private gardens. On the other hand, it seems the core activity of harvesting, though somewhat erratic recently, seems not to follow the same positive trend and even seems to have worsened over the last couple of years. Room for improvement is indeed considerable, as only between 60% and 70% of costs generated by the core activity are covered by direct related earnings¹⁷.

As one can easily see on this figure, recurrent losses have occurred since the beginning of the 1990s, coming entirely from losses on their core activities. At the same time, it appears that forestry firms have tried to circumvent these losses by expanding their non-core activities, by offering a wider variety of services and diversifying their businesses, which is reflected by the increasing revenues and costs of non-core activities. However, this attempt has not been as successful as it should have been to have a significant impact on the industry, the net profit from non-core activities having not increased along its related turnover, and having even shrunk recently.

¹⁶These figures come from the Swiss Forestry Statistics, and regroup only forestry firms managing at least 50 hectares of forest.

¹⁷FOEV, 2012. *Annuaire La forêt et le bois*, p. 73

Compared to the increasing losses on core activity, that have reached almost 200 mio CHF in some years, the small (and decreasing) profits from non-core activities were almost negligible, barely able to compensate a few percentages of the core losses. The profits of the forestry industry, on their side, have never exceeded losses of 100 mio CHF, and have even improved recently, to losses of a couple of tens of mio CHF (which is by far the best results since the beginning of the 1990s). This difference is solely due to the contributions from the government that have strongly increased, multiplied by a factor of 20 over the last 35 years. These contributions are included in revenues depicted in figure 3.

As we can also clearly see in figure 3, two short periods of time differ significantly from the rest of the series. The first relates to the Vivian hurricane, that occurred in the beginning of 1990, and the second corresponds to the Lothar hurricane, at the end of 1999. In both cases, it is interesting to see that the two years following each of these natural events have been the least profitable from the core activities point of view. Hurricanes have forced the forestry firms to pick up and harvest all the fallen woods, flooding the wood market with abnormal quantities. The direct consequence has been a relative decrease of wood prices. At the same time, harvesting costs went up, despite an almost certain increase in efficiency¹⁸. For the case of Lothar, this situation of strong deficits (whether or not as a consequence of the hurricane is an open question) even lasted for four years, before improving slightly. In terms of species, whereas hardwood harvesting has increased by 10-30% after both hurricanes, it seems the latter have hit most hardly the softwood, where the increase in terms of harvesting the year following the hurricane was around 65% for Vivian and more than 100% for Lothar. As softwood accounts for between 60% to 75% of total wood production in Switzerland, this has created a large impact at the country level.

¹⁸See Mack (2009) for more information.

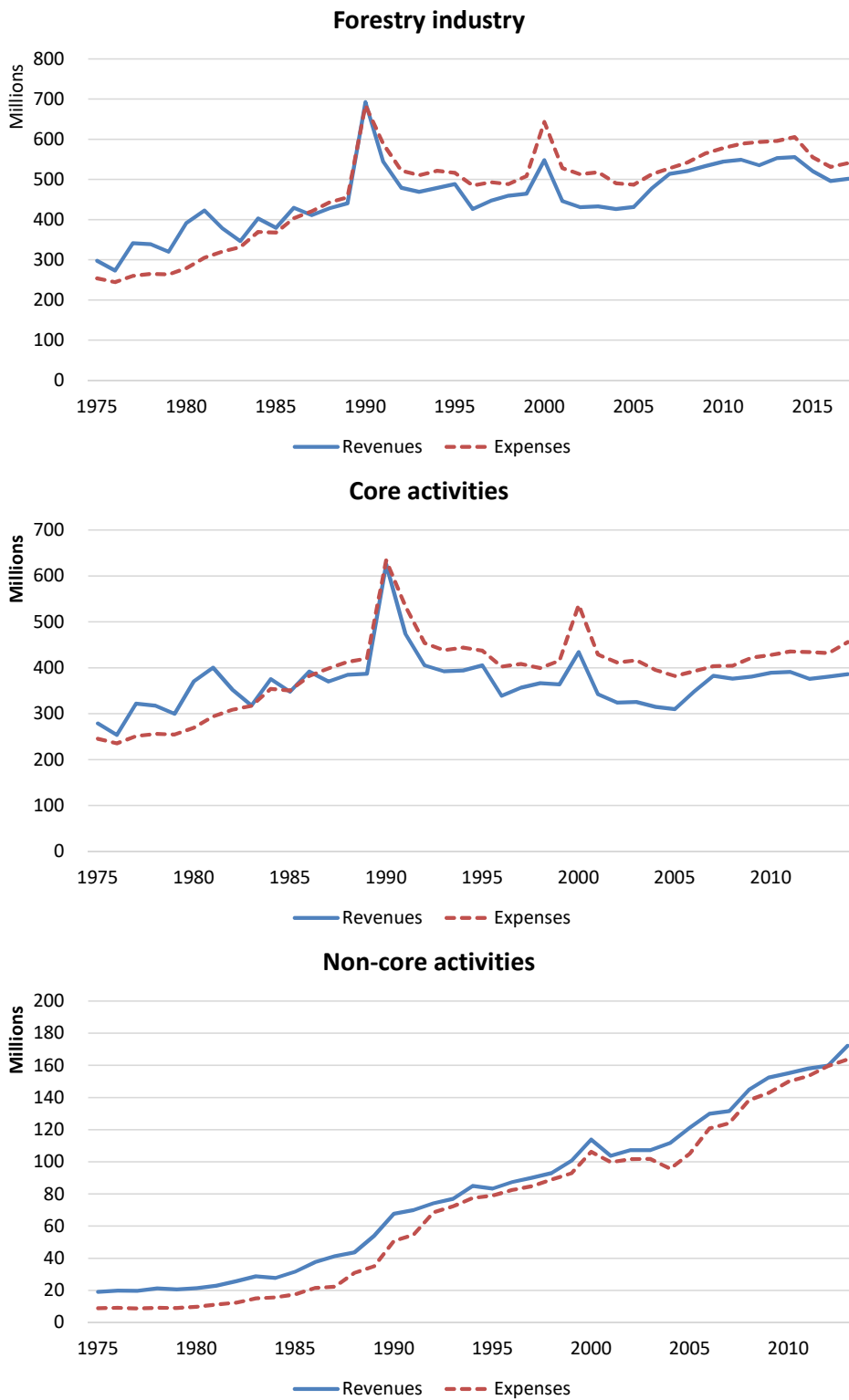


Figure 3: Profit and loss of the Swiss Forestry Industry

Deeper investigation is required for more concrete conclusions, but these figures suggest that species respond and resist very differently to natural events, which might be used as a mean of diversification to mitigate such calamities.

In addition to figure 3, table 3 shows the evolution of losses since 1990 in absolute values and in terms of percentages using two indicators : the percentage of loss over total revenue and the coverage of total losses by the non-core activities. Aside from 2002 which was an exceptional period in terms of external events (hurricanes), one can see that . Years after 2014 are not shown as core and non-core activities are hardly comparable due to changes in definition. The general level of losses has been rather stable since then. Two interesting recent trends should be mentioned. First, after a peak in 2003, the losses in both absolute and relative terms have been steadily decreasing until 2007, reaching almost the equilibrium. The last decade, though, was a difficult time for the forestry sector in financial terms and after a 2.6% loss in 2007, the situation worsened to reach 10.9% in 2012. Since then, the loss settled around 7%. Second, in the early 2000s, the coverage of losses with non-core activities increased tremendously and reached a peak at 35.7% in 2007 (explaining the best financial result over almost three decades). Since then, however, the coverage has been very erratic, from 0.5% in 2012 to 28.8% in 2014.

Table 3: Evolution of losses and non-core activities

	1990	1994	1998	2002	2006	2010	2014
Total profit/loss (mCHF)	-44.3	-42.5	-28.8	-81.9	-34.8	-33.4	-49.9
% Total profit/loss	-8.1%	-8.9%	-6.3%	-19.0%	-7.3%	-6.3%	-9.0%
% Non-core loss coverage	25.8%	15.0%	12.3%	6.3%	20.9%	13.5%	28.8%

Covering losses from core activities using non-core activities certainly has its limitations. Without any further in-depth analyses of these non-core activities or potential vertical integration to reach financial equilibrium, this thesis, and especially the next chapter, aims at understanding the reasons these core losses occur and find financial solutions.

In a further attempt to explain the profitability (and efficiency) problem faced by the Swiss forestry industry, recent international pressures have played a role and increased the difficulties of the sector, among other reasons. This will therefore be the subject of the next section.

International trade

The Swiss forestry industry is considerably linked internationally, mainly to a few European economic partners. Figure 4 shows the evolution through time of imports and exports of raw wood from 1988 to 2017¹⁹. It appears that exports are larger than imports, even if the gap has tightened during the last couple of years. Wood is primarily exported to France, Italy and Austria, and three quarters of the imported wood come from Germany (on the contrary, exports to Germany represents a very small amount compared to the three other countries).

In this graph, we can again see the strong impact of the hurricane Lothar that passed over Europe and especially over Switzerland at the end of 1999. Several thousands tons of wood were uprooted, which flooded the Swiss market by a high excess supply and therefore exports went up by a huge amount as well, being multiplied by almost a factor of 4 in 2000, with impacts over several years.

The forestry firms rely on international demand for raw wood and are therefore exposed to international risks. They suffered from the recent economic crisis, which might explain part of the recent decline of exports. The recent strong

¹⁹Sources : Swiss Customs Administration and FOEV

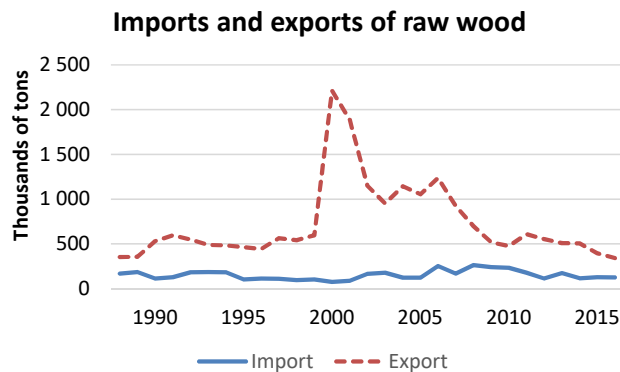


Figure 4: Evolution of imports and exports of raw wood through time.

Swiss franc has even worsened the situation as international prices are applied for the exports, making them less profitable for Swiss firms. Nonetheless, exports of raw wood represents only a small part of total revenues from wood of forestry firms (excluding subsidies). In 2015, they accounted for approximately 3.5%, figure that has been stable over the last few years.

Exports of raw wood (in m³) represented in 2011 around 12% of total exports of wood products, whereas its imports represented only a couple of percentages of the total. In monetary terms however, raw wood, both exports and imports, account for a very small amount, less than 0.1%. This is of course expected as this is the product with the lower value-added per volume (or ton).

Switzerland is therefore a net exporter of raw wood and has been so for many years now, even though the international environment of the recent years led to a less striking situation. As we are going to see in the next sections, the trend is reversed in terms of manufactured and more valuable wood products, for which the country is a net importer.

The international flows of wood at the different production stages (as shown in figure 1) presumably show some cost efficiency problems in the transformation of raw materials into semi-finished and finished products in Switzerland. Indeed, a significant amount of raw wood is exported, making Switzerland a net exporter

of raw wood, before importing the finished goods which are then consumed in the country. It seems therefore more efficient to transport and manufacture abroad than to directly manufacture within the country. A potential explanation for this observation is, among others, the relative high price of labour in Switzerland.

Institutional environment

Legal environment

Figure 5 shows the timeline of the forest policies from the Federal Act on Forests (1991) until 2030 horizon. At the same time, article 77 of the Swiss Constitution is applicable and treats explicitly forests. It forces the government to act so that forests can fulfil their protective and wood-related (production) functions, among others.

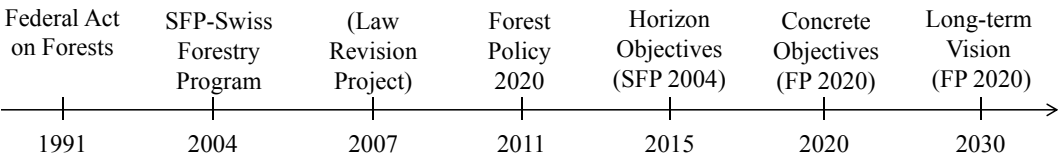


Figure 5: Forest Policies in Switzerland

The Federal Act on Forests is the legal basis of all policies adopted since 1991 (including of course the very general article in the Swiss Constitution). In 2007, A revision project was proposed but was refused one year later (in parentheses in figure 5).

The Swiss (National) Forestry Program started in 2004 constitutes the basic framework under which the Forest Policy 2020 was established. Its main goal was to increase demand for wood and wood products in a sustainable and economically sound way. It describes the required actions to undertake until 2015, with 12 specific objectives at that time, including 5 stronger priorities, that include guarantee of the protection function, preservation of the biodiversity and

of the forest "health" (soils, trees, water), high value-added wood chain and a viable economic sector.

The wood resource policy (FOEN, 2008) was mainly put in place to address the issues faced after the introduction of Swiss National Forestry Program, resulting as expected in a large increase of the wood and wood product demand. Generally speaking, it "support[s] the consistent but sustainable utilization of wood from domestic forests and the resource efficient use of the raw material wood". Its 6 objectives to be achieved until 2020 fall in two categories: sustainability of the wood supply (also part of the Federal Act on Forests), and the resource-efficiency of the supply allocation in terms of maximum value and minimum (negative) environmental impacts. In this context, the wood resource policy also has to take into account other policies, such as climate and energy ones. Of course, international environment plays here an important role as well.

In the continuity of the Swiss National Forestry Program, the Forest Policy 2020 was introduced in 2011, with 11 objectives to be fulfilled, also, until 2020 but within a more general and long-term vision (2030). This vision focuses on the durability of the forests' existence, their functions (protective, wood production and ecological preservation) as well as on the value-added chain of the whole wood market (from the tree to the final products). Finally, collaboration between government, firms and financing institutions is also important.

The objectives of the Forest Policy 2020 are, on the other hand, much more concrete and quantifiable. For the most part, they consider similar objectives than the Swiss National Forestry Program and help establish the foundations for the long-term vision discussed above.

A final important remark concerns a particular point of the legal framework: forest clearance. Indeed, forest clearance is allowed if certain conditions are satisfied, which are mainly for public facilities. However, cleared forest has usually

to be compensated. In practice, very few forestlands fall into the context and are being cleared yearly. This could mean that a forest area does not have to be economically profitable to stay as such, which is however often assumed when modelling forest management. In other words, forestland does not fully compete with other land utilization.

Subsidies

From the perspective of the Swiss Confederation and the cantons, the contributions to the forestry industry represented in 2010 just over 250 million CHF, from which 129.6 are supported by the Confederation and 120.8 by cantons. These contributions are made in four primary domains: protective forest, protection works, biodiversity and forest economy. They represent respectively 51%, 21.4%, 10.4% and 12%. The remaining contributions are other contributions of the Confederation and represents 5.2%.

It is important to note that the federal subsidies have been significantly modified in the beginning of 2008. After this period, direct federal subsidies have been largely reduced but were replaced by an increase of subsidies at the cantonal level. A direct consequence of this modification is that cantons are more flexible in their respective financing policy and the related choices. For more information, see FOEV (2008)²⁰.

From the Swiss Forestry Statistics, identifying all forestry firms exploiting more than 50 hectares, the contributions are very different across regions and cantons. Per hectare, they vary on average from 34 CHF for the Jura, or 50 CHF for Ticino and Schaffhausen, to 240 CHF for Valais, 245 CHF for Fribourg and up to 305 and 340 CHF for Nidwalden and Obwalden. The plausible main reasons for such considerable differences stem from the various and dissimilar

²⁰FOEV, 2008. Manuel RPT dans le domaine de l'environnement.

environments faced by firms in each canton. Also, forests are not managed in the same manner, and do not require the same amount of work.

The activities receiving the most part of those contributions are the first and second level of production, which represent maintenance of the forest and logging (first level) and mainly transport and storage (second level).

From a cost perspective, it is important to differentiate between costs per area or volume. Indeed, the TBN data show that when considering the costs per hectare of the first two levels of production, the firms in the Alps are the ones incurring the smallest costs of around 231 CHF/ha in 2010, whereas in the Mittelland it goes up to 716 CHF/ha. However, in terms of CHF/m³ of wood, the results are, as expected, totally reversed: 127 CHF/m³ for the Alps and 83 CHF/m³ for the Mittelland region (and down to 78 CHF/m³ for the Jura). Even though the aggregation of wood production can be somewhat questionable, the magnitudes of the numbers are most likely not.

Likewise, the total revenues per hectare dramatically vary across cantons, from an extreme minimum of 94 CHF per hectare for Ticino, to an extreme maximum of 3'595 CHF per hectare for Appenzell A.-Rh. These figures highlight, once again, the very large heterogeneity of the situations and contexts from one canton to the other, and of course more generally across regions as well. From these observations, it is very clear that firms face dramatically different environments.

3 Costs Analysis and Economies of Scale

Abstract

This chapter attempts to bring some understandings of the cost structure of the forest industry in Switzerland and potentially give insights to increase the cost efficiency and put an end to almost three decades of recurring deficits. A multi-output cost function is estimated based on data collected by the Swiss Forestry Pilot Network (TBN). Marginal costs and economies of scale are also computed and analysed. The results show a strong heterogeneity across the four regions in Switzerland. They also reveal great potential of cost reductions through economies of scale in the Swiss forestry industry. Outsourcing is also an important determinant and a possible alternative in order to reduce costs. Policy implications for cost efficiency improvement and regulation are finally discussed.

3.1 Introduction

Since the beginning of the 90s, the Swiss forestry industry has suffered recurrent deficits that have spread to the large majority of forestry firms²¹. Whereas the revenues have substantially decreased over that period, the firms have been unable to proportionally reduce costs. Nowadays, the direct productions costs are up to twice the costs of some neighbouring countries (Bürigi and Pauli (2013)). This failure to keep a prosperous and profitable industry raises many questions, and concrete answers are pending.

The context of regulations and multifunctionality of the forests is extremely important. For now more than a century Swiss forests have not been solely considered for their wood production any more, but as a complex system fulfilling many services for our society, in terms of protection, biodiversity, recreations, etc.²². This vision has a significant impact in terms of costs and management, as harvesting methods had to be adapted accordingly.

In this context, firms are heavily subsidised by governments, at different levels. For some reasons, related or not to this current situation, the Swiss firms persistently fail to earn profits from their core activities. This chapter attempts to understand the problems and hopefully bring some insightful solutions. The main objective is to create a cost model taking into account the many specificities of the Swiss forestry industry using available data at the firm level.

The focus of this chapter is put on the structure of the cost function in the forestry industry in Switzerland, on their marginal costs and the economies of scale, as one potential mean to reduce costs and therefore deficits. This chapter attempts to consider not only the wood production, which is tangible, but also all other functions of the forestry industry that are non-wood related (but not

²¹ Annuaire La forêt et le bois, 2013. OFEV.

²² The prohibition of clear-cutting in Switzerland goes back to 1876, with the recognition of the protective function of forests.

necessarily less costly or important)²³. In this multi-output framework, Box-Cox transformations with random-effects are used as the model specification.

Economies of scope are also an important aspect of multi-output sectors but are left for further researches. In the case of the forestry sector, the aspect of economies of scope, although of clear and significant interest, is thought to be of slightly less importance compared to the economies of scale, considered paramount to this sector. Recent studies, such as Mack (2009) already showed evidence of their existence from a technical point of view and this analysis is meant to give further evidence in terms of costs. Also, results regarding economies of scope, compared to economies of scale, could need some substantial modifications of the current organisation of the forestry structure (potentially such as specialisation), very hard to implement in practice. Economies of scale, on the contrary, can be more easily understood and applied with more flexibility.

The forestry industry is fragmented into many small firms, and is mostly owned by the public sector (71%)²⁴, as shown in chapter 2. Based on this observation, it appears to be an appropriate hypothesis that the financial health might not be the first priority of most forestry firms²⁵. Incentives for an efficient management are rather low due to large financial support from authorities. Also, it is legitimate to assume that forest harvesting requires substantial infrastructure and therefore large investment in capital. This seems to gather some predispositions for substantial economies of scale, which is therefore the first hypothesis of the chapter: it is expected that strong cost reductions can be achieved through mergers of forestry firms, benefiting from economies of scale. Farsi (2013) and Krähenbühl (2013) have already brought evidence of such phenomenon.

²³Throughout the chapter, non-wood related functions refer to the services delivered by forests that are not related to the direct sale of wood, such as protection, water purification, recreation, landscape, biodiversity, etc.

²⁴Annuaire La forêt et le bois, 2013. OFEV, p. 11.

²⁵Indeed, it is shown in chapter 4 that forestry firms in Switzerland are not profit maximizers.

Finally, an important factor that should not be forgotten is outsourcing, consisting of mandating a specialized firm to manage fully or partly its forests. Whereas economies of scale can contain a great potential for cost reductions, so does the outsourcing strategy. Many (exploiting) forestry firms already use it, and this also means that the analysis of economies of scale should take this into account.

To our knowledge, this chapter is the first to explicitly consider the outsourcing strategy in this manner. Moreover, it empirically analyses costs in the Swiss forestry industry and brings additional evidence about the role of multifunctionality in the forests.

3.2 Theoretical framework and background

Forestry economics is complex and involves extended multi-product theory, as most of non-timber goods and services are not marketable and therefore difficult to value and quantify.

3.2.1 Theory and properties of the cost function

First, let us start by defining the cost function $C(y, w, z)$ as:

$$C(y, w, z) = \min\{x \cdot w; x \in V(y)\} \quad (1)$$

where x is the vector of variable inputs, y the vector of outputs and z the vector of fixed inputs (if any). $V(y)$ is the input requirement set or, in other words, the set of inputs x which makes y feasible. Equation 1 states that the cost function is the minimum cost of variable inputs x for which y is feasible, or simply the minimum cost required to produce y .

This cost function has a set of important properties (Chambers, 1988):

- (a) Nonnegativity : $C(y, w, z) > 0$ for $w, y > 0$,
- (b) Nondecreasing in w : $w' > w$, then $C(y, w', z) > C(y, w, z)$,
- (c) Linearly homogeneous in w : $t > 0$, then $C(y, tw, z) = tC(y, w, z)$,
- (d) Concave and continuous in w ,
- (e) Nondecreasing in y : $y' > y$, then $C(y', w, z) > C(y, w, z)$,
- (f) No fixed costs : $C(0, w, z) = 0$.

Except for (c), the other properties are not explicitly taken into account in the regression model described in section 3.3. Nonetheless, we can easily check for any of them using the result of the estimations. It turns out they are all satisfied with the exception of (f). This last property requires no fixed costs. But it is however logical when looking at equation 1. Indeed, the definition of the

cost function only takes into account the variable part of the costs, $w \cdot x$ and not the fixed part related to z . Taking the latter into account, the cost function would only shift upwards without losing any property. Therefore, the regression model explicitly takes the fixed and variable costs into account without impairing the results.

As for (c), the linear homogeneity is forced using the prices of inputs. As the logarithm is used to transform the cost and price of inputs variables, the sum of the regression estimates for price of inputs have to be equal to 1 to satisfy the linear homogeneity property. Therefore, the price of capital is subtracted to both the cost and price of labour variables, which technically forces property (c) to hold. The regression estimate for the "adjusted" price of labour is equivalent to the regression estimate for the price of labour, and the estimate for the price of capital can be estimated so that both estimates equal 1.

3.2.2 Literature review

Costs analysis, and by extension economies of scale, is no exception in the forestry economics. This field is one among many other economic fields based on multi-product theory. Multi-output cost functions, in one form or another, are used in many different research topics as well as many public services theories. Whereas forest management analysis might have particularities, costs analysis of the forestry industries is largely comparable to other industries. See for example Bailey and Friedlaender (1982) for a review on multi-output theory.

Many of the papers mentioned below consider economies of scale. Most of them use the definition of Panzar and Willig (1977) as the "standard" economies of scale. In this paper, they present the basic theory of economies of scale in a multiple-product setting. Following closely, Panzar and Willig (1981) present the theory and definition of the economies of scope. For more information on the

subject, see also Baumol, Panzar and Willig (1982). An empirical application of all these theories is to be found in Kim (1987), in the case of water utility distribution.

A very large number of papers analysing costs and efficiency in the case of multi-product use a very common flexible form, that is the standard translog cost function, mostly used since it is one of the simplest flexible functional form available for empirical analysis while being theoretically sound. Nevertheless other forms are available, with different levels of complexity. The most well-known flexible forms are presented in Caves et al. (1980). The estimation techniques have largely improved over the last few decades, giving researchers access to new specifications that were hardly applicable in the 1980s. Non-linear models such as Box-Cox transformations or generalized translog are examples of such specifications.

Here is a small outlook on other economic fields and papers that cover costs analysis based on economies of scale and scope discussed above.

Transportation and public transportation is an important topic of the multi-output theory. Jara-Diaz (1982) offers a comprehensive review, even though not recent, of the literature and presents the related theoretical foundation. Farsi et al. (2006, 2007) are examples of public transportation analysis where multi-output cost functions are estimated using a translog specification. Similar methods are also applied to the railroads industry (Caves et al. 1981, Coelli and Perelman 1996).

The health care sector in general and more specifically hospitals or nursing homes are also considered in many translog cost analysis. Farsi et al. (2008), Filippini (2001) or McKay (1988) analyse the nursing home industry. Breyer (1987) used slightly different specification than translog for his hospital cost function, with a quadratic form. While as simple as translog, it has the disadvantage of

violating important theoretical assumptions.

In the utilities sector, one can easily find many more examples of translog cost function in costs and economies of scale analysis, such as Christensen and Greene (1976) or Kim (1985). However, some authors have tried different specifications. Farsi and Filippini (2009) consider translog but also quadratic and Cobb-Douglas forms. They estimate economies of scale for one or several outputs at a time, as well as economies of scope. More generally, Fraquelli et al. (2002) assess the differences between four specifications in the context of economies of scale and scope: standard translog, generalized translog (with Box-Cox transformations replacing the logarithm of the standard form), the log-transformed PB (Pulley and Braunstein 1992, cited in Fraquelli et al. (2002)) and separable quadratic (special case of the quadratic form).

Cost and efficiency analysis has also been studied for a long time and fairly extensively in the case of the forestry industry. Interestingly, crisis such as the one affecting currently the Swiss sector with recurrent deficits is no exception in this industry. In his supply analysis in the middle of 1970s, Hyde (1980, p. 181) discusses an issue in the U.S. industry:

”This problem is economically efficient management of public forestland - and it ought to be a priority public policy issue. The land management inefficiencies of public agencies, in particular the U.S. Forest Service, are such that in the Douglas-fir region larger annual harvests can be had from a smaller timberland base - and probably with a smaller agency timber production budget.”

This is one of the reasons that have brought many authors to analyse costs in the harvesting and wood production sector. Consequently, one primary question often asked considering costs and marginal costs is related to economies of scale: do economies of scale exist in the industry? As a direct consequence, it can be a

clear and fairly simple (at least on paper) solution to decrease costs and increase efficiency.

Authors share the same answer irrespective of region and period considered: economies of scale most often exist and should be exploited. Granskog (1978) describes the tendency of the U.S. forestry industry at the end of the 1960s and beginning of the 1970s to increase average size of firms and earn from the re-organization. His conclusion is that, assuming "sufficient market demand", economies of scale can be exploited as large capital investments are needed and can be more fully utilized in larger firms. More recently, Kant and Nautiyal (1997) used restricted and unrestricted cost functions to show that, in the Canadian logging industry, economies of scale exist and could be exploited.

Sutton (1973) analyses the forestry industry in New-Zealand and concludes that economies of scale exist. The author however points out some possible "social problems", mainly on labour issues such as lack of contract work or risk of job losses.

Grebner and Amacher (2000) offer an interesting case study of the forestry industry after large modifications of the policies in the 1980s in New-Zealand. Privatization and deregulation (such as price controls removals) are analysed. Even though this is a very specific case, some insights can still be drawn. Indeed, results suggest that during a short period following the policy changes, efficiency has seemingly lowered until the industry has been able to fully incorporate them and recover (or even exceed) its past efficiency level. The measures were therefore positive in that regard.

Whereas economies of scale are considerably studied, some papers took a slightly different approach. Stuart et al. (2010) considered the returns to scale of the logging industry in the United States using a Cobb-Douglas production

function²⁶. Unlike the seemingly consensual existence of economies of scale, the authors here found that decreasing returns to scale were more likely to occur at current firm levels. Note that the time period considered is 1988-2007 and therefore is hardly comparable to, for example, Granskog (1978) which describes the transformation of the forestry sector long before, with strong economies of scale. Indeed this could mean that all possible cost reductions through size increase have actually been used. Turning to productivity and technical efficiency, Bonds and Hughes (2007) studied data from the state of Mississippi from 1997 to 2001 using a stochastic frontier analysis. In this region, most of forestry firms are public, and results show fairly low technical efficiency but a significant relation between private outsourcing and forestry earnings. This could therefore be a way of controlling costs and increasing the forestry industry efficiency. The case of productivity in Canada has been studied in CSLS (2003).

Even though costs are the center of interest in this section, the analyses focusing on value-added are largely comparable and deserve a few words. Analysis of technical change is a field in which it is largely used. For a thorough review on the subject, see Stier and Bengston (1992). An example of such analysis is Lantz (2003), studying the value-added of the forestry industry in Canada. Using fixed effects model, he shows that scale increase has a positive impact via "cost savings" whereas an increase in technology has a negative impact on value-added creation.

In the context of multiple-use management with non-timber goods and services offered by public and private firms, Leppänen et al. (2005) estimated the financial impact on private firms of stricter forest conservation (defined as "protection of nature reserves, excluding private property rights and harvesting").

²⁶Although returns to scale and economies of scale are not directly comparable, the assumption of constant prices for all inputs is sufficient to make them (locally) equivalent (Sandmo (1970)), and therefore somewhat comparable in this context.

Their methodology considers surplus of owners and time-series analysis, and results show strong losses incurred by private owners.

Most of these papers consider the policy implications their analysis may have. In this context and for the Swiss case, Bisang and Zimmermann (2005) is a very interesting example. They present methods for the evaluation of forest policy, mostly qualitative, with the Swiss case as a practical example.

As far as Switzerland is concerned, efficiency measurement in the Swiss public forestry industry has been the center of interest of several studies. Mack (2009) applies statistical methods of Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) empirically and determines the efficiency of firms. Results show strong heterogeneity of efficiency levels across firms and ambiguous relationship between subsidies and efficiency. Schönenberger et al. (2009) should also be mentioned for their work on the specific impact of subsidies on technical efficiency. Using DEA, they show a significant and negative impact of subsidies on technical efficiency.

Recently, Bürgi and Pauli (2013), using a cause and effect analysis, bring potential explanations for the relatively high production costs incurred compared to neighbouring countries. Finally and maybe more importantly, Farsi (2013) and Krähenbühl (2013) have set the basis for this chapter, by analysing the cost structure of the industry. The objective of this chapter is to use the same general approach, strengthen the foundations of the analysis and refine the analysis, especially in terms of outsourcing and marginal costs.

Technical remark on costs analysis in the forestry industry

Compared to many other industries, the forestry industry has some important characteristics that makes it special, at least in terms of estimations and choice of specification form. Whereas there are numerous different types of outputs, most

forestry firms are only producing some of them at the same time. This results in a lot of zero observations for the output variables. The standard translog, being the most used form, is unable to handle those observations properly without additional modification. If nothing is done, only firms producing all outputs are considered, which surely results in a strong selection bias. Either a variable or a model transformation is therefore needed. The former can be done through a technique presented in Wenninger (2003). This basically goes down to replacing the zeros with some strictly positive values so that logarithm of all variables is always defined. Which value one should use is then basically the only question, and answers are most often subjective (it is for example convenient to change 0 to 1 so that $\ln(1) = 0$).

Model transformation, on the other hand, might be theoretically more sound. Again, Wenninger (2003) presents an alternative to the translog cost function which is the hybrid model (log of the quadratic form). Many other forms are available, such as generalization of the translog form (see Fraquelli et al. (2002)), or different applications of the Box-Cox transformations (Box and Cox (1964) and again Fraquelli et al. (2002)).

3.3 Econometric model

In most cited papers above, a fairly simple specification is used with only one output (wood) being considered. In the Swiss forestry industry, this is believed to be an important shortcoming that cannot be possibly overlooked without major issues. Indeed, the Forest Policy 2020 explicitly puts the many non-wood related functions of the forests in the spotlight. In turn it implies that an appropriate costs analysis should take these into account. For this reason, this chapter shares several common characteristics with the analysis of many other public services, in a multi-output framework.

In this chapter, the costs model is based on a multi-output specification using Box-Cox transformations (Box-Cox, 1964) and therefore, no quadratic model is used. As seen above, many different variable transformations exist (Bickel and Doksum, 1981; Berndt and Khaled, 1979; John and Draper, 1980; Manly, 1976; Turkey, 1957). However, the Box-Cox transformation is, for the purpose of this chapter, one of the simplest yet most appropriate ones. Although most utilization of this transformation includes only one coefficient λ , this chapter use a more general framework allowing each estimate to have a specific transformation coefficient λ_m independent from each other, for every output, which is a generalization from the "standard" Box-Cox transformation (which uses one and only one coefficient λ for all the transformed variables), and of course from the log-log framework as well²⁷.

The dependent variable is the only variable still transformed using logarithm, creating a mixed log-Box-Cox specification. The main reason of this choice is that it is computationally far more easier than using the Box-Cox transformation again, and it is believed not to have much influence on the results of the estima-

²⁷The logarithm is a special case of the Box-Cox transformation when the coefficient tends to 0.

tion²⁸. Moreover, the dependent variable does not include any zero values (i.e. the total costs of forestry firms are strictly positive), which makes the logarithm suitable.

In terms of computation, most algorithms developed around the Box-Cox transformation, such as Ogwang and Rao (1997) or Spitzer (1982), consider a single λ . Cameron and Trivedi (2005, 2010) and mostly Gould et al. (2010) describe the basis for a maximum likelihood estimation that can be used in basically any non-linear framework. Therefore, a user-written procedure was developed in Stata in order to estimate the parameters.

Another property of the Box-Cox transformation in general, and one crucial point here, is that it allows transformed variables to have observations at zero, which is not the case in the log-log model, translog, or any other related forms due to obvious properties of the logarithm. It is indeed a great advantage as output variables include many zeros in the forestry industry. There are of course several ways to deal with this problem and still use any of those functional forms with logarithm, for example as presented in Weninger (2003), but it is a fact that, explicitly or not, one assumption has to be made on those zero values, and those observations have to be, in one way or another, modified. From this perspective and given the important amount of zero values in the considered variables, the Box-Cox transformation is considered to be a better specification.

Finally, the generalized Box-Cox transformation is a good, yet simple, model specification in this context. It holds all the benefits of the "simple" structure but relaxes a restrictive assumption. The focus is here on the coefficient λ_m which relates to output m only, and is not the same for all. Despite simplicity, there are conceptually no reason to use a similar transformation coefficient for all variables when they are as heterogeneous as they are in this analysis. In the forestry

²⁸Indeed, as it is the only fixed value for the transformation, the model is thought to be sufficiently flexible to only marginally reduce the overall benefit of this specification.

industry, it is therefore expected that this flexibility is welcome given the types of outputs which could require different treatments. As allowing for distinct transformation coefficients does not increase much the model complexity, this solution was the one chosen for this analysis.

As the dependent variable is strictly positive, using the logarithm implies neither any loss of information nor a modification of observations. It also dramatically simplifies the estimation procedure, which would be exponentially more time-consuming otherwise. The econometric equation is given by the following non-linear specification:

$$\ln(C_{i,t}) = h(Y, X; \beta, \gamma) + \varepsilon_{i,t} = \beta_0 + \sum_{m=1}^M \beta_m \frac{y_{m,i,t}^{\lambda_m} - 1}{\lambda_m} + \sum_{j=1}^J \gamma_j x_{j,i,t} + \varepsilon_{i,t} \quad (2)$$

For notation simplicity, $\frac{y_{m,i,t}^{\lambda_m} - 1}{\lambda_m}$ will be denoted by $y_{m,i,t}^{(\lambda_m)}$. In equation 2, $C_{i,t}$ represents total costs of firm i at time t normalized by the price of capital $P_{f,t}^K$ ²⁹ (f referring to the firm f), $y_{m,i,t}$ is the quantity of the m^{th} output for firm i at time t , and λ_m is the related Box-Cox transformation coefficient of output m . $x_{j,i,t}$ is the j^{th} non-transformed variable (i.e. non-output variable), either a dummy variable or expressed in percentage. Finally, the price of labour is transformed using logarithm and normalized by the price of capital to comply with theoretical conditions. Finally $\varepsilon_{i,t}$ denotes the error term and includes random effects in the case of the panel data models. The error terms are always assumed to be normally distributed and i.i.d., with zero mean and standard deviation σ . The random effects $\mu_{i,t}$ are also assumed to be normally distributed with zero mean and standard deviation σ_μ for each firm.

It must be mentioned that several independent variables could show some

²⁹The costs, as well as the price of labour, are normalized by the capital price in order to impose linear homogeneity of factor prices, pre-condition to the duality theory between the cost and transformation functions. See McFadden (1978) or Diewert (1982) for more information.

level of endogeneity, especially outputs as well as the percentage of outsourcing, as it is based on cost levels. Unfortunately, the lack of good instruments prevents the utilization of instrumental variable methods. The work presented in this dissertation is exploratory, and therefore such drawbacks are important to be kept in mind when interpreting the results, although not much can be done to avoid them. As for the outsourcing, it can also play an important role and create biases when the economies of scale are estimated. This will be further discussed with the presentation of the related results.

The non-linear specification in equation 2 is estimated using maximum likelihood. Assuming first no random effects, and after the usual transformation by taking the logarithm of the likelihood function, the function to be maximized with respect to β , γ , λ and σ is

$$\ln(\mathcal{L}) = \sum_{n=1}^N \left(-\frac{1}{2} \ln(2\pi) - \ln(\sigma) - \frac{(\ln(C_n) - h(Y, X; \beta, \gamma, \lambda))^2}{2\sigma^2} \right). \quad (3)$$

This is a very simple and common function for the maximum likelihood estimation. Assuming random effects, the estimation gets slightly more complicated, though. As shown in Gould et al. (2010), a non-linear random-effects specification can be estimated using maximum likelihood procedure with the following log-likelihood function:

$$\ln(\mathcal{L}) = \sum_{i=1}^I \ln(\mathcal{L}_i) \quad (4)$$

with

$$\ln(\mathcal{L}_i) = -\frac{1}{2} \left[\frac{\sum_{t=1}^{T_i} z_i^2 - a_i \left(\sum_{t=1}^{T_i} z_i \right)^2}{\sigma^2} + \ln \left(\frac{T_i \sigma_\mu^2}{\sigma^2} + 1 \right) + T_i \ln(2\pi\sigma^2) \right] \quad (5)$$

where

$$z_i = \ln(C_{i,t}) - h(Y, X; \beta, \gamma, \lambda)$$

$$a_i = \frac{\sigma_\mu^2}{T_i \sigma_\mu^2 + \sigma^2}$$

I stands for the number of groups in the analysis. Essentially similar, this second likelihood function is yet slightly more complex and computationally a lot more demanding. Nonetheless, the same general procedure using a user-written program was applied to both likelihood functions with very successful results in general.

Economies of scale

The non-linearity and the generalization of the Box-Cox transformation with different λ coefficients do not substantially increase the complexity of the estimation of marginal costs and economies of scale, and still enable estimations for each observation (as would allow any second order equation, for that matter).

From equation 2, the economies of scale, denoted $ES_{i,t}$, are defined as the inverse of the sum of the elasticities of costs with respect to each output, that is

$$ES_{i,t} = \frac{1}{\sum_{m=1}^M \frac{\partial \ln(C_{i,t})}{\partial \ln(y_{m,i,t})}} \quad (6)$$

This definition follows Panzar and Willig (1977) which develop explicitly the above equation. The related and fairly weak assumptions needed are presented formally and further discussed in the above mentioned paper³⁰. As outlined in section 3.2, many other papers use this specification, such as Caves et al. (1981, 1984), or Farsi et al. (2006).

Due to the non-linear specification of the model, economies of scale will

³⁰In short and without technical details, the existing technology should be represented by a continuously differentiable function. Moreover, there should be efficient productions, and production should be weakly monotonous.

vary with each output. More precisely, from the definition of the elasticities and equation 6, one can easily get the following equation :

$$\frac{\partial \ln(C_{i,t})}{\partial \ln(y_{m,i,t})} = \beta_m y_{m,i,t} \frac{\partial y_{m,i,t}^{(\lambda_m)}}{\partial y_{m,i,t}} = \beta_m y_{m,i,t}^{\lambda_m} \quad (7)$$

which, when multiplied by the cost level $C_{i,t}$ and divided by $y_{m,i,t}$, represents the marginal costs of output m for firm i at time t :

$$MC_{m,i,t} = \frac{\partial C_{i,t}}{\partial y_{m,i,t}} = \frac{\partial \ln(C_{i,t})}{\partial \ln(y_{m,i,t})} \frac{C_{i,t}}{y_{m,i,t}} = \beta_m y_{m,i,t}^{(\lambda_m-1)} C_{i,t}. \quad (8)$$

In the case of the generalized Box-Cox transformation, equation 6 can therefore also be rewritten as

$$ES_{i,t} = \frac{1}{\sum_{m=1}^M \beta_m y_{m,i,t}^{\lambda_m}} = \frac{1}{\sum_{m=1}^M MC_{m,i,t} \frac{y_{m,i,t}}{C_{i,t}}}. \quad (9)$$

3.4 Data

For this analysis, the choice was to use the Swiss Forestry Pilot Network (TBN), which collects financial and technical data of around 200 forestry firms, from 2007 to 2014. It was chosen over the Swiss Forestry Statistics (SFS) for simple reason of variable availability. The following subsection gives more information about the differences between the two.

3.4.1 Data sources comparison

Compared to the Swiss Forestry Statistics (the second important source of data for the Swiss forestry industry) the main advantages of this data set is the availability of the prices of factor of production, the accuracy of observations (in general, the data quality is thought to be slightly higher), and the numerous variables allowing a higher level of flexibility in the analysis. For this reason, in order to be able to specify the model in accordance with theory, the Swiss Forestry Pilot Network (TBN) is used. The main drawback of the TBN data is the sample size, which should be larger in order to safely create, for example, region-specific regressions (the Swiss Forestry Statistics in contrast have around 2000 observations per year). Another potential disadvantage is that this data source is mostly representative for public and larger firms, although all sizes are represented.

Table 4 shows most important differences between the two main data sources, namely the Swiss Forestry Statistics (abbreviated SFS) and the Swiss Forestry Pilot Network (abbreviated TBN). In general, it is interesting to see that most variables are not substantially different across the two databases.

In terms of observations, the distribution across regions is not significantly different from one source to the other. The most important difference is the firms' size. Indeed, the Swiss Forestry Pilot Network includes substantially big-

ger firms. As this chapter focuses, among other aspects, on economies of scale, this difference should be kept in mind when interpreting results. Moreover, it should also be mentioned that neither of these databases includes firm with less than 50 hectares under management, although these micro firms account for about 2 % of total forestland in Switzerland.

Table 4: Differences between data sources (year 2010)

	Alps	Prealps	Plateau	Jura	Switzerland
	Observations per year				
SFS	378	278	453	339	1448
TBN	37	30	55	43	165
	Firm's size in ha (median)				
SFS	1146	463	267	527	595
TBN	1710	653	451	964	712
	Public firms (%)				
SFS	39.9%	29.1%	53.9%	73.2%	50.2%
TBN	67.6%	50.0%	50.9%	46.5%	53.3%
	Subsidies (%)				
SFS	38.4%	22.5%	14.9%	14.6%	22.4%
TBN	53.4%	25.5%	19.3%	19.1%	27.9%
	Outsourcing (%)				
SFS	30.8%	26.1%	34.5%	36.7%	32.4%
TBN	30.9%	35.7%	22.4%	39.8%	31.3%

Turning to the other variables presented in table 4, ownership, subsidies and outsourcing varies between one source and the other, especially within regions, but we can see that in general, at the Swiss level, the differences is in general relatively small. The outsourcing is almost equivalent, far from significantly different. As for subsidies, the Swiss Forestry Pilot Network shows a slightly bigger percentage, just like the proportion of public firms. However, it would

be abusive to correlate the two. As far as subsidies are concerned, the region is a better predictor for the level of subsidies (especially the Alps where subsidies represent a large proportion of firms' revenues).

3.4.2 Descriptive statistics of the Swiss Forestry Pilot Network (TBN)

No forestry firm managing less than 50 hectares is available in any of the two data sets. Although those firms represent around 37% of all firms in the Swiss forestry sector, they account for about 2% of the overall Swiss forests³¹. As mentioned above, the data source includes slightly more public firms than the Swiss Forestry Statistics (although not statistically different) and most importantly, the firms' size is substantially higher in the TBN. Despite these facts, the data used in this chapter are assumed to be representative of the overall industry. Moreover this data set is undoubtedly the most complete and essentially the only one on the Swiss forestry industry enabling to create a multi-output cost function.

The data gather a total of 1604 observations for 242 firms over the period from 2007 to 2014. After removing mostly missing values of important variables, such as wood production, costs or factor prices, this gives a final sample of 1'026 observations.

Data come from the four main regions of Switzerland, which are the Alps (North and South together), the pre-Alps, the Plateau and the Jura. There are respectively, 225, 183, 350 and 268 observations in each of these regions, which gives a relatively homogeneous data set representative of Switzerland region-wise. It is expected to be sufficient for the purpose of this chapter and even in order to highlight some important differences across regions.

Table 5 shows information regarding some of the most important variables in the data set. In general, the main observation from this table is the heterogeneity

³¹ Annuaire La forêt et le bois, 2013. OFEV.

across regions. Note that the different values can slightly differ from table 4 as the latter includes only the year 2010, where table 5 includes all years of the database.

Table 5: Descriptive statistics across regions

Variable		Alps	pre-Alps	Plateau	Jura	Total
%Outsourcing	mean	31.6%	37.2%	24.2%	40.0%	32.2%
	median	30.9%	29.6%	17.6%	34.0%	27.7%
	1%	0%	0%	0%	0%	0%
	99%	84.8%	99.0%	78.8%	88.6%	92.6%
%Subsidies	mean	56.3%	32.4%	19.8%	19.0%	29.8%
	median	62.7%	30.1%	17.1%	18.3%	23.4%
	1%	0%	0%	0%	0%	0%
	99%	93.4%	89.8%	67.8%	47.3%	87.7%
Area (ha)	mean	1891	866	540	1068	1036
	median	1710	654	459	964	715
	1%	50	62	93	80	58
	99%	6724	3011	1899	3477	4182
m ³ /ha	mean	2.47	6.34	9.47	5.64	6.36
	median	2.04	5.83	8.88	5.61	6.07
	1%	0.00	0.91	1.53	1.24	0.28
	99%	10.78	16.09	19.38	12.14	16.18

One can clearly see that regions are highly heterogeneous from one another, especially when considering subsidies. Indeed, the Alps region is the one which is the most subsidized, as more than half of the revenues of the firms in this region come from subsidies, whereas it drops to less than one fifth in the Plateau or Jura regions. This can be easily explained by the fact that in the Alps, the majority of forests are considered protective³². As for the production of wood

³²In this sample, for 90% of firms, protective forests account for more than 50% of their forests

per hectare (m^3/ha), it shows an opposite relationship: the production in the Alps is at a fairly low level compared to all other regions. Note finally that the level of 0% for outsourcing and subsidies are achieved by a very small part of the overall data only, with a total at the country level of 8 and 13 observations, respectively.

The goal here is mainly to highlight how heterogeneous this industry is. Note however that the values shown here do not correspond to the overall Swiss forestry industry, since only relatively big firms are considered. Nonetheless, the differences in size are equally significant when all firms are considered in this sample. The mean sizes of the area in the Alps, pre-Alps, Plateau and Jura regions were 606, 240, 125 and 378 hectares in 2010, respectively³³. It is therefore important to note that the size ratio of the firms considered in the sample and all firms in the forest industry in Switzerland is somewhere between 3 and 4. This should be taken into account when interpreting the estimated economies of scale. Of course, the evidence of their existence using these data would only be strengthened by the fact that the firms considered are relatively bigger than the average Swiss forestry firm.

3.4.3 Description of outputs

Three main types of goods and services are identified for the analysis : woods, areas, and roads. The production of wood is divided into three outputs that are log-wood, fire wood and industrial wood. The distinction is made as each type of wood requires different amount of labor and is sold at a different price (as well as used for different final purposes); therefore, there are not easily and directly comparable. Nonetheless it is clear that, as they all come from trees, their production is closely related to one another and can be somehow considered joint.

under management, and almost half of them only manage protective forests. This is in line with actual figures at the country level. See FOEN (2013b) for more information.

³³ Annuaire La forêt et le bois, 2011. OFEV.

The forestland is included in the model as an output, as it is considered that forest, aside from creating public services, is also (and maybe foremost) in itself a public good. The very existence of forest is valuable to most people³⁴. Among the obligations of the forestry firms, there is of course the task to maintain their forests in good and practicable conditions. For the purpose of the analysis, the forest area is then subdivided into two different types, even if the data would allow to make a distinction between four different areas that are productive (wood production oriented), protective, recreational and biodiversity (or nature oriented). As the protective area is subject to many restrictions (definitely less the case for the other types), it was chosen to create only two types of forests, protective and non-protective ones. Moreover, the objective is also to stay as simple as possible without unnecessarily multiplying the number of outputs.

Finally, roads were added to the outputs for similar reasons than the types of forests and since their role in the forest management is ambiguous. On one hand, it could easily be thought that roads are an important asset for the forestry firms allowing workers to move easily through forests, where accessibility is often an issue. On the other hand, the roads must be maintained. This brings considerable costs and can be very time- and money-consuming. Along with roads, its density can also be of significant importance. For all these reasons, it is not clear which of cost or benefit prevails on the other.

All in all, these six outputs are chosen for the model, which is hoped to maintain the best balance between simplicity and representativeness.

Table 6 shows some descriptive statistics of the six outputs. In parentheses in the minimum column is the percentage of the observations sharing the 0-value.

Whereas it is almost never the case that a firm does not produce any log-wood, it is more common to have a firm without any production of fire or indus-

³⁴See Pearce (2001) for more information including about the economic value of forests existence.

Table 6: Descriptive statistics of output variables

Variable	Mean	Median	Std. Dev.	1%	99%
Log-wood (m ³ /year)	2528.5	1998.7	2056.6	0 (0.8%)	9068
Fire wood (m ³ /year)	1313.9	1005.5	1243.7	0 (5.9%)	5465.3
Indust. wood (m ³ /year)	643.3	256.5	978.2	0 (19.6%)	4554
Protect. area (ha)	465.5	5.2	920.7	0 (43.8%)	4958
Nonprot. area (ha)	588	462	550.0	0 (9.6%)	2208
Road (km)	67.8	66	52.6	0 (4.5%)	296

trial wood. As for the types of forests, more than half of the firms do not have any area considered as protective area, and only slightly more than one third of all observations (36.6%) hold protective as well as non-protective forests. Finally, concerning the outputs in general, it is rare to see a firm producing all six outputs: it happens only for 169 observations, out of the 655, that is slightly above a quarter of the sample. It is a fact in this industry that firms generally do not produce all outputs, therefore it only emphasizes the importance to specify a model that can best deal with such a structure.

3.5 Results

In this section, results of the econometric models are presented. The estimations of the economies of scale and marginal costs are then discussed.

3.5.1 Estimated parameters

The results of the regression estimations are given in table 18. Regressions 1 and 2 are both based on equation 2 and differ by the fact that regression 1 assumes that $\lambda = \lambda_m$, for all m (standard assumption of a Box-Cox specification, shown for comparison purposes). Regression 3 is similar to regression 2 but includes panel data methods (random effects).

The first observation is the high homogeneity of the estimators for the non-transformed variables across all models. Despite minor differences, the models generally agree on most aspects. As an example, the coefficient of the labour price (standardized by capital price) is very much homogeneous across regressions.

In general, the ancillary services tend to increase costs, as it could have been expected. Likewise, both road and tree densities tend to decrease costs when increased. However, the most important impact is the road density, which suggests that although the maintenance costs might be high, it still lowers the general level of costs due to an increased accessibility of the forests. A complement to this discussion is held below when the road as an output is considered.

Table 7: Estimations results of the generalized Box-Cox

<i>Variable</i>	Model 1	Model 2	Model 3
$\ln(\text{Total costs})$			<i>RE</i>
$\%Ancill. services_{f,t}$	0.013***	0.014***	0.003***
$Road density_{f,t}$	-0.285**	-0.274***	-0.420***
$Tree density_{f,t}$	-0.055***	-0.052***	-0.075***
$\ln(\frac{P_L}{P_K})_{f,t}$	0.246***	0.263***	0.251***
$\%Outsourcing_{f,t}$	-0.808***	-0.837***	-0.725***
$\%Subsidies_{f,t}$	0.223***	0.251***	0.187***
$\beta_{W, Timber}$	0.001***	0.022**	0.044***
$\lambda_{W, Timber}$		0.258***	0.152***
$\beta_{W, Fire}$	0.001***	0.005***	0.001
$\lambda_{W, Fire}$		0.470***	0.529***
$\beta_{W, Industry}$	0.001***	0.002*	0.001*
$\lambda_{W, Industry}$		0.561***	0.499***
$\beta_{A, Protection}$	0.004***	0.003***	0.001***
$\lambda_{A, Protection}$		0.706***	0.800***
$\beta_{A, Nonprotection}$	0.005***	0.003***	0.001***
$\lambda_{A, Nonprotection}$		0.722***	0.879***
β_{Road}	0.001	0.000	0.017***
λ_{Road}		0.000	0.212***
λ	0.650***		
<i>Jura</i>	0.069***	0.070***	0.060
<i>Pre-Alps</i>	0.096***	0.108***	0.018
<i>Alps</i>	0.311***	0.329***	0.275***
Constant	6.488***	6.234***	6.442***
σ	0.234***	0.227***	
σ_u			0.249***
σ_e			0.100***
<i>N</i>	1'026	1'026	1'026

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

The percentage of outsourcing seems to have a strong potential of cost reduction. Outsourcing to more efficient or specialized firms has at first sight a strong potential which might very well not be entirely exploited. This is a crucial point arising here, as it might be a very efficient and simple way to decrease cost level of the forestry industry. As for the percentage subsidies, it is positively correlated with costs. This was expected as subsidies are given mostly in exchange for some public services (such as maintenance of protective forests) which then lead to higher costs (with a factor of about 0.19 to 0.25). Moreover, subsidies are spent mostly in fairly harsh environment (such as protective forests) which furthermore explains this result.

In terms of inputs, the linear homogeneity assumption requires that the overall effect of inputs, labor and capital, is 1. In order to satisfy this condition, only the price of labor normalized by the price of capital is used in the model. With estimates of around 0.25, the price of labor seems to be of smaller importance compared to the price of capital, which by construction is around 0.75.

Another important observation concerns the differences in regions. The Plateau is considered as the basis for the analysis. In contrast, the Alps particularly stand out of the others: costs there are higher than in any other region, irrespective of the model specification. This was an expected result, even though such a magnitude would maybe not have been suspected: the costs are higher by between 32% to 39%, everything else being equal. The pre-Alps appears in regressions 1 and 2 to be the second region with the highest total costs, even though random-effects models suggest that there are no significant differences. The last region, Jura, also shows significant differences in regressions 1 and 2 with the Plateau, but not when random-effects are considered. The distribution of protective forests, strongly present in the Alps, is surely a big part of the explanation.

The main differences between the models, and especially between the first

two regressions and regression 3, lie in the output coefficients (β_m). The cost drivers of the costs from the outputs perspective seems to be both the wood production and the area under management, with an emphasis on timber. On their side, roads show ambiguous results. Regressions 1 and 2 give insignificant results, but the random-effects model display strongly significant estimates (whereas fire and industrial wood drop in significance). People working in the forestry industry generally say that roads, even though they give a means to facilitate transportation and accessibility, are very costly in terms of maintenance. The conclusion might simply be that both effects partly offset each other : having roads is a valuable asset that decreases direct production costs, but it is in turn as costly to maintain.

The other outputs are all significant. Note that for the λ_m coefficients, it does not mean that the related variable is indeed significant by itself, but only that the assumption of log-relation with the dependent variable can be rejected, which is always the case. The β coefficients, on the other hand, show which transformed variables are, or not, significant. The transformation coefficients λ_m vary substantially between outputs, mostly with significant differences from one another. They also reveal that the best fit for the model is strictly different from the logarithm. However, results are not completely different than the standard Box-Cox models. Nonetheless, it enables to show some subtle differences and presenting all these models also highlight the fact that the results surely are sensitive to model specification.

3.5.2 Economies of scale and marginal costs

The estimation of marginal costs and economies of scale is based on the generalized Box-Cox random-effects model with all variables (Regression 3) and using equation 9. Important findings concerning the economies of scale are first

discussed, before focusing on the marginal costs of each output.

Figures 6 to 8 show the distribution of the economies of scale with respect to timber output, protective area, non-protective area and total area, respectively. The three other outputs in the regression show similar results and are not shown for the sake of simplicity.

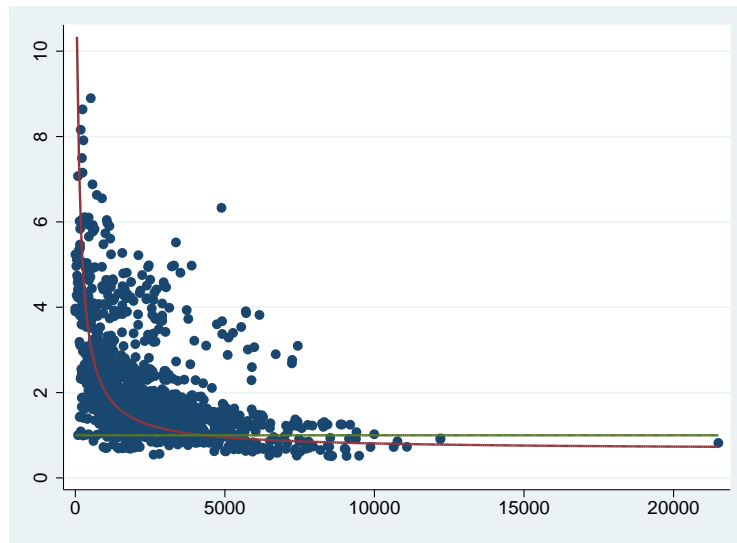


Figure 6: Economies of scale with respect to *timber output* (m^3).

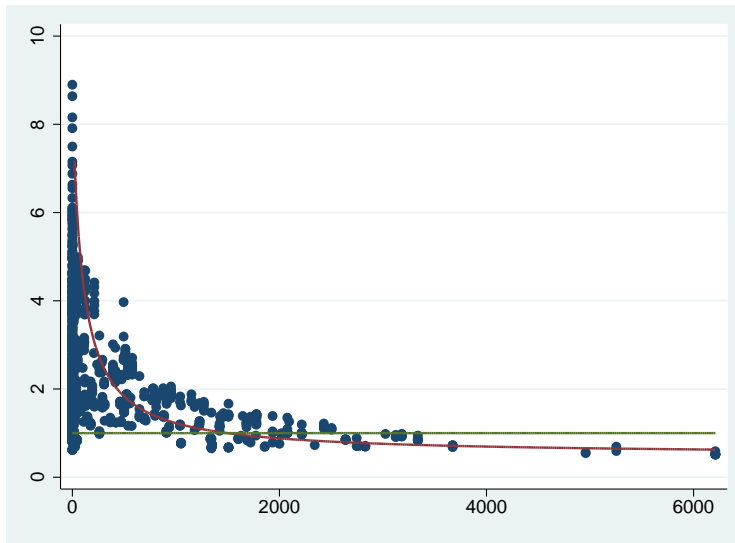


Figure 7: Economies of scale with respect to *protective area (ha)*.

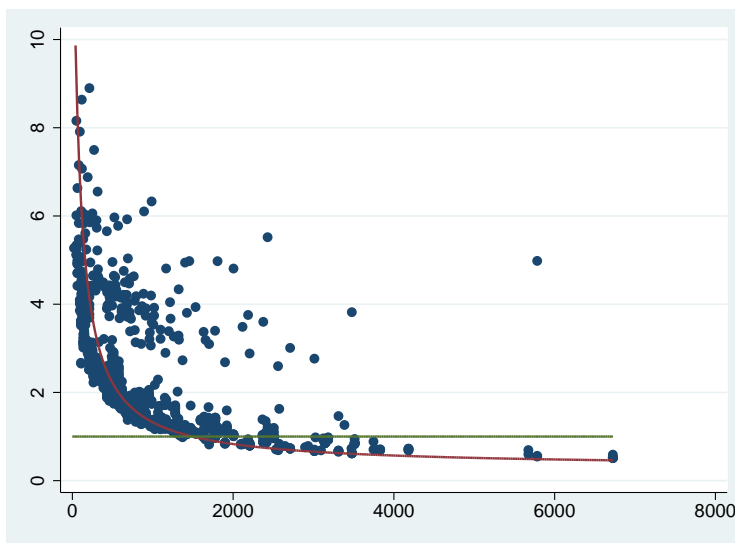


Figure 8: Economies of scale with respect to *total area (ha)*.

The concept presented in these figures is the following. Each observation is given a value in terms of economies of scale. For all values above 1, the higher it is the higher the economies of scale, meaning the higher the potential cost reduction through an increase in the firm's size. At a value of 1 exactly, there is statistically no economies nor diseconomies of scale. Therefore, the average cost of output is optimal. For values below 1, diseconomies of scale exist, meaning theoretically that the average cost of output could be reduced through a decrease of the firm's size.

As the economic theory asserts, economies of scale are generally decreasing with respect to a specific output. Figures 6 to 8 show this general trend which suggest the switch from economies of scale (above a value of 1) to diseconomies of scale (below 1) as the size increases. The level of neither economies nor diseconomies of scale (i.e. equal to 1) is shown in all figures with a horizontal line. The curves show the general trend of the scatter plots.

This allows to believe that there exists an optimal size in the forestry industry. However, given the spread in figures 6 and 7, and above all the high heterogeneity of the forestry firms facing numerous different environments, this optimal size should surely be an optimal interval rather than a single value. Nonetheless, what seems to mostly drive the economies of scale is the total area under management. Indeed, figure 8 shows fairly homogeneous results, with most observations close to one another and following a decreasing and clear pattern in terms of economies of scale, strong evidence of the existence of potential large cost reductions through size. As a matter of fact, 884 out of the 1026 observations (86.2%) exhibit economies of scale. Also, it is important to put into perspective this concept of optimal size. Generally speaking, the horizontal line (equal to 1) should be thought as the minimum scale efficiency, meaning that the firm can, on average, then produce with minimum costs. As for the optimal size, it can then

be thought as a minimum size, rather than an optimal size.

Finally, outsourcing and its effects should be mentioned here. Its use could potentially distort the estimation of economies of scale. However, a regression of outsourcing on usual independent variables show no significance between outsourcing and size of firms, which would have otherwise been problematic. Significant differences exist between regions, bringing an additional argument to avoid very specific results. Also, estimations of the regressions presented in table 18 are robust, even when observations with the highest levels of outsourcing are removed from the estimation. For these reasons, it is assumed that outsourcing might not have a strong distorting effect on results. If anything, there might only be a slight underestimation of economies of scale and minimum scale efficiency, which could only strengthen the conclusion of this analysis.

Table 8 shows deciles of the economies of scale levels. It is important to note that these deciles are "standardized" and do not represent any particular firm. Any decile of economies of scale is calculated with the corresponding decile of each output. Therefore it is not possible to establish any direct relation between table 8 and the 72.1% of observations lying in the economies of scale area. The results show that the optimal size is theoretically somewhere around deciles 8 (80%). As we can see, the 8th decile gives a value of 1.03, slightly above but very close to 1 meaning, that the optimal size (thought here as the minimum scale efficiency) is slight above the 8th decile.

This corresponds to a magnitude of, for log output, around 4000 m³ per year, and for the total area of around 1500 hectares, although figure 8 seems to suggest that total area under management could well go higher. Without giving exact values, it still gives a good general idea of the situation. No more precise value is given willingly to consider the fact that environmental heterogeneity leads to differences in the optimal size.

Table 8: Deciles of economies of scale

Decile	Economies of scale
10%	7.89
20%	5.35
30%	3.45
40%	2.65
50%	2.15
60%	1.81
70%	1.41
80%	1.04
90%	0.72

Also, even considering the important fact that there might be different optimal firm sizes depending on regions, figures 6 to 8 still show that theoretically most firms in the sample (86.2% of observations) could improve their costs through economies of scale. Knowing as mentioned earlier that the sample contains firms that are, for most of them, among the biggest in Switzerland only intensifies the argument of strong and untapped potential of economies of scale within the Swiss forestry industry. Indeed, according to the Federal Office for the Environment in its forest and wood report³⁵ and the definition of the Swiss Forestry Statistics, more than half of all forestry firms (52%) in Switzerland manages less than 100 hectares, and around 85% of Swiss forestry firms manage less than 500 hectares (accounting for around one third of all Swiss forests), which is substantially below the threshold presented above. Along with the previous findings, it is even more safely arguable that the economies of scale are really strong.

³⁵ Annuaire La Forêt et le bois, 2013

On the other hand, the diseconomies of scale as shown in table 8 for the highest deciles are not fully supported from a theoretical point of view. In light of the current understanding of the market, there is no tangible economic argument to assert without a doubt that a forestry firm of several thousands hectares is too large from a cost efficiency point of view, even more so when international examples are considered, such as in North America or even nearby European countries. In any case, there are very few firms that big and it can be expected that they are still more cost efficient than smaller ones.

In fact, a simple descriptive statistic shows it very clearly. Looking at total cost per hectare within several size groups (in terms of total area under management), the observation of the difference is clear-cut. As an example, the forestry firms between 500 and 1000 hectares, compared to those between 250 and 500 hectares, show costs per hectare that are in general significantly lower, from 10% to almost 20% depending on regions. For the pre-Alps and Alps, the difference is not significant, although the mean of costs is lower for bigger firms; the number of observations is however not high enough to get significance. Furthermore, for forestry firms above 1000 hectares, the differences become insignificant for all regions. Even though the number of observations might still be an issue, this could also suggest that potential for cost reductions might have mostly disappeared above this threshold (which again does not mean that bigger is worse).

The next logical question arising is how to benefit from these economies of scale in practice. There is a strong potential lying there, but catching it might not be as easy as it sounds. In reality, merging firms is difficult for several reasons. One of the most important ones is the job stability. Merging several firms would most certainly mean sacrificing jobs. Therefore, some alternatives might be needed at least in the short- and medium-terms. It turns out, when looking at the cost side, that labor only accounts for a third of all costs, meaning two

thirds are capital related. Increased collaboration should be a first important step towards higher cost efficiency. Without even mentioning outsourcing, collaboration can arise at many levels. First, since investments in terms of machineries and equipments are substantial in this sector, rationalizing them might be a first step. They could be rent from one firm to the other. Partnership between several firms to make investments together could lead to a higher usage of capital and therefore a lower cost, everything else being equal.

A second possibility to benefit from economies of scale without direct mergers could be an increase in terms of synchronizing the work. It is not unusual to see a firm working on a piece of forest and the neighbouring firm coming the following week to work on the piece of forest right next to the first one. This type of inefficiencies could be easily reduced through a higher level of organization and better communication. Local governments could play a role through a work of sensitization of forestry firms to these subjects. An information platform allowing firms to organize themselves with one another could potentially be another action to take. All in all, forcing firms to apply these measures is difficult, if not impossible. Therefore, facilitating information exchanges and sensitization to these types of increased collaboration are, at least in a first step, good measures to introduce.

Table 9 shows some percentiles of the marginal costs for each significant output (roads are excluded because of its insignificance in the model). These marginal costs are calculated according to equation 8 and with coefficients estimated in regression 3, as for the economies of scale.

All marginal costs are expressed in CHF. They correspond to an additional cubic meter for the production of wood or an additional hectare for the type of forest under management. The results show great differences in marginal costs between percentiles, which can be linked to the differences in levels of

Table 9: Marginal costs (in CHF)

Decile	10%	25%	50%	75%	90%
Timber (CHF/m ³)	17.55	23.10	32.43	45.26	64.62
Fire wood (CHF/m ³)	12.17	17.23	24.99	36.71	56.02
Industrial wood (CHF/m ³)	14.93	20.38	32.00	49.79	84.17
Protective area (CHF/ha)	57.50	114.45	194.16	313.16	470.15
Non-prot. area (CHF/ha)	92.64	150.32	248.11	342.63	474.39
Road (CHF/km)	102.82	173.52	341.60	593.46	1061.47

economies of scale across observations. For example, the marginal cost for timber at decile 9 is more than three times the marginal costs at the first decile. Fire wood is an even more striking example as the ratio between the two is higher than five.

Costs of one additional hectare for each type of forest seem to differ widely in lower percentiles but are very similar when higher percentiles are considered. It is important here to keep in mind the distribution of the protective and non-protective areas. As shown in table 6, more than half of the observations has no protective forest, whereas only one tenth does not have any non-protective area. However, the explanation could simply lie in the fact that small areas of protective forests are easily manageable and can be left untouched fairly easily, respectively can indirectly profit from the work done in nearby areas. However, when these areas get bigger and bigger, it appears that time and money have to be invested to properly manage them, respectively that work done in nearby areas is not sufficient any more for proper management.

3.6 Conclusion

This chapter developed a cost analysis of the Swiss forestry industry with a multi-output specification. A generalization of the Box-Cox transformation with individual transformation coefficients was used, along with panel data random-effects. Based on these models, economies of scale and marginal costs were estimated.

In general, most outputs considered in the analysis appear to have a significant and positive relation with costs. As an exception, roads has a small but significant estimate, along with its density playing on the other hand a significant (and negative) role. Roads have some positive as well as negative impacts on costs, respectively maintenance costs and moving benefits, and the results seem to show that costs and benefits somehow offset each other.

Two main hypotheses about the potential cost reductions were formulated. First, economies of scale were tested for significance as it would mean that the current structure of the industry is not optimal from a cost perspective. Second, outsourcing was believed to allow forestry firms to reduce costs even further.

Both hypotheses were formally tested and the nulls appeared to be rejected twice. Economies of scale are indeed strong in our sample. Therefore the related potential for cost reductions cannot be anything else than very strong when the entire Swiss forestry industry is considered, knowing that the firms included in the sample are among the biggest firms in Switzerland (as a reminder, the mean size ratio between the sample and the whole industry is between 3 and 4). Scale economies in the Swiss forestry industry should be considered as a great tool and could lead to significant cost reductions for most Swiss firms. Indeed, 85% of them manage less than 500 hectares of forests, which is far below what the model suggests to be an optimal size (or minimum scale efficiency), theoretically lying around 1500 hectares but surely very sensitive to the environment of the forestry

firms.

From a practical standpoint, mergers of firms might be hard to put in place in this highly fragmented industry where the economic point of view is one among many other objectives and likely not the most important one. However, there exist other alternatives to achieve similar results. Partnerships, coordination and shared investments should definitely be promoted as well. Of course, it means in a nutshell that firms should work more together and cooperate at many different levels. This could lead to a better management from an overall perspective and to lower the deficits of firms in the long-run, which are at the end mostly borne by local governments (cantons, towns, etc.).

Also, as outlined above, outsourcing seems to have a substantial negative impact on the general level of costs and bears therefore a great potential for cost reductions. Therefore, hiring third parties for specific tasks is beneficial and could be either a complement (at best) or a substitute (at least) to cost reductions through economies of scale. All in all, the findings are here very similar: the fragmentation and the partitioning of the Swiss forestry industry is highly cost inefficient and should be fought with significant energy.

While the analysis conducted in this chapter clearly show the potential for cost reductions, its exact magnitude should need some further research and formally take into account the distribution of the industry, respectively the bias associated with the distribution of the database (or use a different one) which reduces the effect shown in this chapter. Also, the optimal size was estimated but the sample size did not allow for regional, or more specifically, environmental differences, which would be definitely valuable information in this heterogeneous industry.

4 Supply Analysis and Market Power

Abstract

This chapter 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 different 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.

4.1 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, the function of wood production and its sale is, besides the subsidies, almost the unique source of revenues for forestry firms. It could then, from an economic point of view, be considered as the most important. At the very least, it is crucial for the financial viability of the firms and of the industry in general. Therefore, it also indirectly enables the fulfilments of other obligations of forest maintenance, generally related to the multifunctionality of the forests and non-wood related functions (i.e. not directly related to the wood harvesting).

The objective of this chapter 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 quantity supplied, price most often plays a central role. This chapter therefore analyses supply with a special focus on it. 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 rejected from the perspective of the wood supply³⁶.

Strict profit-maximization behaviour is strongly suspected not to hold. Instead, others models, such as the target-revenue model, might better fit actual

³⁶Forest 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.

choices of forestry firms. Indeed the latter could be in line with the inter-temporal feature of this very specific industry, as well as with the numerous functions that are assigned to Swiss forests and firms (in addition to timber harvesting). To test this hypothesis, the elasticity of supply is estimated using an econometric analysis modelling supplied quantity as a function of price and several other 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. The estimated elasticity of supply might also be dependent on several characteristics of firms, such as ownership and the regions in which the firm operates.

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 (through loss coverage) constitute the main arguments for this suspicion. Hence, in this second part of the analysis, the formation of price in general is modelled and the level of market power among forestry firms is specifically estimated. In this second econometric analysis, price is used as the dependent variable in a econometric regression using several important independent variables, 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. 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.

4.2 Theoretical framework and literature review

For many years now, timber supply analysis in general has been an important subject of interest in economic research. The overwhelming part of contributions in this field can be divided into two main branches. The first one focuses on the process of decision making of forest harvesting. The study here is mostly theoretical with very few empirical studies. The reason is fairly simple and is also the drawback of this type of contributions: the need of extensive and reliable data sources. As a small example, empirical analyses using strict decision making processes would need information about the age of all trees and their growth over time. The contributions turn out to be mostly theoretical, giving theoretical insights for the second types of analysis and the interpretation of results. For the analysis conducted in this chapter, the theoretical background is very important to avoid simplistic and potentially erroneous conclusions when studying the price elasticity of supply in this intertemporal optimization. The second type of contributions is a more applied approach, as it aggregates all individual decisions at the firm, or market, level. It describes the overall mechanisms and the drivers of wood supply. While the former is the foundation of the theory of supply, its empirical applicability is, again, impossible in Switzerland given the data requirements. However, the aggregate models, on their side, fit perfectly the exploratory need of this study focusing on the general mechanisms behind wood supply and the influence of prices.

This section starts with the description of basic decision making models with primary focus on wood production where the only question asked is when to harvest. Then, even though the question stays often more or less very similar, the general framework changes in the second part with the introduction of the multifunctionality in the context of timber management. Finally the last part presents some aggregate supply models, which are in the continuity of the previous the-

ory. This section summarizes the main body of literature in decision making models and in multiple-use management in forestry economics, with its related methods in general.

Decision making models

What we could call the foundation of the theory describing decision making of forest owners is due to Faustmann (1849), the very first contribution to the rotation age problem, which formulates the simple question: when should the owner cut trees? 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 below. The solution to the problem is the rotation age, which is the age at which trees should be harvested. 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 multifunctionality of forests. We will come back to this issue later.

Before going further, an important assumption should already be mentioned, which presents the general framework. The early research on the subject, and still most of recent ones, was done assuming a uniform distribution of ages in any forestland managed by a specific owner. If different qualities of lands are considered, the same would apply to any forestland of a given quality. Some short-run deviations are possible, but these should vanish on the long-run and after necessary adjustments. From this framework, the central (and basically only) problem is to find the optimal age T^* of a forest at the time of harvest. The above mentioned assumption has the clear advantage of leading directly to constant production over time, which can be fairly important in the context of

forest management. Even though empirically somehow hazardous, it is then conceptually and practically easier to consider the problem as such, and the intertemporal optimization is simplified to its most basic expression. Indeed, the problem goes down to when harvesting is optimal in any given forest stand. The second assumption, which we have not mentioned yet, is that the growth (or production) function is the same for all forest stands. If not, even a uniform distribution of ages would not lead to constant production over time.

Even though a few papers have successfully relaxed the uniformity assumption and still achieve constant harvesting over time, most of them are reluctant to leave it behind. An example is Ussivuori and Kuuluvainen (2005), developing a model where harvesting volume can be sustainably kept at a certain level without assuming a uniform distribution on the age structure of the forest, by cutting forest stands of different ages.

Once the framework is in place, the optimization can be carried out. Before going into the Faustmann model, many different objectives can be considered (or at least thought of) when trying to give a proper answer to the question: when should one harvest? One first objective that comes to mind is called Maximum Sustainable Yield (MSY), sometimes known as biological model (see for example Hyde 1980), which simply maximizes the average annual harvest. That is, based on the function $F(t)$ of standing volume of wood (m^3) over time, 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

$$s(t) = \frac{F(t)}{t} \tag{10}$$

where $F(t)$ is the growth function of forest depending, for simplicity, solely on time t . $s(t)$ also depends on the time t , or age of forest t , at which harvest will

occur. Therefore, the optimization problem is nothing more than

$$\max_T \frac{F(T)}{T}$$

Optimally, assuming second-order conditions are satisfied, we simply get

$$\frac{F(T^*)}{T^*} = F'(T^*) \quad (11)$$

This maximization is also known as the Mean Annual Increment (MAI). Typically, a growth function $F(t)$ is increasing over time, with first a positive second derivative until some inflection point, switching then to a negative second derivative (i.e. 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 hump-shaped). As the function goes through the origin, this ensures to have one and only one optimal solution (strictly greater than zero). Equation 11 tells us that, when the marginal growth of forest (what we could refer to as Current Annual Increment, or CAI) is equal to the mean annual growth, the optimum is reached. For t smaller than t_{MSY} , it appears that $F'(t_{MSY})$ is bigger than the wood supply, and vice versa. This is conceptually very intuitive when shown graphically. van Kooten and Folmer (2004) is one of the reference books in which these few concepts are explained and discussed³⁷. Though intuitive, the MSY criterion is naive as it only considers the production (in terms of volume) and avoids economic aspects such as the time value of money (i.e. discount rate) and the costs of replanting. It could at most be insightful in case of natural forests, even though opportunity costs are important and should be taken into account³⁸. This type of forest refers to land where no silvicultural effort is invested.

Samuelson (1976) debates rotation models in general and reminds potential problems in the MSY criterion, largely used at that time. As Amacher (2012)

³⁷See for example van Kooten and Folmer (2004), p. 366.

³⁸Hyde (1980), p. 61

rightly summarized :

”Largely, his focus was to abolish the singular focus foresters of the time ... had on achieving the maximum sustainable yield (MSY) of an (even aged) forest, a focus that ignores land rent.”

This might be seen as a simple error, but the National Forest Management Act of 1976, in the United States, stipulates that maximizing MAI is the criterion to be applied, at a minimum (owners might harvest later, but not before). However, an exception is made concerning the multiple use management (see Calish et al., 1978).

By filling this gap and considering more complex models, the optimal age most often significantly shortens. The Faustmann optimization, with multiple rotations (an infinite number of them), is a good example. Whereas MSY maximizes the average annual timber production, the objective of the Faustmann model is to maximize the profits earned by the owner from selling timber at the end of each rotation period. Formally, we want to find the optimal rotation age T such that

$$T^* = \underset{T}{\operatorname{argmax}} (pF(T) - c)(e^{-rT} + e^{-2rT} + \dots) = \underset{T}{\operatorname{argmax}} \frac{(pF(T) - c)e^{-rT}}{1 - e^{-rT}}$$

where c is the replanting costs incurred in the beginning of each period, p is the price of wood, and r the discount rate, all assumed to be constant over time. Such a function implicitly assumes that the forest stand has just been replanted. With an increasing function $F(T)$ (as stated before at a decreasing rate with negative second derivative $F''(T) < 0$ assumed at the optimum) the solution given by the first order condition is:

$$pF'(T^*) = r(pF(T^*) - c) + r\pi(T^*) \quad (12)$$

with $\pi(T^*)$ being the net present value of future profits (i.e. the function to maximize). Or similarly, as seen in Binkley (1993) :

$$\frac{\partial F(t^*)/\partial t^*}{F(t^*) - c/p} = \frac{r}{1 - e^{-rt^*}} \Leftrightarrow p \frac{\partial F(t^*)}{\partial t^*} = r \frac{pF(t^*) - c}{1 - e^{-rt^*}}. \quad (13)$$

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

$$\eta = \frac{\partial s(t^*)}{\partial p} \cdot \frac{p}{s(t^*)} = \frac{\partial s(t^*)}{\partial t^*} \cdot \frac{\partial t^*}{\partial p} \cdot \frac{p}{s(t^*)} = \frac{\partial t^*}{\partial p} \cdot \left[F'(t^*) - \frac{F(t^*)}{t^*} \right] \cdot \frac{p}{F(t^*)} \quad (14)$$

$\frac{p}{F(t^*)}$ is positive, and $\left[F'(t^*) - \frac{F(t^*)}{t^*} \right]$, 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). $\frac{\partial t^*}{\partial p}$ is negative³⁹; intuitively the higher the price, the less important the harvesting costs and therefore the shorter the rotation age. As a consequence, it appears that $\left[F'(t^*) - \frac{F(t^*)}{t^*} \right]$ 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 can be satisfied if and only if the optimal rotation age is small, and specifically smaller than the Maximum Sustainable Yield (MSY). In other words, the elasticity of supply becomes 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

³⁹In fact, $\frac{\partial t^*}{\partial p}$ can potentially be positive in a very specific case where $F(t)$ is relatively small compared to $\frac{\partial F(t^*)}{\partial t^*}$, as it can be seen from equation 13. 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 $\frac{\partial t^*}{\partial p}$ can be safely considered to be negative in general.

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 forests⁴⁰) 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 forests⁴¹) at 85 years in Croatia. Natterer et al. (2004) also mention the old age of Swiss 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%)⁴². 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 14 tell us that such a behaviour should lead to a positive elasticity of supply in the case of the Swiss forestry industry.

Going back to the Faustmann optimization problem, equation 12 only depends on the level of replanting costs c at the beginning of each period, relative to the price p , and the discount rate r (also assumed constant over time). Note that all these variables are exogenous.

It is important to note that rotation age problem can be solved either with the analysis of a single rotation, or through several rotations (usually an infinite number of them), as in the Faustman case. Until now, we went only through the second case of an infinite number of rotations.

Despite intuition, the single rotation problem is slightly more complex. If one

⁴⁰La forêt et le bois, 2013. OFEN.

⁴¹Idem.

⁴²National Forest Inventory 3, 2004-2006. WSL.

maximizes the profit of a single rotation, with no further modification compared to the Faustmann model, the solution will not be optimal any more. As highlighted by Hyde (1980) and Samuelson (1976), the fact that different optima are found when transforming a single rotation to multiple ones comes from the fact that land rent is not taken properly into account in the former. Therefore, when considering waiting one more year until harvesting, only the discount rate versus the increase in wood quantity to be harvested are taken into account, omitting the value of land use during this additional year. Once corrected for this, Samuelson (1976) shows that the solutions are indeed equivalent.

The maximization problem, with a single rotation and considering the cost of land, becomes,

$$T^* = \underset{T}{\operatorname{argmax}} (pF(T) - c)e^{-rT} - \int_0^T e^{-rt} R dt$$

where R is the rent cost of forestland. At the optimum, we have,

$$pF'(T^*) = r(pF(T^*) - c) + \frac{R}{r}(e^{-rT} - 1) \quad (15)$$

This optimization is of course more appropriate than the maximization problem with one rotation but no cost of land. In such a case, the last term of equation 15 would vanish, biasing the results. However, and this can be used as an intuition for Samuelson' results, when several periods are considered, then the boundary of the integral of rent costs goes to infinity, which can then be considered as a simple constant (since it does not depend on T any more). We can then ignore this term and we get back to the basic Faustmann problem. However, ignoring this term is only appropriate when the land is chosen to be used as forestland for ever. When choosing the utilization of land or assessing the potential of wood production for some time period, ignoring this term is misleading.

A last point concerns the theoretical implications of incorporating oppor-

tunity costs. As seen before, and under some market efficiency assumptions (among others the constant real timber price and costs), optimizing one or several rotations does not change the solution. This means that when optimizing rotation age, one can simply consider the infinite case for a single rotation, even if land might be reallocated. Indeed it is not needed to know in advance for how long will wood production continue in the future.

Empirical analysis generally suggests optimal rotation age between 60 and 70 years⁴³, but it is important to recall that environmental characteristics (altitude, climate, etc.) can extensively change these figures in one way or another.

Hyde (1980) also analysed the case of variable silvicultural efforts c , i.e. costs incurred at the beginning of each period. It includes fertilizing, replanting and all related costs. Whereas these costs were assumed constant in the Faustmann model, Hyde (1980) considers them as a variable which might possibly alter the optimal solution (and indeed does). Above all variable efforts change the impact of comparative statics of the different factors (discount rate, prices, etc.) via direct effects they have on silvicultural efforts, which then distort the optimal solution T^* .

Hyde (1980) is surely a reference book for the early works on the subject. Many important topics are developed about the responsiveness of different factors on the optimal solution to the rotation age problem.

Assumptions on prices are crucial when discussing the optimal rotation age problem. It appears that the expectation of prices in the medium to long term can extensively modify the behaviour of firms. Assuming first silvicultural efforts c to be constant, a price increase expected in the near future by forestry firms and considered as permanent would lead to a increase in optimal rotation age in the short-term (delaying harvesting in order to benefit from the price increase) and

⁴³See, for example, Natterer et al. (2004).

to a decrease in optimal rotation age in the long-term (the silvicultural efforts being now less important in relative terms). Therefore, the optimal behaviour can indeed be a sustainable decrease of wood supply in order to benefit from the price increase, which finally leads to a smaller production per hectare on average. Note that this does not mean that overall supply decreases when price increases, as the overall supply might still be increasing by devoting more lands, if possible, to timber production (as the profitability increases and brings new suppliers in the market, respectively through expansion of existing suppliers). However, considering the amount of land devoted to wood production fixed, this would indeed mean that there could be a negative (and long-term) response from supply to an increase in wood prices. This is a theoretical possibility leading to negative elasticity of supply in the case of profit maximization. However, it must be noted that the mechanism described here is the one occurring at the optimum with the related characteristics.

When referring to the Faustman specification, one of the major problems arising in this model is the lack of valuation of the existence of forest. It indirectly assumes that forests (and more precisely timber) only have value when harvested and sold on the market. In other words, forest functions such as protection, recreation, biodiversity or ecology are absolutely not taken into account.

The second half of the twentieth century has been surely a very prolific time with large amount of research devoted to this multifunctional field. The next sub-section is devoted to it.

Multiple-use management

Following the previous discussion, the consideration of timber supply and timber management has first solely considered timber as a product, and forest as a production area, without any other function. Recently, forest management

in a broader sense appeared, with the multiple-use or multifunctionality of the forests.

Before going further, defining the concept of multifunctionality is important. Thompson et al. (1974) have suggested several meanings users of this concept might find appropriate. Our definition would surely not sound as good, so here is the last of them, being surely the predominant one in this field and the best from our perspective. Multifunctionality exists when "... 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...".

The authors also presented how the different functions of the forest are linked through a matrix of compatibility. It is no surprise to observe that most uses other than timber supply are largely compatible with one another, but that wood production is often only compatible in a limited manner or subject to constraints, if not fully incompatible. It is therefore of great importance to consider them and understand these interrelations. Kline and Mazzotta (2012) made a similar matrix for "ecosystem services", after reviewing the related economic theory, with similar conclusions.

In empirical analysis, all non-wood related functions should be explicitly taken into account as best as possible. However, the main problem when modelling the multifunctionality of the forests is its high complexity; subsequently, the enormous data required in order to be able to grasp an almost exact idea of reality are in practice unavailable. Some authors nonetheless venture to deepen and extend the empirical knowledge by analysing supply of forests and decision-making processes when harvesting trees, mainly in North America. Whereas all of them have taken non-wood related functions in one way or another, the approaches are very different and heterogeneous.

Many papers, more or less recent, have introduced multifunctionality in one

way or another, but at the cost of increasing complexity of models and therefore the related empirical analysis. However, the solution to the now well established rotation age problem can be dramatically altered when non-timber goods and services (or amenities) are considered. As a matter of fact, the non-timber values of forest are very hard to quantify. Still, many authors explored this topic, which is as complex as it is important in our present society, and more precisely for our specific study.

Although some other authors laid the foundations of this field (such as Pearse (1969)), it is undeniably Hartman (1976) who brought the first crucial contribution, being one of the first to consider non-timber values and functions explicitly, highlighting theoretically the importance of amenity values of the forests through an extension of the standard rotation model of Faustmann (1849).

Depending on the value of what the author calls "recreational services", assumed to be non-decreasing over time, he shows that the solution to the rotation age problem might be largely extended, or even tend to infinity, leading to a special case where harvesting is never optimal. This occurs when the value of the standing forest exceeds the earnings from harvesting, and therefore the decision to harvest should never be taken. Anyhow, it is clear that this new factor distorts the optimal solution. Therefore, these amenities should be reflected in the forest management at some point, at least when public forestland management is considered.

Formally, defining $G(T)$ as the value of the standing forest at time T , or amenity function, the optimal rotation problem is

$$T^* = \underset{T}{\operatorname{argmax}} \Pi = \underset{T}{\operatorname{argmax}} \frac{(pF(T) - c)e^{-rT} + \int_0^T e^{-rt} G(t) dt}{1 - e^{-rT}}$$

Note that land rent is not explicitly considered here as time horizon is infinite.

The solution is then given by :

$$pF'(T^*) + G(T^*) = r\Pi + r(pF(T^*) - c) \quad (16)$$

The left-hand side of the equation is the marginal value, or benefit, of waiting one more year (i.e. or unit of time). Note that what is considered is $G(T)$ and not its derivative, since forests bring values every year, whereas $F'(T)$ represents the increase in timber stock that is relevant from a harvesting point of view. The right-hand side is the related costs of waiting one more year, which is the cost of delaying overall earnings one year (the first term being the present value of all future profits and the second being the profit from the next harvest which could have occurred this year). Under some function $G(\cdot)$, practically not so extreme or completely inconsistent, it can well lead to the fact that the condition above is never satisfied, leaving the optimal rotation age to tend to infinity (with the left-hand side exceeding the right-hand side forever).

As we will see in the following sections, this type of model might be more appropriate when we talk about Swiss forests as they are indeed generally old, way older than they should be under Faustman or others standard models, which suggests that amenity values play their role in Switzerland.

As a matter of fact, most rotation models have solutions that require, at least for even-flow timber harvesting over time, a normal forest structure. The latter refers to a forest which is evenly aged from 0 to T with harvesting coming at time T . And, as just seen, the Swiss forests do not completely correspond to such a structure, whatever is the rotation age. Therefore, whether these models are really suitable for Switzerland, and whether a normal forest assumption is appropriate or not, can be open questions.

Even though already complex, in the sense that the function $G(\cdot)$ is very difficult to estimate, this type of model based on a single timber stand still makes

a strong simplification. They assume, explicitly or not, that each given unit of forest can be taken into account independently from the others. This assumption is conceptually somehow questionable, since it appears clearly that the decision taken on a unit of forest will have some consequences on nearby forest stands, at least from the perspective of some of the non-timber functions. Animals living in a harvested stand will have to move to another stand to find a new place to live in, modifying the existing environment for the fauna and flora. Protective forests might be weakened by partial harvesting, and the not being able to fully fulfil its function. More information about this problem of interrelations between forest stands are discussed at the end of this section.

These considerations of multiple-use management in general are central in forestry economics. The economic objective of timber production is combined with public services that often do not directly benefit to the forestry firm. It is however important to keep in mind that the decision making process is still the main topic in multiple-use management, playing the key role in the different modelling approaches.

Multiple-use management has been increasingly the center of interest in the field of forestry economics. Most of the contributions focus on the public forest management. Indeed, it is theoretically the most sensitive to multiple-use management and all the related non-timber public goods and services offered, often without any direct financial compensation. Policy implications are numerous as subsidies and financial incentives can be put in place to encourage private firms to take those issues into account as well.

This consideration has been the starting point of a significant amount of contributions on the subject, often based on Hartman (1976).

Abt and Prestemon (2003) extended slightly the Hartman model in order to apply it empirically through regression analysis. Equation 16 is somehow the

center of interest in this framework. Assuming that the marginal benefit of delaying harvest is higher than the cost of delaying, then it means that a higher profit would be generated by directly harvesting. Formally, in such a case,

$$\Pi_t > \Pi_{t+1},$$

with t being the time at which harvest occurs. Starting with the maximization function defined by Hartman (1976), the authors define a binary variable for the choice of the manager to harvest or not any given stand of forest at any given point in time. From this point of view, a binary variable Y_t is created that takes a value of 1 when harvest occurs and 0 otherwise. That is,

$$Y_t = \begin{cases} 1 & \text{if } y_t^* = \Pi_t - \Pi_{t+1} > 0 \\ 0 & \text{otherwise.} \end{cases}$$

The objective of the econometric analysis is then to describe the main drivers of this decision process in forests of North Carolina in the 1980s. As they base their analysis on the Hartman model, amenities have to be considered and they proxy them using heights of trees. Their econometric model directly uses y_t^* as the dependent variable in a linear model. Y_t could very well be modelled as well, using some non-linear regression models. Results suggest that industrial forest landowners do not value amenities, and do not take them into account in their decisions process.

Pattanayak et al. (2003), on their side, consider an empirical model with ecosystem and socio-demographic characteristics, such as owner type, site class or timber inventory, and proxy amenity values using an index. The model is theoretically very similar to Abt and Prestemon (2003) but differs in the sense that they directly model Y_t using a probit model. Despite weak significance in general, results show, as expected, negative impacts on wood production after an increase of amenities.

Such empirical methods are of great interest since they can be applied directly to describe the decision processes (if sufficient information is available). Even if there is a lack of information, these models can be simplified so that only aggregate supply is considered, as we are going to see in the next sub-section.

Some authors went further in this field and tried to relax specific assumptions, such as Tahvonen and Salo (1999), who considered the case of nonindustrial private owners using an intertemporal optimization with capital accumulation, utility and amenity functions. They point out the fact that optimal rotation age might not, in some cases, be constant over time and even that harvesting might not occur indefinitely. As capital accumulates and as utility of harvesting marginally decreases, a point is reached where harvesting is not optimal any more. Amenity values then exceeds the harvesting profits for ever.

As a matter of fact, only few papers are available in this field of decision making modelling. As stated before, the lack of complete data set to apply such models is certainly the main reason. Decision modelling is based on many observations, at the forest stand level, which are often not available. Most of the research is then done using a specification where less data are needed. This is the topic of the next section.

Aggregate supply models

The most common empirical approach consists of taking the point of view of a landowner managing several units of forest, all sufficiently small to be considered homogeneous. The objective is then to model the choice to harvest or not, aggregating at some level depending on perspective considered and on available data, with the theory of rotation optimization as background. Many authors chose this specification.

Consider the basic idea of the Hartman model discussed above, before gen-

eralizing it. Instead of taking the point of view of a long term manager, we only focus on some specific year t and some living forest with strictly positive age. The question is then asked whether harvesting should occur or if waiting is more profitable. One unit of forest, sufficiently small to be considered homogeneous, and without accounting for any other nearby units of forest for the moment, is harvested if the marginal benefit of waiting is smaller or equal to the marginal cost of delaying. Formally, this means that the unit of forest h is harvested when the following inequality is satisfied:

$$pF'(T_h) + G_h(T_h) \leq e^{rT_h} r \Pi_h$$

In other words,

$$D_h = \begin{cases} 1 & \text{if } pF'(T_h) + G_h(T_h) \leq e^{rT_h} r \Pi_h \\ 0 & \text{otherwise} \end{cases} \quad (17)$$

Equation 16 referred to an optimal solution with continuous function of time. What is considered here is discrete, as forest harvesting usually occurs at a specific time of the year (could indeed easily be simplified to once a year). It therefore becomes an inequality condition, as the strict inequality is possible.

Even though the consideration has solely been on one unit of forestland, all these units can now be aggregated. From the point of view of a forestry firm f with multiple units of forest, each of different ages, its wood supply, denoted Q_f , is given by:

$$Q_f = \sum_h D_h \cdot I_h \cdot A_h \quad (18)$$

where D_h is already defined above, I_h is the amount of stock of wood per unit of area in forest stand h (inventory function), and A_h is the size of forest stand h .

Note again that each stand h is defined to be sufficiently small such that all trees belonging to h share the same characteristics.

Even though the notation might be slightly different, equation 18, in its very basic concept, is used in all empirical analysis in the case of wood supply analysis. Aggregation can be done according to very different variables, not only stands at a firm level (but also region, firms, time, quality of land, and so on and so forth). Equation 18 is the basis of all aggregate supply models discussed below. It shows that the quantity supplied depends on the type and the age of forests, the area under management, and all the other variables considered in equation 17. Similarly, we can therefore write, for any time t ,

$$Q_{f,t} = S(X_{H,f}, E_t) \quad (19)$$

where $X_{H,t}$ are all the variables depending on the forest under management H to which all forest stands h belong, and E_t are all other economic variables, such are discount rate and wood prices.

All aggregate regression analysis are derived from this equation, usually using logarithm of supply as the dependent variable (i.e. most often translog). Independent variables, on their side, vary widely across authors as we will see.

Polyakov et al. (2010) estimate, based on the theory of harvesting decisions developed above, a regression model with logarithm of supply as the dependent variable and prices as unique independent variables for several U.S. states. Results mainly show positive (but below 1) elasticities of price, irrespective of the type of wood. In addition they also estimate a logit model for the probability of harvesting.

Adams et al. (1991) use aggregate methods to explore the relationship between timber harvest and prices in U.S. forests. Results show that public forestry firms are more (positively) sensitive to prices than private ones in the short-run.

Using basically the same data, Prestemon and Wear (1999) model the inventory effects on timber supply and find significant impacts of inventory on price responses. These impacts however depend to a large extent on the type of firms and wood considered.

In the same vein of explaining the effects of different factors on timber supply, characteristics of forest owners and preconceived ideas such as inefficiency of public owners or overexploitation of private firms are explored in Berck (1979). He uses, as most other authors for similar analysis, a translog supply function with the logarithm of supply as dependent variable. Among other results, the paper shows that private owners are not cutting prematurely despite conventional wisdom, and that public owners are inefficient. The shadow losses incurred by them, which should represent the values of amenity given their current harvesting decisions, are higher than any plausible level.

The conclusion about public forest management is in some sense shared some years later by van Kooten and Bulte (1999), cited by van Kooten and Holmer (2004), where they find that, saving biodiversity marginally has a very high opportunity cost in terms of harvesting potential. In other words, this leads to the conclusion that even from a social point of view, keeping old trees cannot be considered efficient according to those analyses.

Pattanayak et al. (2000) model and assess the joint production of timber and non-timber values in forest areas, confirming empirically its existence. Their idea was to use a three-stage least square using inventory and its skewness as proxy for amenity values. According to them, significant skewness could mean that forests are not managed solely according to timber production and therefore that non-timber functions are taken into account. They find price elasticities ranging from 0.6 to 1.27, and a significant negative correlation between skewness and wood supply. The authors also summarized some other micro-econometric studies,

with only positive price elasticities but of very different magnitudes (from 0.2 to 7.7).

A similar concept is used in Raunikaar and Buongiorno (2005) to assess whether non-industrial forest landowners value forest amenities by proxying their implicit values. Results show that landowners are willing, to some extent, to reduce their profits for amenities in south central United States.

Still in this context of joint production, Robert and Stenger (2012) have to be cited, in which the authors consider the potential effects of financial incentives for some public goods or services, with encouraging results in terms of policy implications. Non-timber services are indeed potentially increased with such measures.

A broad picture of the available empirical techniques and alternatives in forestry economics with related critics are to be found in Wear and Parks (1994). In particular, both aggregate supply and harvesting decisions models are reviewed. Empirical studies with closer look at the links between theory and empirical analysis are considered by Kuuluvainen et al. (2003) in a very extensive review of forest analysis.

Concerning amenity values as a direct subject of interest, Kilchling et al. (2009) have to be mentioned as one of the rare Swiss studies, questioning consumers on what they value most importantly in non-timber forest products and assessing the market potential. Results show that quality and environmental friendliness are the most important factors valued by consumers and sellers.

Other considerations

Even though many papers can be classified into one of the last three subsections of supply analysis, there is a significant amount of work that has been done in different areas, not close enough to others to be classified above, but

still sufficiently close to wood supply analysis to deserve being mentioned in this section. The interrelations between forest stands is the main subject in this sub-section, but is not comprehensive as other fields are also explored.

Bowes and Krutilla (1985) considered basic models, such as Faustmann or Hartman, and even the Maximum Sustainable Yield (MSY), with their respective comparative statics. The authors raised a potential disadvantage of the second model, as Hartman himself had pointed out in his paper some years before. Indeed, authors generally agree on the fact that interrelations between forest stands should be taken into account, but this is however not the case in the Hartman model. A couple of years later, Bowes and Krutilla (1989b) summarize their point of view as follows: "Attention to site interdependencies is the key to successful multiple use management of forestlands". In this context, Bowes and Krutilla (1985) considered a somewhat extended model, mainly theoretical, to circumvent this problem and to "focus on the manager's ability to influence the flow of goods and services". Even though it is interesting from a theoretical point of view, interrelations are extremely complex to model empirically, once again mainly because of the considerable needs of many precise information about the forest structure.

Bowes and Krutilla (1989a) put together state-of-the-art knowledge of that time in the field of multiple-use management of forestlands in a very extensive and complete reference book. As stated before, important remarks are also made about the lack of interrelations between forest stands in Faustmann and Hartman models. A general framework is established and important points are raised, but no clear solution or any applicable model is given in order to consider them empirically. As shown below, some authors tried to fill this lack of thorough analysis of stands interrelations in a multiple-stand framework. Nonetheless, a large amount of work still has to be done in this complex field of interest.

In another subject that has received surprisingly only slight attention from economic research, Vincent and Binkley (1993) examine the specialization of forest stand use, through the use of simple graphs, explanations and deductions. They point out the fact that, "as long as returns to management effort do not diminish too rapidly", specialization of stand use would be economically efficient (from a multiple-use management approach). In addition to its conclusions, this paper is interesting as it is, to our knowledge, one of the rare studies having a clear multiple-stand approach. Zhang (2005) revisited Vincent and Binkley (1993) with some slight modifications, relying on a more theoretical model than his predecessors, but with similar conclusions. These support a structure with forest areas where timber production would be intense, with few possibilities, if any, for any other functions, but letting then other forests mostly unharvested and available for all other uses, with of course more specialization within these lands.

Swallow and Wear (1993) is another example considering interactions and interrelations between stands, by "developing a single-stand, multiple-use model that incorporates interactions with surrounding stands." Results show that some dynamics might come out in practice depending on the structure of these relations, losing the constant and stable inter-temporal solution, mainly because of the nature of the relations, which are assumed to involve over time with the growth of trees.

More recently, Koskela and Ollikainen (2001) present an extensive theory on the subject of interdependence between forest stands. They highlight the importance for the rotation age problem of the nature of this interdependence and its behaviour over time, as forest age changes. Their theoretical results examine private as well as public firms.

Although it is important to be aware of these facts, it is above all clear, as

pointed out in the previous section, that when turning to empirical analysis, data availability becomes a strong issue and an important barrier to such models that are most often practically not applicable.

Whereas many recent studies have been carried out in the multiple-use management framework, harvesting decision modelling with other focus were also considerable.

Vokoun et al. (2006) focus on landowner characteristics in the harvesting decision process and its related intensity. Empirical analysis is conducted through discrete choice modelling based on a survey in Virginia. Results show, among others, that urbanization is a crucial factor in the intensity of harvesting (with a negative correlation).

This conclusion is shared by Munn et al. (2002) which specifically model the impact of urbanization and population density on timber harvesting decisions. Causes for such relations can come from different aspects. Urbanization creates forest fragmentation, which is then less efficient and more costly to harvest (even though accessibility is surely improved). Also, landowners might be wealthier than in rural regions, and therefore earnings from wood harvesting is not, or less, needed. This brings us back to Tahvonen and Salo (1999) who explore the utility maximization of the owner and the negative correlation between wealth and harvesting frequency. Finally, as urbanization and population density increase, non-timber functions (mainly the recreational one) are more highly valued.

In all likelihood and as shown theoretically by many authors, wood price is surely a central factor determining harvesting decisions, and most results show that it is the case with a strong and positive relationship. If this fact seems to be barely questionable, the magnitude of the price elasticity is *a priori* unknown. Considering Norwegian farmers and using a tobit model, Bolkesjø and Baardsen (2002) calculate price elasticities for roundwood supply and find them to be be-

tween 0.4 and 1.1 (recall that Pattanayak et al. (2010) present different studies with price elasticities ranging from 0.2 to as much as 7.7).

Conway et al. (2003) examine some specific non-market factors that they consider important in harvesting decisions of non-industrial forest landowners. These concern bequests, nontimber activities and financial status about savings and debt. Empirical evidence of their strong impact is demonstrated for all these factors. For more information on bequest motives, see also Amacher et al. (2002), in which these are the primary focus.

Finally, Swallow et al. (1990), on their side, assess the implications of the convexity assumption of forest benefits (i.e. basically non-decreasing amenity values) and the possible implications in case of violation. The debate is surely still open on whether the convexity assumption might be appropriate, and the same is true for many other assumptions as well. Therefore it highlights the fact that current assumptions made in this field of research are crucial and results might be (and indeed are) strongly sensitive to them.

4.2.1 From theory to empirical modelling

While considerable research have already been done in the context of the forestry industry in terms of supply analysis and price elasticity, they are for the most part theoretical or based on general approximations with aggregate data, and often either neglecting the multifunctionality aspect of forests or missing other important factors such as price. Econometric analysis still exist for numerous markets, but is missing for the Swiss forestry industry and such an analysis can be of significant importance in terms of policy implications, in particular in the current difficult context. Moreover, a particular attention to price has never been given. The problem of multifunctionality is also an important shortcoming in many analysis. Without the intention of solving all problems at once, this

contribution attempts to bring specific insights in those subjects. Moreover, the context in Switzerland which is particular by the fragmentation of its industry with numerous small firms, and extensively rich by the very heterogeneous environments firms face in general.

As already mentioned, the price formation is given a special attention, motivated by the fact that transportation and transaction costs in general are fairly high in the industry, creating a potential source of market power. It is indeed difficult as specific data are required in order to enable proper analysis. It is however a crucial point if one wants to fully understand the forestry industry, and can be valid for other similar hybrid industries, at the frontier between public and private sectors. In short, appropriate econometric models are used to model supply at the firm level in the context of Swiss forest.

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

Supply analysis

The first part of the research estimates a supply function as well as the elasticity of supply, and tests specific hypotheses about the firms' behaviour in the forestry industry. The first hypothesis tested is whether Swiss forestry firms do or do not behave in a profit maximizing manner. From the previous descriptive analysis, there already are 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 still partly for costs reasons, 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 cost diminishes through 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 production of wood.

The supply function is defined as follows:

$$\begin{aligned}
 \ln(Q_{f,t}) = & \beta_{0,f} + \delta_t + \beta_1 \cdot \ln(\text{Price}_{f,t}) + \beta_2 \cdot \ln(\text{Price}_{f,t}) \times \text{Region}_r \\
 & + \beta_3 \cdot \ln(\text{Price}_{f,t}) \times \text{Region}_r \times \ln(\text{area prod.}_{f,t}^{MC}) \\
 & + \beta_4 \cdot \ln(\text{Price}_{f,t}) \times \text{Region}_r \times \text{private} \\
 & + \beta_5 \cdot \ln(\text{area prod.}_{f,t}) + \beta_6 \cdot \ln(\text{area non.}_{f,t}) \\
 & + \beta_7 \cdot \% \text{Outsourcing}_{f,t} + \beta_8 \cdot \text{Subsidies}_{f,t} / \text{Costs}_{f,t} \\
 & + \beta_9 \cdot \% \text{Other costs}_{f,t} + \varepsilon_{f,t} \quad (20)
 \end{aligned}$$

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. $\ln(\text{Price}_{f,t})$ are firm-specific wood prices. $\ln(\text{area prod.}_{f,t})$ and $\ln(\text{area non.}_{f,t})$ are logarithms of productive and

non-productive hectares under management⁴⁴. Interaction 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 $\ln(\text{area prod.}_{f,t}^{MC})$ (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 revenues. $\%Other\ costs_{f,t}$ denotes the % of administrative costs, and finally $\varepsilon_{f,t}$ is the error term⁴⁵.

A few comments should be made about the model. In this exploratory analysis, the issue of potential endogeneity is important. As an example, $\%Outsourcing_{f,t}$ (defined as a ratio between outsourcing and total costs) and $Subsidies_{f,t}/Costs_{f,t}$ are both subject to endogeneity issues due to the construction of these variables. The cost variable is included and depends directly on the dependent variable $Q_{f,t}$. Dropping them from the model could be a solution, or creating dummy variables with certain thresholds. It turns out that the estimation was conducted with all of these alternatives and the estimations are robust to the changes of specification. Except for some minor estimates of interactions, all other estimates do not significantly change from one model to the other. Therefore, it was decided to keep the model as it is. Furthermore, and more importantly, the price variable is also subject to endogeneity issue. This is even more important because the related estimate is central in this analysis. A discussion about endogeneity of price and

⁴⁴Productive areas are by definition all forests fulfilling any type of function, that is from the production of wood to biodiversity preservation or protection.

⁴⁵Beside 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 all supported the conclusions presented below and are not presented here for the sake of simplicity.

the measures taken to deal with it is conducted in section 4.2.2.

Finally, as we can see in the model presented above in equations 19 and 18, the age of trees play an important role as it determines the volume of wood available and is the main driver of growth rate. Unfortunately, this information is missing in the case of the Swiss forestry industry. Nevertheless, when aggregating decisions and assuming fairly uniform age distribution among trees within forests under management, the age at which trees are harvested loses its direct impact as, all else equal, the supply will be sustainable over time. Without this information, the analysis still allows to focus on external factors, such as prices, forest types and environments, as it is performed in this chapter.

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 exist 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 significant and positive influence on price.

Furthermore, everything else being equal, a higher amount of subsidies (in addition to the government covering financial deficits) could also mean that the forestry firms are in general less dependent on revenues from wood. As a consequence, this could increase their potential market power, through the fact that a substantial share of their revenues is earned from non-wood related activities (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, everything else being equal. This is thus our second hypothesis.

The existence of market power is an important question, and also theoretically questions the very existence of a supply function. Indeed, assuming there is market power (as in the special case of a monopoly), the supply function is not a meaningful concept any more. It is therefore interesting to consider this problematic and keep it in mind when interpreting results. Nevertheless, this analysis, and this thesis, is an exploratory work. It is known and understood that drawbacks may exist and that the analysis is based on important hypotheses that might sometimes be questionable. Nonetheless, it is thought to be of valuable interest.

In this context, the following regression model is used:

$$\begin{aligned} \ln(\text{Price}_{f,t}) = & \alpha_{0,f} + \alpha_1 \cdot \ln(\text{Index}_{r,t}) + \alpha_2 \cdot \text{Log}_{f,t} + \alpha_3 \cdot \ln(\text{Demand}_t^{\text{raw}}) \\ & + \alpha_4 \cdot \ln(\text{Imports}_t^{\text{semi}}) + \alpha_5 \cdot \ln(\text{area prod.}_{f,t}^{\text{MC,R}}) \\ & + \alpha_6 \cdot \text{Subsidies}_{f,t} / \text{Costs}_{f,t} + \alpha_7 \cdot \text{Private} + \mu_{f,t} \quad (21) \end{aligned}$$

where $\ln(\text{Index}_t)$ is a regional price index⁴⁶, being considered to be a good measure of the overall economic situation. $\text{Log}_{f,t}$ 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 strictly given, the different environments faced by firms have a significant influence (for example on wood species), which then has a clear importance for prices. $\ln(\text{Demand}_t^{\text{raw}})$ and $\ln(\text{Imports}_t^{\text{semi}})$ denotes the logarithm of raw wood national demand (defined as national supply – exports + import) and imports of semi-finished products in Switzerland, respectively. $\mu_{f,t}$ finally denotes the error terms.

⁴⁶This is the same index presented in table 13 of section 4.3.

4.2.2 Price and endogeneity

Before considering the analysis itself, 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

$$Price_{f,t} = \frac{Revenues_{f,t}}{Quantity_{f,t}} \quad (22)$$

where $Revenues_{f,t}$ are defined by the revenues coming from wood sales and $Quantity_{f,t}$ the amount of m³ harvested during the same period (year). Equivalently, one can write

$$\ln(Price_{f,t}) = \ln(Revenues_{f,t}) - \ln(Quantity_{f,t}). \quad (23)$$

As a first comment, the aggregation of different types of wood in equation 20, 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 are related to the structure of the forest, 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 sufficiently representative.

However, a second concern can be raised with more problematic implications. Taking the logarithm, a simple mechanical problem arises as the dependent variable $\ln(Q_{f,t})$ indirectly appears on the right-hand side of equation 20 (through the use of the price variable, with a negative sign). Along with this sim-

ple 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 4.4. The simultaneous relation between price and quantity in these 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, hurricanes or any other events that could have led 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. The use of instrumental variables does not reduce the endogeneity problem if no proper instruments are found. 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 conclusions about the absolute value of the elasticity. Finally, as a mean to deal with these potential issues, regression with price indices are also presented in order to strengthen the conclusions.

4.3 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 2000 firms. They respond annually and give basic information about their management, such as ownership, costs, revenues, land under management and wood production, among others. This data source is chosen over the Swiss Forestry Pilot Network (TBN) because the number of variables needed for this analysis is fairly small. Nevertheless, the latter data source was also used in order to compare the results.

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 dropping the ones with no production, cost or revenue, 10,822 remain. Table 10 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 10: 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 overwhelming majority of the forestry industry in terms of volume.

Private firms, public firms and regions

From the point of view of their structure, the forestry firms are highly fragmented with a large number of small and very small firms. As seen in chapter 2, 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 has been slowly increasing for a few years now. This might be the consequence of the generally growing awareness that this industry's fragmentation is problematic. Although the average of productive forest area per firm is increasing in all regions of Switzerland⁴⁷, there are still large differences among them on average : 442 ha in Jura, 132 ha in Plateau, and up to 795 ha in the Alps.⁴⁸

Firms are either owned by governments, cantons or smaller districts, public entities (e.g. army), "bourgeoisie" (local institutions) 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 be publicly influenced, 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 the ownership is not evenly distributed over Switzerland. Table 11 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.

⁴⁷Traditionally, 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).

⁴⁸Annuaire La forêt et le bois, 2013.

Table 11: 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

It appears already that there exist some important differences between the private and public firms. For example, private firms are consistency outperforming the public ones in terms of profit per hectare in all regions (significantly, at the median)⁴⁹. However, they do not produce more than public firms in all regions. Whereas they actually do in Jura and the Plateau, public firms produce on the other hand more in the pre-Alps and Alps. The first two regions are in general flatter, making them potentially easier to access 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, it can well be that there exists a certain level of self-selection when private forestry firms are considered. Therefore, although they might indeed be more efficient than public ones, it might also be that the whole environment is significantly more suitable; public forestry firms inherit, by force of circumstances, the less accessible and convenient areas. 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

⁴⁹The differences are also significant when considering the mean, except in the Alps where they are not statistically different.

11 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 might not be (at least fully) related to size and economies of scale, and is to be found elsewhere.

Like the structure of firms and as already mentioned above, the production of wood largely varies by regions. Table 12 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 Jura and Pre-Alps, produce both slightly more than their forest shares.

Table 12: 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 a clear consequence of the heterogeneous environments. The forestry firms produce more or less (per hectare) depending on their region, 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 functions).

As a final word on overall wood production in Switzerland, table 13 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.

Figures on production are extracted 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 wood⁵⁰ 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. They are shown in real terms (based on December 2000).

Table 13: 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 uncorrelated with prices. Although the latter has slightly increased over the 10-year period by a few percentages, the production has meanwhile decreased by almost 10%. It is quite implausible that natural causes, such as the hurricane Lothar in 1999, have had strong impacts on the overall wood production during this period. The explanation is thus to be found somewhere else.

⁵⁰The 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%).

4.4 Results

4.4.1 Supply analysis

In this section, the main determinants of supply in the context of forestry industry are presented, and the estimations of elasticity of supply as well as the differences existing between different firms are presented. A first general comment must however be made. As highlighted in 4.2, many variables might bear a certain level of endogeneity. As a consequence, this would therefore mean that the observations made here might be seen as correlations and not causalities. The discussion of results has been as objective as possible, but the reader should keep in mind that these analyses are exploratory.

Tables 14 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 as well as 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 elasticities 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. Model 4 presents a similar specification to model 3 but using the TBN data source.

The first important observation 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.

Table 14: Supply analysis

Variables	Model 1	Model 2	Model 3	Model 4
$\ln(Q_{f,t})$	FE	FE	FE	FE (TBN)
$\ln(\text{Price}_{f,t})$	-0.304***	-0.216***	-0.248***	-0.073*
$\ln(\text{area prod}_{f,t})$	0.540***	0.669***	0.848***	0.793***
$\ln(\text{area non}_{f,t})$	0.009	0.015	0.010	0.031
$\text{Subsidies}_{f,t}/\text{Costs}_{f,t}$	-0.051	-0.052	-0.044	-0.244**
$\% \text{Outsourcing}_{f,t}$	0.261***	0.257***	0.253***	0.759***
$\% \text{Other costs}_{f,t}$	-0.356***	-0.360***	-0.350***	-0.503
$\ln(\text{Price}_{f,t}) \times \text{Plateau}$		-0.032		
$\ln(\text{Price}_{f,t}) \times \text{Pre-Alps}$		-0.160**		
$\ln(\text{Price}_{f,t}) \times \text{Alps}$		-0.265***		
$\ln(\text{Price}_{f,t}) \times \text{private}$	0.066***			
$\ln(\text{Price}_{f,t}) \times \text{Jura} \times \text{private}$		-0.003		
$\ln(\text{Price}_{f,t}) \times \text{Plateau} \times \text{private}$		-0.009		
$\ln(\text{Price}_{f,t}) \times \text{Pre-Alps} \times \text{private}$		0.161***		
$\ln(\text{Price}_{f,t}) \times \text{Alps} \times \text{private}$		0.195***		
$\ln(\text{Price}_{f,t}) \times \ln(\text{area prod}_{f,t}^{MC})$	0.086***			
$\ln(\text{Price}_{f,t}) \times \text{Jura} \times \ln(\text{area prod}_{f,t}^{MC})$		0.001		
$\ln(\text{Price}_{f,t}) \times \text{Plat.} \times \ln(\text{area prod}_{f,t}^{MC})$		0.034		
$\ln(\text{Price}_{f,t}) \times \text{PreAlps} \times \ln(\text{area prod}_{f,t}^{MC})$		0.046		
$\ln(\text{Price}_{f,t}) \times \text{Alps} \times \ln(\text{area prod}_{f,t}^{MC})$		0.150***		
$\ln(\text{Price}_{f,t}) \times 2004$			-0.084***	
$\ln(\text{Price}_{f,t}) \times 2005$			0.008	
$\ln(\text{Price}_{f,t}) \times 2006$			-0.051	
$\ln(\text{Price}_{f,t}) \times 2007$			-0.008	
$\ln(\text{Price}_{f,t}) \times 2008$			0.026	-0.133*
$\ln(\text{Price}_{f,t}) \times 2009$			0.012	-0.132*
$\ln(\text{Price}_{f,t}) \times 2010$				-0.263***
$\ln(\text{Price}_{f,t}) \times 2011$				-0.086
$\ln(\text{Price}_{f,t}) \times 2012$				-0.194****
$\ln(\text{Price}_{f,t}) \times 2013$				-0.2016***
$\ln(\text{Price}_{f,t}) \times 2014$				-0.141**
<i>N</i>	10822	10822	10822	952
<i>Overall R²</i>	0.153	0.155	0.165	0.192

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

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)⁵¹.

Not simply uncorrelated with market price, 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.

First, region is an important aspect that makes firms behave differently. Firms in a rougher environment, such as in mountainous areas (e.g. the Alps) have a lower elasticity of supply, everything else being equal. This is especially true for the public ones.

Second, the private firms are in general more competitive than public ones in these difficult regions, with differences of 0.161 and 0.195 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 survive financially, in contrast to private firms. Moreover, their sensitivity to non-wood related 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 4.3, it is clear that

⁵¹On 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 been chosen because they cover the whole forestry industry.

the levels of wood production and many other aspects are widely different. Also, it is not improbable to expect that private firms benefit from the best environment in each region and that their differences are therefore not so important.

Table 15: 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

Table 15 shows the elasticity of supply for specific characteristics of firms, that are ownership and regions.

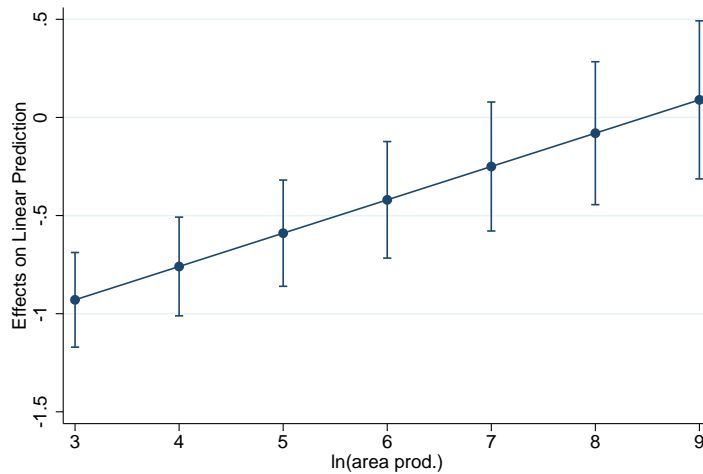


Figure 9: Elasticities of supply at different level of $\ln(\text{area prod.})$ with 95% confidence interval (Alps).

Finally, the interaction between $\ln(\text{Price}_{f,t})$ and $\ln(\text{area prod.}_{f,t}^{MC})$ 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 cost reductions larger when size

increases, or because of an increased concern for the production of wood and its sales, is hard to tell. Figure 9 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 pure target-revenue model, although most of them are undoubtedly above this specific level.

As mentioned earlier, the results of the models 1 to 3 shown in table 14 were challenged with model 4 using the second source of data available for the Swiss forestry industry: the Swiss Forestry Pilot Network (TBN). When comparing these results, two comments must be made. First, the distinction between private and public firms cannot be made since the Pilot Network only includes public firms. Therefore, this is the reason the model using TBN data is similar to model 3 because it does not include private variable. Second, firms are in general substantially bigger than the average in Switzerland in the Pilot Network. Therefore, this might have an impact on the estimates as the data is only representative of big and public firms. In general, overall results do not significantly change between the two data sources. Subsidies seems to have a significant and negative effect on quantities given model 4. However, it must be mentioned that the results using TBN data are a lot more sensitive to the model specification.

4.4.2 A non-competitive market

The observation of a negative price estimate is expected based on preliminary analysis. It is however again important to note that from a theoretical point of view, these negative price elasticities do not directly lead to the conclusion that forestry firms are not acting as profit-maximizers. Indeed, as presented in section 4.2, the dynamics of harvesting over time and the inter-temporal optimization are important and cannot be ignored. Especially, price expectations are decisive from a theoretical point of view. However, as seen above, the needed assumptions for

a profit-maximization behaviour to induce negative price elasticity of supply is in practice not credible for the case of the Swiss forestry industry and can be safely ruled out. Indeed, there exists a substantial evidence leading to the conclusion that forestry firms are not profit maximizers.

Even though theory allows for the possibility that profit-maximization behaviour lead to a negative elasticity of supply, it is under the assumption that forestry firms are behaving at the optimum. Binkley (1993), as mentioned earlier, shows that it could be the case if the optimal rotation age is smaller than the Maximum Sustainable Yield (MSY). And this is in fact the most important aspect. However, the generally old Swiss forests (see section 2.2 for details) strongly rejects this second possibility. In other words, either the optimal rotation age is for some reason significantly longer (in line with the current structure of the forests), ruling out the possible theoretical explanation, or the forestry firms are not at the optimum which similarly rejects the competitive behaviour.

To summarize from the theoretical point of view, the observation of a negative elasticity of supply seems to strongly reject the hypothesis of competitive behaviour and profit maximisation with respect to wood supply. Given the above-mentioned arguments, a positive elasticity of supply is a necessary (but not sufficient) condition for a profit maximization behaviour. By rejecting the hypothesis that the elasticity is positive, so is the hypothesis such that the forestry firms are maximizing their profits. In short, the results show a behaviour that is going in another direction with different objectives (as seen in section 4.2).

The interpretation of a negative price elasticity of supply might be questionable. Assuming the market is not competitive and forestry firms are not acting as profit maximizers, the concept of price elasticity of supply might lose its value to describe a supply side which is not driven by usual forces such as price. In such cases, the price elasticity of supply does not, so to speak, exist any more. At the

end, going back to the original test, the competitive hypothesis has been rejected, and going a lot further in the interpretation of the results could be questionable. A discussion is nonetheless open, keeping this caveat in mind.

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 extractable from the Swiss forests. Every year, standing wood is growing by around 1.6 millions m³ due to a lack of harvesting, as mentioned in section 4.1.

In addition, no financial incentives exist for public forestry firms to seek profits. Their deficits are covered by public authorities. Traditionally, the latter are 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. Assuming that the costs of the firms are mostly invariant over time, the firms would try to reach a certain level of revenues, leading to a target revenue behaviour.

Finally, the multifunctionality 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 wood⁵². It is clear that the current political decisions in terms of multifunctionality of the forests with goals for the next 10 to 25 years have contributed to the current situation. Whereas no judgement is made on the current policies, this analysis highlights the frictions

⁵²In 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 (protection, wood production and ecological preservation) as well as on the value-added chain of the whole wood market (from the tree to the final products).

existing in the forestry industry in terms of wood supply. Although the firms might 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 forests *per se*. Although the Swiss forests are currently underexploited, only 22% of Swiss people think that it should indeed be more intensively managed⁵³. 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.

The results of non-competitive market could be explained by the current overall situation in terms of multifunctionality 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, 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 regarding other public services.

Non-wood related functions, and their implicit values, are important factors that affect the production of wood, either through regulations or public pressure. In any case, the seemingly high implicit value of the non-wood related functions makes 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 simple consequence of a need for external revenues. That is, the economic activity of

⁵³Based on a survey on socio-cultural aspects of forest monitoring in Switzerland (WaMos, OFEV, 2010).

wood production and sales is set aside by the multifunctionality of forests.

All this still does not mean that the current situation is inappropriate or strongly inefficient overall. It has the benefit of making the wood production greener than in many other places, as non-wood related considerations in general are properly taken into account. The environmental cost is therefore lower. Unfortunately this is not reflected economically in prices. It should somehow be transferred into the market, ideally through a price difference relative 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 m³ sold) could also be an 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 is no evidence of any real incentives for a significant improvement in terms of cost efficiency. The analysis of Bürgi and Pauli (2013) carried out in this context confirms that there are indeed costs problems. This was explored in chapter 3.

Putting it all together, findings are coherent. The true elasticity of supply (and even its very existence) is hard to assess as various models predict different levels. The non-competitive market seem however to be unambiguous. The previous arguments and considerations have also all led to the conclusion that forestry firms are not profit-maximizers. As a matter of fact, there undoubtedly exist other considerations that are of bigger importance than the production of wood in the forestry industry. The many restrictions influencing 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-wood related functions are considerable. At the end, the price to pay in terms of efficiency and more generally in terms of profitability of the firms could be small compared to the related benefit.

4.4.3 Formation of price and market power

In this part of the chapter, the objective is to assess the level of market power held by forestry firms. The forestry sector constitutes a highly fragmented industry, arguably even with a certain level of oligopoly on the demand side, 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 could be generally small. Indeed, wood is heavy and its price per m^3 is in comparison small, making the transportation costs a non-negligible part of the overall costs for both the forestry firm and the sawmill. This means that the forestry industry could, locally, hold some bargaining power with respect to neighboring sawmills depending on their relative size.

Specifically, the determinants of price are estimated and some hypotheses about market power are tested. That is, it is expected that size could have a 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 firms' revenues. In this context, the dependency of firms on 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 21) is again presented below:

$$\begin{aligned} \ln(\text{Price}_{f,t}) = & \alpha_{0,f} + \alpha_1 \cdot \ln(\text{Index}_{r,t}) + \alpha_2 \cdot \text{Log}_{f,t} + \alpha_3 \cdot \ln(\text{Demand}_t^{\text{raw}}) \\ & + \alpha_4 \cdot \ln(\text{Imports}_t^{\text{semi}}) + \alpha_5 \cdot \ln(\text{area prod.}_{f,t}^{\text{MC,R}}) \\ & + \alpha_6 \cdot \text{Subsidies}_{f,t} / \text{Costs}_{f,t} + \alpha_7 \cdot \text{Private} + \mu_{f,t} \end{aligned}$$

The first variables control respectively for economic environment ($\ln(\text{Index}_{r,t})$) and the type of wood sold ($\text{Log}_{f,t}$). Also, $\ln(\text{Demand}_t^{\text{raw}})$ and $\ln(\text{Imports}_t^{\text{semi}})$ are introduced to further consider the economic environment, as well as the demand side of the national market⁵⁴. Then, the proxy for the firm's size, namely $\ln(\text{area prod.}_{f,t}^{\text{MC,R}})$, 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, everything else being equal. As a second measure to test for market power, the coverage of costs by subsidies is used, denoted $\text{Subsidies}_{f,t} / \text{Costs}_{f,t}$. 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 16 presents the results of panel data models. The method is denoted by (CRE) for correlated random-effects. Note that because there are several variables that only vary through time, year dummies had to be excluded from the model.

⁵⁴The same comments regarding potential endogeneity issues can be made for the last two variables of $\ln(\text{Demand}_t^{\text{raw}})$ and $\ln(\text{Imports}_t^{\text{semi}})$. Again, dropping them from the model does not significantly change most of the estimates and does not overall create any substantial difference that could lead to any other interpretation. Therefore they are let as control variables.

Table 16: Price formation and market power

Variables	Model 1	Model 2	Model 3	Model 4
$\ln(\text{Price}_{f,t})$	(CRE)	(CRE)	(CRE)	(TBN)
$\ln(\text{Index}_{r,t})$	0.812***	1.152***	0.810***	0.465
$\ln(\text{Demand}_t^{\text{raw}})$	-0.358*		-0.322	
$\ln(\text{Imports}_t^{\text{semi}})$	0.240**		0.239**	
$\% \text{Log}_{f,t}$	0.345***	0.344***	0.344***	0.472***
<i>Private</i>	-0.561	-0.000	-0.000	
$\text{Subsidies}_{f,t}/\text{Costs}_{f,t}$	-0.209***	-0.207***		-0.046
$\text{Sub}_{f,t}/\text{Costs}_{f,t} \times \text{Private}$	-0.007	-0.009		
$\text{Jura} \times \% \text{Sub}_{f,t}/\text{Costs}_{f,t}$			-0.273***	
$\text{Plateau} \times \% \text{Sub}_{f,t}/\text{Costs}_{f,t}$			-0.167***	
$\text{Pre-Alps} \times \% \text{Sub}_{f,t}/\text{Costs}_{f,t}$			-0.143***	
$\text{Alps} \times \% \text{Sub}_{f,t}/\text{Costs}_{f,t}$			-0.438***	
$\ln(\text{area}_{f,t}^{\text{MC},M})$	0.103***	0.103***		0.063*
$\ln(\text{area}_{f,t}^{\text{MC},M}) \times \text{Private}$	0.051**	0.051**		
$\text{Jura} \times \ln(\text{area}_{f,t}^{\text{MC},M})$			0.067***	
$\text{Plateau} \times \ln(\text{area}_{f,t}^{\text{MC},M})$			0.111***	
$\text{Pre-Alps} \times \ln(\text{area}_{f,t}^{\text{MC},M})$			0.141***	
$\text{Alps} \times \ln(\text{area}_{f,t}^{\text{MC},M})$			0.171***	
<i>Plateau</i>	0.107***	0.098***	0.251	0.109*
<i>Pre-Alps</i>	-0.199***	-0.231***	-0.331	0.008
<i>Alps</i>	-0.413***	-0.462***	-1.157	-0.327***
Constant	1.120	-1.417	0.745	1.923
<i>N</i>	10822	10822	10822	952
<i>Overall R²</i>	0.160	0.160	0.165	0.098

$\text{Subsidies}_{f,t}$ and $\ln(\text{area prod}_{f,t}^{\text{MC},R})$ are shortened by $\text{Sub}_{f,t}$ and $\ln(\text{area}_{f,t}^{\text{MC},R})$.

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

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

Also, the domestic 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 a price-quantity relation and even more in such a 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, everything else being equal, a higher demand for such products as well as raw material (in this case, raw wood).

Model 2 is similar to model 1 besides the fact that year dummies were added. Therefore, domestic demand and imports are excluded from the model (both variables have only one observation per year). Model 4, on the other hand, is the only model using the Swiss Forestry Pilot Network (TBN) and not the Swiss Forestry Statistics as the others. The goal is to compare the results between the two data sources. As mentioned in 4.4.1, the firms included in the TBN data source are more representative of large and public firms, although all sizes are represented. Still, this might have some impact on the different estimates and one should be aware of these differences when comparing results. Also, this is the reason to drop the private variable from model 4.

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, meaning that, everything else being equal, a higher amount of subsidies does not allow firms to have a bargaining power in the price negotiation. They even accept lower prices, either because a higher part of their revenues is guaranteed and therefore they need less revenues, everything else being equal, or as a consequence of some other factor. More probably, it might come from an indirect effect. Subsidies are given to forestry firms for specific tasks. Therefore, a higher percentage of subsidies means that a larger portion of the work done by firms comes from external mandates and not only for economic activities. In those cases, wood production becomes a by-product and not an end in itself, and thus its quality is not considered when harvested. It can then be safe to argue that in general, the trees cut for protection purposes or for other public functions are worth less than the ones cut for the sole economic activities. This means that it must be sold cheaper.

As for the TBN data, no significant relation can be shown in model 4 between subsidies and price level. The interpretation is however difficult, because this might simply come from the fact that most of the effect explained above is concentrated in relatively smaller firms.

The second part of the market power hypothesis is focused on size. Whereas the same models using fixed-effects could not reveal any market power, it is not the case when using (correlated) random-effects. It is important here to note that $\ln(\text{area prod}_{f,t})$ mostly varies 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 value⁵⁵. Indeed, the estimate of the size proxy is positive and significant, although fairly small, when random effects are used instead of fixed effects.

⁵⁵Although Hausman test suggests that fixed-effects should be used, estimations with correlated random-effects are in general very similar to the fixed-effects models: the main differences lie in the size proxy.

Models 1 and 2 focus on the differences existing between public and private firms. We can see from the results first that private firms seem not to be able to sell their wood at a higher price, as the private estimate is always insignificant. However, there seem to be a small difference lying in the effect of size. Indeed, the interaction between the private dummy and $\ln(\text{area}_{f,t}^{MC,R})$ is positive and significant, at 0.051, giving a total size effect for private firms at 0.154, slightly higher than for public ones (0.103). This means that bigger private firms could benefit from a higher level of market power, and therefore selling their wood at a higher price.

In models 3, 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 the other hand, the pre-Alps and Alps are the regions in which size has the biggest effect, with 0.141 and 0.171, respectively. According to the empirical estimations, the market power therefore seems to be higher in mountainous area (i.e. rougher environment), and be held to a greater extent by private firms.

In general, these results should still be taken with caution. The heterogeneity among the firms, the regions, and the different types of forests under management, is tremendous, even in the small country of Switzerland. Therefore, especially when considering the different regions separately, the interpretation of the estimates should not lose sight of this strong unobserved heterogeneity which might still slightly impact the different results.

When focusing on market power, the intuition behind it could be that the transportation costs are relatively important compared to the wood price itself. Therefore, this would create regional markets in which forestry firms might influence the price when dealing with sawmills, as these do not have many choices

as to the provenance of their wood. However, structural differences could also explain all or part of this market power. Sawmills could be more inclined to pay a higher price to forestry firms when these are able to deliver substantial amount of wood at a time. In this case, transportation and administrative costs are lower for both the sawmills and the forestry firms, since the delivery of wood can be rationalize and the number of transactions is lower, making the transaction more profitable for both parties even with a higher wood price.

4.5 Conclusion

This chapter'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 multifunctionality 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 chapter does not explicitly consider the whole spectrum of non-wood related 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 us 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 evidence suggests that, whereas subsidies have a negative effect on prices, 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 hold, or simple use, 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.

4.6 Appendix A

In order to corroborate the results presented in section 4.2.1, two alternative specifications are used. First, instrumental variables are used in order to deal with potential endogeneity of price introduced in section 4.2.2. Second, the price variable (constructed by revenues over quantity, therefore potentially endogenous) is substituted by the price index used in the price formation analysis. It is 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, in all others the coefficient is 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 definite conclusion⁵⁶.

Turning to the 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 dramatically⁵⁷.

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 14, the sign is unambiguous and this 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.

⁵⁶Out of the numerous instruments and specification used, only one turned out to be positive, significant and not rejected by the Sargan test. In light of all the preceding evidence, it is considered to be a type II error.

⁵⁷The energy wood index (with non-significant estimates) is not shown here for simplicity.

Table A.1: Instrumental variables

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
$\ln(Q_{f,t})$	(FE)	(FE)	(RE)	(RE)	(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***
<i>Private</i>			-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
<i>Plateau</i>			0.572***	0.563***	0.569***
<i>Pre-Alps</i>			-0.265***	-0.258***	-0.262***
<i>Alps</i>			-1.877***	-1.850***	-1.866***
Constant			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	Model 2	Model 3	Model 4	Model 5	Model 6
$\ln(Q_{f,t})$	(FE)	(FE)	(FE)	(RE)	(RE)	(RE)
$\ln(\text{Price Index}_t)$	-1.224***			-1.105***		
$\ln(\text{Price Log}_t)$		-2.677***			-2.645***	
$\ln(\text{Price Indus.}_t)$			-0.531**			-0.429**
$\ln(\text{area prod}_{f,t})$	0.826***	0.810***	0.836***	0.990***	0.989***	0.991***
$\ln(\text{area non}_{f,t})$	0.016	0.019	0.015	-0.034***	-0.033***	-0.034***
$\text{Sub}_{f,t}/\text{Costs}_{f,t}$	0.007	0.005	0.009	0.016	0.014	0.018
$\% \text{Outsourcing}_{f,t}$	0.254***	0.255***	0.256***	0.219***	0.219***	0.219***
$\% \text{Other costs}_{f,t}$	-0.336***	-0.338***	-0.336***	0.119*	0.117*	0.119*
<i>Private</i>				-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
<i>Plateau</i>				0.490***	0.600***	0.408***
<i>Pre-Alps</i>				-0.022	0.018	-0.166***
<i>Alps</i>				-1.313***	-1.206***	-1.511***
Constant				7.383***	14.609***	4.458***

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

5 Analysis of behaviour in a multifunctional context

Abstract

This chapter considers the multifunctionality of the Swiss forests by estimating a restricted revenue function allowing to calculate the implicit value of the non-wood and non-marketable functions, using the data collected by the Swiss Forestry Pilot Network (TBN). Results show that protective areas exhibit positive implicit value. In contrast, recreation and biodiversity do not show any significant results, meaning the associated constraints on their side are mostly insignificant. Nonetheless, biodiversity is part of the priorities of the Swiss National Forest Program, and related incentives, especially in financial terms, could surely be questioned in order to find better solutions and meet environmental objectives.

5.1 Introduction

The Swiss forestry industry has been shaped by a long history of sustainability and development in close union with nature. As a first step, law forbidding clear-cutting all over the country exists since 1876⁵⁸. This measure, including the principle of durability, was a small revolution at that time⁵⁹. A significant reason for this enforcement was the concept of sustainability and the importance given to the idea that each generation should be able to have its fair share of natural resources. As a consequence, the forestry firms now manage forestlands not only by focusing on the production of timber, but also by taking into account the many non-wood related functions that are extremely valuable for our society yet non-marketable. As mentioned in the general introduction, the Swiss forestry industry is influenced by both aspects of the private sector on one side (wood harvesting) and the public sector on the other (with the long list of public services fulfilled by forests through the activity of forestry firms).

In practice, it is clear that non-wood related functions are extremely important (such as protection against landslide, biodiversity or water purification). As an example, Rauch-Schwegler (1994) has estimated that Swiss forests add value for as much as CHF 9 billions, whereas timber would only account for 5% of the total. These non-wood related functions induce restrictions in many ways, but especially in terms of wood production, because of forestlands fully or partly devoted to non-timber functions⁶⁰ (thus imposing a limitation to timber output). These regulatory or self-imposed restrictions are associated to wood production, as well as to non-timber goods and services (road maintenance, protection, environmental and recreational functions, etc.).

⁵⁸ Archives fédérales suisses. "Feuille fédérale n. 17 du 29 avril 1876".

⁵⁹ Press release from May 29, 2001, OFEV. "125 ans de loi forestière: un succès durable".

⁶⁰ Note that it is fairly rare that a specific forestland only fulfil one precise function, except the protective areas, and to some extent only.

The objective of this chapter is to analyse the Swiss forestry industry in light of the somewhat pervasive multifunctional environment. As many of the forest functions are non-marketable, the analysis uses the concept of shadow price, which can be defined as the monetary value of a non-marketable good or service, or implicit value. From a more technical point of view as applied to this chapter, it represents, for a forest function, the change of revenues for the forestry firms when the constraint related to it is relaxed by one unit. This chapter is therefore an attempt at estimating this implicit (or monetary) value associated with each of the main non-wood related functions by forestry firms, using econometric methods.

It is undeniable that multifunctionality of forests and the services they provide have both a direct and an indirect cost. First of all, the activity associated to the different functions, whatever they are, is costly, both in terms of capital and labour. Second, in this multifunctional environment where the different functions are highly intermingled with one another, focusing on one type of service implicitly means that the others will be somehow impacted. In other words, the functions being mostly incompatible with one another, choosing one means at least partly sacrificing the others. A question raised by FOEN (2014b) is how to be able to compensate the forestry industry and its firms for their work and the services they provide to the society. To answer this question, it is important to understand and take into account the trade-off forestry firms are facing.

Beyond the market boundaries, it is also very interesting to put these numbers into perspective by taking the point of view of the society and the population which value their forests and the services they provide. Pearce (2001) gathers results of empirical studies showing the direct and indirect use values along with the option and existence values (i.e. non-use). The results are of course very heterogeneous and depend as expected on regions of the world but there is a general

consensus for strictly positive values. In Switzerland, recent studies shows that Swiss population values biodiversity and protection the most, way ahead of the wood production and recreation function (Borzykowski et al., 2015). Whereas the biodiversity and protection functions seem to be at the center of their considerations, what about the supply side? What is the implicit values associated to these functions for the forestry firms? This is definitely a crucial question, which gives a first reason for the estimation of the implicit values given to these non-wood related functions by forestry firms.

From the perspectives of the forestry industry and their constraints, along with the demand side and the valuation of the services by the population, the implications in terms of what should or should not be attempted can then be discussed.

When looking closely at the Swiss policy landscape, the majority of subsidies granted in Switzerland is spent for protection functions, either through maintenance of protective forest or construction of protective infrastructure⁶¹. At the same time, subsidies for biodiversity accounted for 10 times less in 2013 (FOEN, 2014).

The Forest Policy 2020 has established five objectives for the Swiss forests that are considered as priorities. Out of them, biodiversity is cited as an important aspect for policy makers, and so is the protection function. However, when looking at figures, financial support for protection is far more important than for biodiversity. Whereas it is difficult to directly compare them without further investigation, it is clear that subsidies play an important role in the decision making process, and that they can be used as incentives to reach a certain policy

⁶¹The Confederation pays subsidies for protective services against natural events such as avalanches, landslides or rockfalls. Protective forests are defined at the federal level and in return for these subsidies, forestry firms are responsible for managing these forests such that their main function remain guaranteed.

objective⁶². As a matter of fact, beside subsidies that are often coming alongside restrictions and obligations (e.g. protective areas), the only leverage left is the own will of forestry firms to impose internal restrictions for the benefits of one or more specific functions.

The forestry firms and its industry form a complex economic environment, mixing both public and private characteristics. Because of the behaviour observed following some other objectives than the pure profit maximization behaviour (see chapter 4), a restricted revenue function, instead of a profit function, is estimated using the forests areas (in hectares) for each type of non-wood related functions.

There are several research questions this chapter attempts to answer in this heterogeneous and multifunctional environment using the estimation of the shadow values of the different forest areas (protection, biodiversity and recreation). First, given the definition of the shadow prices, it allows to assess whether or not the forest functions impose significant constraints on forestry firms. Moreover, with these estimates, it enables the evaluation, in monetary terms, of the costs of constraints imposed by these functions, which could for example then be used in a cost-benefit analysis. It also enables to compare shadow prices across to get a better understanding of the different constraints faced by forestry firms.

Second, the shadow prices somehow represent the value of the different functions from the supply side view point. On the other side of the market, the demand side expresses preferences for two functions (protection and biodiversity, as mentioned above) over the others. Given the estimations of the shadow prices, are those numbers matching each other? In other words, do the shadow prices reflect the ranks, or degree of importance, given by the demand side for each

⁶²It is understood that biodiversity is best preserved when there's as little external intervention as possible, but this has, for the area under consideration, significant opportunity costs that should not be underestimated.

function, relative to each other? The forestry industry being both public and private under different aspects, the intervention of the government should not be underestimated or neglected. The subsidies play a major role as the industry could not otherwise fulfil the entire range of its obligations with respect to society. Therefore, if the estimates from the supply side do not match those from the demand side (in terms of ranking, as the absolute values are extremely difficult to compare), it could be possible to change them by using financial incentives.

Finally, as it has been shown in chapter 4, Swiss forestry firms do not exhibit usual profit maximizing behaviour. Using this analysis, an objective is also to understand what drives the choices of the firms and what are their own internal and external restrictions.

5.2 Related work and theoretical framework

5.2.1 Theory of the production function and the shadow prices

The theoretical subject of profit functions is a well-known theme in economics, being extensively covered, with a significant part devoted to restricted profit function⁶³. In general, it also refers to cost minimization and revenue maximization which are both only very special restricted profit functions where either all outputs or all inputs are restricted, respectively. As a general overview, several books present the production theory with the restricted and unrestricted profit (and revenue) functions, such as Chambers (1988) or Coelli (2005). On a more applied level, Lusk et al. (1999) describes the different empirical properties of the duality theory in the context of both restricted and unrestricted profit functions, while Chambers (1988) describes the different perspectives of its possible applications in production analysis.

Contributions linking theory to practice and empirical analysis also include Bergman (1997), describing the different properties that flexible forms should exhibit in order to theoretically and properly represent a restricted profit function. As an illustration, the author shows practical examples using a generalized Leontief and the translog functional forms. Duality theory and subsequent applications in the context of multi-output production are also presented in Färe and Primont (1995).

Due to its flexibility and interest in many cases of the economic analysis, the utilization of shadow prices has been extremely wide in terms of field of research as well as in terms of methodologies. Recent examples of applications include pricing of the ecosystem services through their contribution to GDP (Richmond et al., 2007), the analysis of surgical procedures in Malta (Borg, 2007) or the

⁶³It was first characterized by Lau (1976), after applying duality approach and describing the different assumptions.

impact of hydro–wind coordination (Ilak et al., 2015). Often the estimation of shadow prices is paired with the measure of efficiency in various fields such as paper recycling in Vietnam (Van Ha, 2007), carbon dioxide emissions in the Chinese manufacturing industries (Lee and Zhang, 2012) or vegetable farming in Uzbekistan (Karimov, 2013). The evaluation of projects in the public sector has been given some attention using shadow prices, such as Campbell (1981) or Drèze and Stern (1990). On their side, Sato and Matsumura (2017) analysed the shadow cost of public funds in the case of privatization of public firms. Zhou et al. (2014) reviews the literature using shadow prices for undesirable outputs along with efficiency measurements. Although the analysis presented in this chapter does not consider undesirable outputs (such as carbon dioxide emissions or other types of waste) and on the contrary analyses desirable non-marketable services, the basic structure of the analysis remains the same.

The combination of public and private services is an important topic of this chapter and also the cause of the use of shadow prices. In very different fields, there have been similar analysis applied to a hybrid sector (lying in-between public and private). A theoretical discussion on the shadow prices of public and private sectors can be found in Gersovitz et al. (1982). More recently, Shobayashi et al. (2003) discuss the different evaluation methods and suggest the use of shadow pricing in the case of public goods and services. As a empirical example, Romstad (2010) used a similar method in the analysis of rural land management.

As already mentioned, the Swiss forestry industry is a hybrid sector with public and private characteristics. One of the latest example of analysis in such a specific sector is Küfeoğlu et al. (2018) who analysed the Finland electricity distribution and estimated the implicit cost of electric power interruptions using shadow prices.

5.2.2 Forestry applications and link to existing literature

First empirical applications in the forestry sector were published in the second half of the XXth century. Oddly, it coincides fairly well with the general enforcement of laws and regulations worldwide protecting the multifunctionality aspects of forests. Among important contributions, Brännlund et al. (1985) were among the first to use econometric analysis for sawtimber and pulpwood and Wear and Parks (1994) review methods available for the analysis of the multi-outputs specification needed in the context of the forestry industry. Restricted profit functions and shadow prices have been estimated at different steps in the life cycle of wood. Murray (1995) creates a restricted profit function and estimates shadow prices for the pulpwood and sawlogs markets, in order to measure the level of oligopsony power. The Norwegian sawmilling industry was also analysed using the same procedures in Baardsen (2003) with estimations of the short-run supply and demand functions as well as returns to scale. However, the multifunctionality aspects were not important in this paper, as the forestry industry was not the focus. Boltz et al. (2002) used shadow pricing to estimate the value of diversity in the U.S. national forests, by focusing only on impacts of diversity on wood sales and not explicitly taking the multifunctional environment into account. Newman and Wear (1993) also used a restricted profit function to identify the differences between industrial and nonindustrial owners in the 80s in the United States of America. They assumed that the estimated gap between the two groups was due to a different evaluation of the standing forests. Unfortunately, no real value for standing forests was estimated, only relative ones between industrial and nonindustrial owners.

On the other side of the Atlantic, Górriz-Mifsud et al. (2016) have assessed the value of ecosystem services in Mediterranean forest by evaluating upper and lower boundaries for them: the willingness-to-pay of society, and the opportunity

costs of a change in forest management for the industry by creating different scenarios. The different scenarios were focusing on three different aspects, that are biodiversity, fire prevention and timber (as well as second and third together). Then, the impact was estimated based on hypotheses of a change in management. It appears that the overall question raised here is fairly close to the one addressed in this chapter. However, the methodology is completely different. The analyses were done through global estimates based on general statistics, while the present chapter uses regression analysis to assess the value, for each forestry firm, of the different functions that can be evaluated given our available data.

In practice, the specification in this chapter is very close to Baardsen (2003), although the objective draws nearer to Górriz-Mifsud et al. (2016), by focusing on the very first level of the wood and wood-derived industries: the forest and its multifunctionality. To the best of my knowledge, this has never been accomplished through regression analysis, and especially not in Switzerland.

5.2.3 Theoretical background and econometric model

We start from the simple profit maximization problem of firms. Formally, the profit function $\Pi(\cdot)$ is given by :

$$\Pi(p, w) = \max_x [p \cdot f(x) - w \cdot x] \quad (24)$$

with $f(\cdot)$ being the production function, p the prices of outputs, x the variable outputs and w its prices. In the simple case of unrestricted profit function, these variables are the only ones that matter. As we are solving for x in the maximization problem, the profit function does not depend on them, but rather on the prices of inputs and outputs only.

We can then extend this to the case of a restricted profit function, where some

inputs and or outputs are considered as fixed (either because of some sort of regulation or in a short-term analysis, suggesting that firms are not fully capable to adjust to changes instantaneously). With this new consideration, we now have the following maximization problem :

$$\begin{aligned} \Pi(p, w, V, U) &= \max_x [p \cdot f(x, V, U) - w \cdot x] \\ \text{s.t. } &V_i = V_{0,i} \\ &U_i \geq U_{0,i} \end{aligned} \tag{25}$$

with, in addition to output prices p , variable inputs x and their prices w , V is defined as fixed inputs and U as fixed outputs. Relating this to the case of the forestry industry, the vector U is of special interest as it combines all the non-marketable services the forestry firms are responsible for, in one way or another. Explicitly taking it into account in the maximization problem allows then to assess their value from the firm's perspective using the estimation of shadow prices. On the other hand, the price p refers to the private service provided by the forestry industry, namely the production of wood.

Usual assumptions apply to the production set so that we can apply the Hotelling Lemma (non-empty, closed and convex set, free disposability of variable netputs and boundedness). For the purpose of this analysis, these are assumed to hold. Complete mathematical developments and extended theoretical discussions about assumptions can be found in Chambers (1988) or Coelli et al. (2005) but will not be discussed further here.

For such a model to be applicable in the case of the Swiss forestry industry, some more general and less mathematically-oriented assumptions must be made. First, prices must be exogenously given. This has been discussed and estimated in chapter 4, showing some market power for the bigger firms in the Swiss forestry industry. It can be therefore discussed whether or not this assumption is

defendable. Nevertheless, it must be reminded that the magnitudes estimated are fairly low and only concerns a minority of firms (the bigger and private ones). Therefore, for the purpose of this analysis, this assumption is supposed to hold. In addition to the exogeneity of prices, another assumption is as important. The outputs, or in other words the different public functions with the areas under management as proxies, should as well be exogenous. Whereas it is true for the protection function which is defined at a federal level, the other outputs (wood production, recreation and biodiversity) might be more problematic. They are defined by the forestry firms themselves. Therefore, it can create distortions and the outputs might therefore not be exogenous. However, there are no alternative to these proxies for the public functions, thus the assumption is considered to hold, assuming the guidelines given to the forestry firms were good enough for the latter to create homogeneous proxies. Nonetheless, one should always keep this in mind when analysing the results.

The second assumption is that forestry firms are actually profit maximizers. Evidence was fairly strong against this assumption in chapter 4. Therefore, to be consistent with theory, it was chosen to use a restricted revenue function in order to reflect the different restrictions on revenues (respectively profit) function, imposed both by regulation and by the firms themselves. Therefore, the model switches from a profit-maximization assumption to a revenue-maximization assumption given the constraints, which is a more reasonable model in the case of the forestry industry, and which then allows for the estimation of shadow prices. Therefore, the equation 25 becomes, with the new revenue function $R(\cdot)$:

$$\begin{aligned}
 R(p, V, U) &= \max_x [p \cdot f(x, V, U)] \\
 s.t. \quad &V_i = V_{0,i} \\
 s.t. \quad &U_i \geq U_{0,i}
 \end{aligned} \tag{26}$$

The vector w now disappears as the prices of variable inputs are not considered in the revenue function (as they are only part of the cost function). However, both the fixed inputs and outputs V and U remain as they are part of the production function (restricting the production possibility set) and therefore also part of the solution to the maximization problem, as shown in Coelli et al. (2005).

Also, it is interesting to note that the revenue function is nothing else than a special case of the restricted profit function where all the inputs are considered fixed⁶⁴. Focusing on the revenue function, the intuition is the following: assuming all inputs are fixed, the cost function becomes a constant which is then irrelevant for the maximization problem, and therefore only the revenue part of the profit function remains. The inverse is true for the cost function with all outputs being fixed (and the revenue function becoming a constant). This might create a consistency issue with chapter 3 where a cost function was estimated. However, this chapter was a long term analysis, whereas this one is more of a short term one. Moreover, the supply analysis of chapter 4 suggested non-competitive behaviour of the forestry industry. As a consequence, the assumption of revenue maximization is the best possible alternative to the profit maximization assumption, although it is still not optimal. As already mentioned, one should be well aware of this potential flaw when interpreting the results of this exploratory analysis.

Similarly to the cost function in section 3.2, this revenue function has a set of important properties (Chambers, 1988):

- (a) Nonnegativity : $R(p, V, U) > 0$,
- (b) Nondecreasing in p : $p' > p$, then $R(p', V, U) > R(p, V, U)$,
- (c) Linearly homogeneous in p : $t > 0$, then $R(tp, V, U) = tR(p, V, U)$,

⁶⁴Coelli et al. (2005) states it very well (p. 39) : "... the cost function is (the negative of) a profit function corresponding to the case where all outputs are fixed; and the revenue function is a restricted profit function where all inputs are fixed".

- (d) Convex and continuous in p ,
- (e) Nondecreasing in $V : V' > V$, then $R(p, V', U) > R(p, V, U)$.

In general, these properties are all self-explanatory. In words, the convexity property of (d) states the following. When the prices of variable outputs moves from p to p' , the old set of variable outputs y (best response to p) is still feasible. Yet, if the firm chooses to move to a new set of variables outputs y' , then necessarily, the revenue will increase when moving from y to y' . Therefore, for any p , the tangent plane to $R(p, V, U)$ at p is therefore a minimum for the revenue function. As a consequence, the latter is locally convex. Since it is true for all p , the revenue function must be convex.

As a side note, assuming that there exists one or more variable inputs x , the function $f(\cdot)$ must have special characteristics with respect to x ⁶⁵. Otherwise, x could very easily tend to infinity. As an alternative, it would be necessary, in order to have a finite solution, to add some further constraints on inputs, which would then violate the initial assumption that there exists variable inputs.

Finally, as mentioned in chapter 4, the maximization problem faced by forestry firms is intertemporal. The decision of harvesting at one point will have an impact on future harvesting possibilities. Therefore, we can generalize the equation 26 to incorporate this process of intertemporal choice :

$$\begin{aligned}
 R(p, V, U) &= \max_{x,t} \sum_{j=1}^{\infty} [e^{-jrt} \cdot p \cdot f(t, x, V, U)] = \max_{x,t} \frac{[p \cdot f(t, x, V, U)] \cdot e^{-rt}}{1 - e^{-rt}} \\
 &\quad s.t. \quad V_i = V_{0,i} \\
 &\quad s.t. \quad U_i \geq U_{0,i}
 \end{aligned} \tag{27}$$

The result of the optimization is similar to the profit-maximization problem discussed in section 4.2, as it is basically a simplification where costs are not

⁶⁵Specifically, since we do not consider the cost function, the return to scale should become non-positive at some point.

included. Therefore it is not further discussed here. However, an important difference here lies in the fact that price is nothing else than a constant associated with the maximization problem. Therefore, also following the theoretical properties of the revenue function, there must be, by construction, linear homogeneity in prices.

By applying Hotelling Lemma, we can find the shadow prices⁶⁶, from the firm's perspective, of the different public services approximated by the different types of forest. It is given by:

$$\rho_i = \frac{\partial R(p, V, U)}{\partial U_i} \quad (28)$$

Mathematically, it is also interesting to note that the shadow price is given here by the constraint multiplier from the maximization problem.

Translating the theory into econometrics, the specification of the regression model is chosen to be the translog for several reasons. First, it gives a rather simple model that can be easily estimated, and more importantly, given some constraints that are presented below, is in agreement with duality theory and the properties of the profit function, respectively the revenue function⁶⁷. Second, on a more practical level, the fact that many forestry firms have negative profits is an additional reason for choosing the revenue function as it could be a problem for the estimation of the profit function using translog. For presentation simplicity, both fixed inputs and outputs U and V are aggregated into one vector Z . As a

⁶⁶See Lau (1976) for a detailed explanation of the theoretical background.

⁶⁷See Bergman (1997) for a thorough discussion on the subject.

result, the regression model is given by the following equation :

$$\begin{aligned} \ln(R_{f,t}) = & \beta_0 + \sum_{i=1}^I \beta_{Z,i} \cdot \ln(Z_i) + \sum_{i=1}^J \beta_{P,i} \cdot \ln(p_i) + \frac{1}{2} \sum_{i=1}^I \sum_{j=1}^I \beta_{Z,i,j} \cdot \ln(Z_i) \cdot \ln(Z_j) \\ & + \frac{1}{2} \sum_{i=1}^J \sum_{j=1}^J \beta_{P,i,j} \cdot \ln(p_i) \cdot \ln(p_j) + \sum_{i=1}^I \sum_{j=1}^J \beta_{ZP,i,j} \cdot \ln(Z_i) \cdot \ln(p_j) + \gamma \cdot X_{f,t} + \mu_f + \varepsilon_{f,t} \end{aligned} \quad (29)$$

where, again, Z_i denotes the i^{th} fixed input or output (out of a total of I), p_i the price of the i^{th} variable output (out of a total of J)⁶⁸, $X_{f,t}$ the control variable and μ_f the random effects. No fixed effects were used in this analysis for the simple reason that the proxies of the public functions, the areas under management, are mostly invariant over time. The fixed effects would therefore take out any significance of these variables and would make the interpretation impossible.

Note that the following constraints must be applied, first in order to satisfy the linear homogeneity in prices (property (c) above of the revenue function), which are:

$$\begin{aligned} \sum_{i=1}^J \beta_{P,i} &= 1 \\ \sum_{i=1}^J \beta_{P,i,j} &= \sum_{i=1}^J \beta_{PZ,i,j} = 0 \end{aligned}$$

The theory, through the equation 27 above, tells us that by construction (unless prices are negative), there should be a positive relationship between the revenue and the price of outputs (property (b) of the revenue function). This is fairly clear, and therefore not in contradiction with the results found in chapter 4 in which the price elasticity of supply was found to be negative.

In addition to the linear homogeneity in prices, the symmetry in cross-price

⁶⁸As seen theoretically above, the prices of the variable inputs are not included in this analysis as they are irrelevant to the solution of the revenue-maximization problem. Furthermore, in the context of this analysis, there are actually no variable input.

and cross-fixed input effects is also assumed, which gives the next and final constraints for the model:

$$\beta_{P,i,j} = \beta_{P,j,i}$$

$$\beta_{Z,i,j} = \beta_{Z,j,i}$$

This gives a total of $(1 + J + I + (I - 1) \cdot I/2 + (J - 1) \cdot J/2)$ constraints. As for the other properties of the revenue function listed above, one can verify them using the estimates of the regression empirically (see section 5.4).

From this regression, it is possible to extract and estimate the marginal revenues of the fixed inputs and outputs. In order to find the shadow price ρ_i of output i , we first take the equation of the revenue share R_i which is given below. According to Baardsen (2003) and following the shared properties of the profit and revenue functions, we get:

$$R_i = \frac{\partial \ln(R_{f,t})}{\partial \ln(Z_i)} = \frac{\rho_i \cdot Z_i}{R_{f,t}} \quad (30)$$

Then, from this equation, we can easily find an expression for ρ_i , which is, using equation 28,

$$\rho_i = \frac{\partial R_{f,t}}{\partial Z_i} = \frac{\partial \ln(R_{f,t})}{\partial \ln(Z_i)} \cdot \frac{R_{f,t}}{Z_i} \quad (31)$$

Based on the regression model shown above, it is finally possible to express the derivative in terms of regression coefficients and variables that can be found after estimating the regression model shown in equation 29. This gives

$$\rho_i = \left(\beta_{Z,i} + \sum_{j=1}^I \beta_{Z,i,j} \ln(Z_j) + \sum_{j=1}^J \beta_{ZP,i,j} \ln(p_j) \right) \cdot \frac{R_{f,t}}{Z_i} \quad (32)$$

Each observation therefore has a specific shadow value associated to it. Some descriptive statistics can then be performed to analyse the different results we get

from the models.

As expressed in equation 32, the unit of the shadow price is in monetary terms (specifically here in CHF) per unit of the fixed output i . That means that for any type of forest area under management, the unit is CHF/ha. Nonetheless, it can easily be transformed into m^3/ha , by dividing the shadow price by the price of wood sold by the firm during the given period. This has the advantage of giving an interesting perspective to the shadow price, as it can then be compared to an annual production of wood per hectare. In other words, this is the constraint faced by firms in terms of wood they are willing (or constrained) to give up for each specific public service.

5.2.4 A note on empirical analysis

In the present case, the available data allows to distinguish between 4 types of forests (in hectares), that are wood-related (production and sales), protective, nature-oriented (biodiversity) and recreational. Only the last three are considered in the following models as (quasi-)fixed outputs and are the only ones to be considered as such. These are undoubtedly the best proxies the data provide for the public services, although they are not perfect. However, regarding protection, it is considered to be a fairly good proxy given the specificities of this public service (which is closely related to the area devoted to it, and so are subsidies).

Focusing on inputs, whether or not the latter should be considered fixed can be discussed. The main empirical reason to treat them as fixed is that employment stability as well as working capacities are often priorities for forestry firms, or at least definitely important aspects, especially for most public entities, above any financial considerations. Moreover, protection of public employees is paramount in Switzerland. However, also from a theoretical point of view and as discussed above, it is similarly important to consider them as fixed in order to be

able to use the revenue maximization model which implies that inputs are fixed (in order to have a finite solution).

5.3 Data

The data used in this chapter are from the Swiss Forestry Pilot Network (TBN), similarly to chapter 3. As a reminder, a sample of around 200 forestry firms are asked yearly, on a voluntary basis, to use an analytical accounting software that gathers precise financial and managerial information about them. The data available consider 6 consecutive years, from 2007 to 2012, for an unbalanced panel of 1206 observations for a total of 237 different forestry firms. Some descriptive statistics specific to multifunctionality aspects are presented below. For the rest of the data presentation and for a presentation of the differences between the Swiss Forestry Pilot Network and the Swiss Forestry Statistics, see section 3.4.

The choice of this data set is based on the available data. The Swiss Forestry Statistics does not make a difference between the different types of forests which is the core of this analysis. Therefore, similarly to the chapter 3 and in order to conduct the following analysis, it is the only data source available.

Among the numerous variables that are made available, the different types of forest area, from a functional perspective, can be distinguished and separated into four main functions: protection, production of wood, recreation and biodiversity/nature. Whereas the first function, protection, is determined at the federal level owing to the SilvaProtect-CH project (see Hess et al. (2014) for general discussion and a quick presentation of the main protection role), it is not the case for the three other functions that are left to the discretion of each forestry firm to decide what are the main function of each hectare of their own forest. Already mentioned in the last section, this creates a potential endogeneity problem.

As a matter of fact, the distinction between one function over the other is sometimes fairly difficult for forestry firms. Indeed, the services the forest provides have no clear borders and some hectares surely fulfil several functions at

a time. Nonetheless, it is assumed that, in addition to protection which is very well defined legally, indications given to forestry firms are assumed to be good enough for trying to draw some specific conclusions related to each and every of the four functions.

Table 17 shows the number of hectares considered in the sample for each type of forest area (along with the proportion in %) both for each region and at the Swiss level (CH). For magnitude and comparison purposes, forests cover more than 30% of Switzerland, with a total of 1,258,658 hectares in 2012 (OFEV, 2013a). The sample used gathers therefore more than one fifth of the total Swiss forest.

Table 17: Sample distribution of forest type, by region (2012) in hectares

	Overall	Alps	Prealps	Plateau	Jura
Protection	108,684 (48%)	90,635 (88%)	15,033 (47%)	820 (2%)	2,196 (4%)
Wood production	89,449 (40%)	6,181 (6%)	9,958 (31%)	31,479 (89%)	41,829 (77%)
Recreation	4,904 (2%)	1,047 (1%)	1,519 (5%)	980 (3%)	1,358 (3%)
Biodiversity	21,511 (10%)	5,654 (5%)	5,608 (17%)	1,595 (5%)	8,654 (16%)
Total sample	224,865	103,517 (46%)	32,118 (14%)	35,193 (16%)	54,037 (24%)
Switzerland	1,258,658	565,311 (45%)	235,348 (19%)	225,857 (18%)	232,142 (18%)

In terms of proportions, since the non-protective functions are left at the discretion of forestry firms, the exact numbers at the Swiss level cannot be known. No information have been found for recreation. Biodiversity, accounting for 10%

of our sample, can to a certain extent be compared to the forest reserves that exists in the country. A recent report (OFEV, 2014c) indicates the total area of forest reserves to be 58,035 hectares, slightly less than 5% of total Swiss forests. The definition used by forestry firms in the TBN database must therefore be widened, and potentially encompass forest areas that are not economically profitable (due for example to accessibility restrictions), and yet do not fulfil any recreation or protection function.

Figure 10, presented in Duc and Brändli (2010), shows the percentage of forest areas that are protective in various regions across Switzerland.

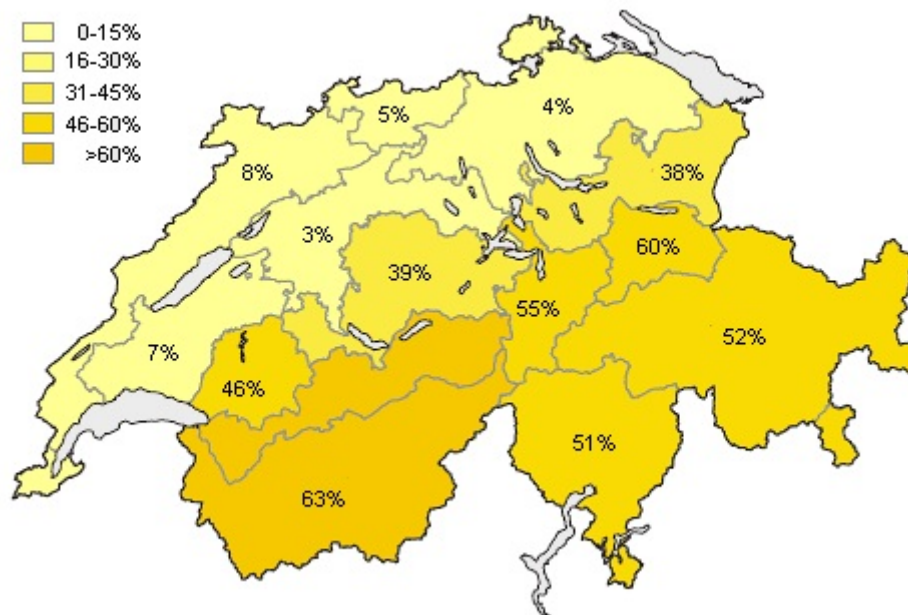


Figure 10: Percentage of protection forests across Switzerland.

For the protection function, it appears that the sample is representative of Swiss forests. The latter contains 48% of protection forests, whereas actual figures are around 46% (OFEV, 2013b). This is partly due to the fact that the Alps (both North and South) are also representative of Swiss forests (46% in the sample, compared to the actual 45%).

For the other three regions, the Prealps are slightly under-represented and that

Jura is slightly over-represented. It is still assumed that these figures are not far enough from reality to cause any significant bias in the subsequent analysis.

5.4 Results

The results are presented in the following order. First, regressions are presented and briefly discussed. Second, equation 32 for the estimation of shadow prices is applied to the current analysis and results are further discussed. Finally, overall comments and some discussions are left for the last part of the section.

5.4.1 The Model

Table 18 shows part of the estimates of the regressions from equation 29 using different specifications. As mentioned before, the random effects are used for the estimation as several variables are invariant across time (such as the different types of area under management). Fixed-effects are absorbing most of the information and are therefore excluded from potential specifications. Most estimates are not shown in this table for the sake of simplicity; only the most important and significant ones are reported.

This study focuses on the different types of areas and their respective impact on firms revenues. Models 1 and 2 only differ from each other in terms of the distinction made between the types of area. From the three types of non-wood related functions available (protective, recreational and nature/biodiversity), they are all used in model 1, whereas recreation and biodiversity are merged in model 2 for simplicity and because of their non-significance in model 1, to check for any difference. This appears to have no major impact on the estimates.

As for the dependent variable of revenues, subsidies are excluded from the analysis as they would mechanically increase the shadow price of protection. Protection has the highest level of subsidies, and the amount paid directly depends on area under management, which would thus distort empirical results.

Table 18: Estimation results of the regression analysis

<i>Variables</i>	Model 1	Model 2
<i>ln(Revenues)</i>		
<i>ln(Protection)</i>	0.100***	0.112***
<i>ln(Rec. + Bio.)</i>	-0.013	
<i>ln(Recreation)</i>		-0.033
<i>ln(Biodiversity)</i>		-0.009
<i>ln(Road)</i>	0.198***	0.204***
<i>ln(Capital)</i>	0.028	0.030*
<i>ln(Labor)</i>	0.357***	0.366***
<i>ln(Price_{wood})</i>	0.569***	0.591***
<i>Road Density</i>	-0.855***	-0.860***
<i>Tree Density</i>	-0.493	-0.568
<i>Outsourcing</i>	1.104***	1.139***
<i>Jura</i>	-0.069	-0.062
<i>Voralpen</i>	-0.372***	-0.390***
<i>Alpen</i>	-0.778***	-0.798***
<i>ln(Prot.) · ln(Prot.)</i>	0.019***	0.022***
<i>ln(Prot.) · ln(Rec + Bio)</i>	-0.005	
<i>ln(Prot.) · ln(Rec.)</i>		0.022
<i>ln(Prot.) · ln(Bio.)</i>		-0.010
<i>ln(Prot.) · ln(Road)</i>	-0.064***	-0.061***
<i>ln(Prot.) · ln(Capital)</i>	0.013***	0.014***
<i>ln(Prot.) · ln(Labor)</i>	-0.026***	-0.026***
<i>ln(Prot.) · ln(Price_{wood})</i>	0.039	0.044
<i>Constant</i>	12.222***	12.240***
<i>N</i>	1412	1412
<i>R²</i>	0.731	0.739

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

The variables of areas, prices and roads are centered to the mean, in order to simplify the interpretation of the estimates, including the interactions terms. Note that the direct effect of the price of wood is the only one to be explicitly considered in the models. Using the assumption of linear homogeneity, the theoretical estimate of the non-wood outputs prices can be then deduced.

Finally, for the specification, it is important to understand that the different areas are not represented in every single firm. Also, the prices of variables netputs were not estimated for all observations. Practically, the logarithms of all missing values and 0s (for the areas) were forced to be equal to 0 in the respective variables (after taking the logarithm and centering). However, because they are therefore considered to be equal to the mean, a dummy variable was added to the model for each one of them, with 1 when there is a missing value and 0 otherwise⁶⁹. Therefore, the impacts of these data modifications should be small.

5.4.2 Estimates

Focusing first on the proxies of the public services, no estimate of the protective area significantly changes with merging the two recreation and biodiversity functions, and so is the case for the recreation and biodiversity areas that are always insignificant, even when considered together. This applies both to the direct effects and to the interactions terms as well (which, again, are not fully shown in table 18 for the sake of simplicity).

When looking at other interesting explanatory variables, roads seem to have an ambiguous effect on revenues. On the one hand, the roads themselves have a positive estimate, which tends to argue in favour of the accessibility of forests.

⁶⁹In a separated model, these dummies have also been added to the interactions terms in order to be complete. Whereas the values and significance of some specific estimates slightly changed, the marginal effects and the shadow prices estimated below did not change in any significant manner. As they were insignificant and did not modify substantially any results, they were dropped from the final models.

On the other hand, the density of roads has a significant and negative estimate. Arguably, accessibility surely is an important aspect of forestry, but these tracks, trails and roads have to be maintained which is without any doubt resource consuming and prevent firms from concentrating on other more profitable activities in terms of revenue, everything else being equal. This agrees with the findings of chapter 3. As for the tree density, it has no significance whatsoever. The outsourcing (calculated as the percentage of overall costs) has positive and significant estimates, around 1.1. In any case, outsourcing and revenues appear to be highly correlated with one another. However, the causality can be very difficult to assess as there might be some multicollinearity issues.

When focusing on inputs, the direct effect of capital seems to have no real bearing on revenues when subsidies are considered, whereas the direct effect of labour has more positive and stable estimates among all regressions, between 0.38 and 0.40.

Finally, the price of wood has an estimate at about 0.6. Although the strict homogeneity of prices is violated when solely considering wood price (which would be wrong), there are other activities of the industry that generate income. Unfortunately, due to the variety of these non-wood revenues, it is very difficult to express them as a price variable. These are therefore not observed but still exist and are considered to fill the gap between the estimate of wood price and the linear homogeneity requirement.

Marginal Effects and Shadow Prices

Equation 32 is used to calculate shadow prices both in monetary and volume (of wood) terms based on estimations of model 1 in table 18 for each firm and each year in the sample.

Table 19 shows the three quartiles of shadow prices for each type of area

considered in model 1 (protective, recreation and biodiversity). Because of a few extreme values⁷⁰, the mean is not considered to be meaningful, and is therefore simply not shown. Also note that since recreation and biodiversity estimates are not significant, the resulting shadow prices are likewise insignificant and the magnitude cannot be interpreted.

Table 19: Shadow prices

		Protection	Recreation	Biodiversity
<i>CHF/ha</i>	1 st quartile	42.4	-1,325.1	-279.6
	Median	94.1	-87.4	-65.7
	3 rd quartile	163.7	321.3	24.9
<i>m³/ha</i>	1 st quartile	0.27	-15.83	-2.47
	Median	0.59	-0.98	-0.48
	3 rd quartile	1.23	2.75	0.23

Figures 11 to 16 in Appendix A show the same information in a slightly different way. Because of some extreme values, the histograms were created between plus or minus CHF 2,000.- per year, respectively plus or minus 20m³ per hectare per year, in order to drop outliers and be able to distinguish the shape of the histograms where most of the data lie.

Focusing on biodiversity first, it is again not significant, explaining why values vastly differ among quartiles and between models⁷¹. Figures 13 and 14 indeed show it clearly: although slightly skewed towards positive values, most

⁷⁰These extreme values are due to the fact that marginal effects are multiplied by total revenues, which is often a large number, and then divided by the area in consideration, which can be very small, a few hectares only in some cases, leading mechanically to huge and irrelevant results. However, there are only a few dozens of those in total, which is considered to be small enough not to be worrying and needing further investigation.

⁷¹These histograms are actually questionable and do not bring much, if anything, useful information. They are nonetheless shown for comparison purposes.

values are close to 0 and fairly normally distributed.

The recreation area hugely varies from one quartile to the other, from high negative values to very high positive ones (figures 15 and 16). Again, nothing surprising here because of the insignificant estimates. It could tend to show that recreation areas are very heterogeneous and that their impact potentially varies widely among firms.

Finally, and most importantly, the protective areas are of a great importance in this model. Several aspects must be mentioned. First of all, the protection area is, from a definition and data point of view, the most reliable one. As a matter of fact, protection areas are defined at a federal level, which is not the case for the three others (wood production, biodiversity preservation and recreation), that are left to the sole appreciation of forestry firms. Moreover, a substantial amount of public expenditure on forests is dedicated to protection (more than 100 millions CHF over a total of 140 millions CHF, as mentioned earlier). In this regard, the associated results are arguably of a significant importance.

Second, the size of the shadow prices is interesting. When considering table 19 and shadow prices in terms of m^3/ha , compared to the annual wood growth given above, the equivalent in terms of wood production is fairly low. In other words, without taking the subsidies into account, the implicit value for the forestry firms of the protection function is small.

Final observation, in contrast with the two other types of forests, the shadow price estimations for protection do not exhibit an extreme variance among quartiles. Whereas it is understandable for both biodiversity and recreation due to their insignificant estimates, the protection area shows a generally small but positive shadow price.

5.4.3 General discussion

Based on above analyses, the estimated shadow prices inform us on how each public service is implicitly valued within forestry firms.

The estimations reveal some important aspects of the forestry reality. The Swiss National Forest Program, in its Action Programme 2004-2015 (SAEFL, 2004) distinguishes 12 "quantified objectives", out of which 5 are considered as priorities: improvement of economic viability of the forestry industry, guaranteed protective function, strong wood value-added chain, soils, trees and drinking water preservation and biodiversity conservation.

Multifunctionality is so to speak never disputed by forestry firms, and it is obvious that policy makers take it very seriously as well. As discussed by SAEFL (2005), behaviour can be controlled by financial incentives. The Swiss agriculture and its policy reform that has been undertaken over the past decades provides a good example. By introducing direct payments, promoting environmental purposes, as a compensation for the loss of some other forms of subsidies (mainly for production), incentives have been high for farmers to follow environmental recommendations and comply to certain standards. In this section, a discussion is opened for each of the three non-wood related functions considered.

Biodiversity

The last objective of the Swiss National Forest Program, namely biodiversity conservation as mentioned above, is a very interesting one for the purpose of this chapter. It has been shown that the estimates for the shadow prices of the biodiversity areas are insignificant⁷². Promotion of biodiversity in forest areas is introduced on a voluntary basis for forest owners and forestry firms and is for the

⁷²Note that when considering subsidies in the dependent variable in addition to revenues, it is still not possible to find significant values.

most part restrictive and costly, at least in terms of opportunity costs. Therefore, it can be asked whether or not the financial incentives are good enough (do they even exist?). Based on insignificant shadow prices, it could be argued that they are actually not effective. However, it is important to put things into perspective. The estimation of non-significant shadow prices could be the consequence of several causes. First, the non-binding constraint associated with biodiversity is not binding. The step further would then be to assume the insignificance of biodiversity itself from the firm's perspective, but this would be going already too far in the interpretation of results. Second, the heterogeneity of the outputs is too high, and, or, the endogeneity issue of the outputs discussed earlier might be more important than initially assumed. For all these reasons, it is very difficult to draw clear and definitive conclusions.

CHF 9.5 millions have been invested in 2013 for biodiversity (FOEN, 2014), compared to more than 10 times the same amount for protection. Although it is clear that comparisons mean very little as the activities largely differ and that direct threats on buildings and infrastructures are not to be taken lightly and are of course of crucial importance, biodiversity is still considered to be a priority by authorities, arguably at the same level than protection, and this should not be forgotten.

A second question that can be raised here is whether or not the federal state should give to the forestry industry financial incentives. Economically, the estimation of the value of biodiversity is of course complicated. Empirical analysis has been performed, as discussed in Pearce (2001), but assessing the economic value of biological evolution over million, if not billion, years is a arduous task, at a very minimum. The debate is potentially endless and well beyond the scope of this dissertation. However, there are still luckily some estimations that can be obtained and used as a framework for future policies and potential financial

incentives, which might be close enough to reality and to the real preoccupations of the politics.

Borzykowski et al. (2017) estimate, using surveys, the amount Swiss people are willing to pay for larger reserves in the country (mostly, if not exclusively, for biodiversity reasons). The proposition offered in the survey was to increase the number of reserves from 5% (current level) to 10%, i.e. double them. It appears that the amount people are willing to pay is fairly high, between CHF 400 and CHF 470 per household depending on specifications. This would lead at the country level to a willingness-to-pay above CHF 1 billion⁷³. The equivalent for one additional hectare of forests reserves would lie well above CHF 20,000. This is a huge number to be considered with appropriate caution. Whether or not the exact number should be taken into account, the mere observation of such a magnitude should be enough to convince sceptics of the great interest of the population for the biodiversity function and its willingness to pay for additional investments in this particular forest function.

This discussion stays open as to support a modification of current policies towards higher subsidies and stronger incentives for forestry firms to increase the interest for biodiversity issues. Although creating forest reserves means for the firm less to no maintenance as the goal of reserves is to let nature take its course, there are still opportunity costs that should be taken into account and not be underestimated, as well as potential diseconomies of scale⁷⁴.

Recreation

There is not as much to say for this particular function as there is for the others. Recreation is considered a priority neither for policy makers, nor Swiss

⁷³1.4 billion, assuming 3.5 million households (STATPOP, OFEV) and the lower bound of CHF 400.

⁷⁴The effect of creating forest reserves for firms is that less hectares are to be managed, meaning less inputs and outputs.

population, and it seems nor forestry firms. The five main objectives of the Swiss National Forest Program do not include anything regarding recreation, although it is mentioned in one of the additional objectives. Nonetheless, the potential issues mentioned when discussing the biodiversity above still holds. And of course, if heterogeneity, or endogeneity of outputs, would be verified for one, it would then equally impact the other. And again, the non-significance of shadow prices only shows that the related constraint is not binding, with the conclusion that recreation activities in forest areas are not restricting forestry firms. In other words, forestry firms seem not to be constrained, either internally or through regulation, in any manner by recreation. Finally, regarding the Swiss population, Borzykowski et al. (2017) showed that it values protection and biodiversity the most and then in a second time, recreation and the wood production function.

Note however that there might be an additional measurement problem for two reasons. First, the term recreation is vast and might include various types of recreation areas so heterogeneous that they could become hardly comparable with one another. It would thus not be appropriate to gather them in the same variable. Second, since it must be a difficult task for forestry firms to categorize each type of area under one precise function, recreation can potentially be the catch-all. The same argument could be applied to the biodiversity function, except that there are at least official reserves there and that it can be, to some extent, easier to differentiate it from the others.

Protection

50% of Swiss forests are considered protective. It is without a doubt one of the most important functions forests fulfil. Indeed in Switzerland, the infrastructure protected by forests is estimated to weigh CHF 200 billion (Losey, 2014).

The Federal Act on Forest (ForA 921.0, Art. 19) states that

where necessary for the protection of human life and significant material assets, the cantons shall secure avalanche release areas and landslide, erosion and rockfall areas and carry out torrent control works in forests. The measures used should be as natural as possible.

Moreover, according to Swiss law, protection costs should not be supported by forestry firms or forest owners. Related costs are to be incurred by cantons, federal state and to some extent owners of the protected facilities themselves; but neither the forestry firms, nor the forest owners. However, discussions with the latter show some tension around this topic: whereas the general rule and most likely common sense require that costs related to protection should be indeed covered by the State and those directly benefiting from it, some people in the forestry industry complain about the fact that even including subsidies, there is a financial burden associated to this type of task, the financial coverage being insufficient with respect to the expenses.

Solutions are definitely not easy to find and further investigations are without a doubt needed to separate facts from opinions. As mentioned above, direct payments used for protective areas resemble the ones for the Swiss agriculture that have been introduced during the last decades⁷⁵. These direct payments seem to work efficiently in the Swiss agriculture. Indeed, a report from OECD (2015) indicates that recent changes in Swiss policies paid off with increased efficiency and better compliance with several standards (such as environmental ones).

However, it is necessary to recognise that the current situation needs further research and discussions. Whereas the value of the protection function for the society is undeniable, its maintenance seems problematic for forestry firms, and their concerns could indeed be legitimate, as results have shown that the implicit

⁷⁵These payments have replaced production subsidies.

value of the protection function is fairly low for forestry firms. Assuming solutions were to be looked for, increasing efficiency of forestry firms, thus decreasing costs, could be a solution. This includes for example mergers and collaboration among firms, among others. If it is clear that long-term objectives should be considered, maintenance might potentially also be reduced without impairing the value of the protective function itself. Working more intensively with subsidies is another solution, fixing the other side of the problem. Although it is always easier to cut subsidies and limit payments, the associated costs are negligible compared to the benefits the Swiss forests provide, as alternatives (using hard infrastructures for protection purposes) are extremely expensive in comparison.

5.4.4 A note on heterogeneity

The Swiss forestry industry is characterized by a strong heterogeneity in its environments, types of owners and forests, firm sizes and objectives. Using empirical analysis, estimations have been conducted in order to assess whether or not this heterogeneity can be somehow modelled using latent class models. This was considered to be a potential alternative method for studying this industry.

Results of the latent class analysis are not shown in this chapter. It appears that they do not induce substantial or considerable conclusions. Estimations are very sensitive to specification and independent variables, preventing from getting robust and interpretable results. Moreover, information criteria often do not support the maximum number of classes that could be practically estimated⁷⁶.

All in all, only one class appears in general to be significant (with expected signs), while others are mostly insignificant, both for the types of area under management and for the controls. However, depending on the specification, results are rarely incoherent. For all these reasons, the results from the analysis

⁷⁶Estimations usually did not converge empirically beyond 3 to 5 classes.

using the latent class model cannot sustain any formal conclusion. The heterogeneity problem is nonetheless an important issue that has been addressed in the best possible way.

5.5 Conclusion

In this chapter, a few questions regarding multifunctionality have been addressed. It is an attempt to quantify the value of each hectare of forest devoted to each of the four functions available. A restricted revenue function was modelled in order to estimate the shadow price of each function and to assess the value of public services for forestry firms.

Results show that the protection function has a significant but small shadow price. This was expected as the regulation around protection is the most intrusive for the forestry industry which has only a small level of flexibility in its management. This is of course understandable when considering its importance for infrastructure all over the country. However, it is recognized that protection is not the only public service provided by forests, and that other objectives are as important in the long-run. In contrast, biodiversity and recreation do not show any significant results and it therefore means that the constraint associated to them is rather low or insignificant for forestry firms.

In terms of economic policy, biodiversity (in contrast to recreational areas) is considered as one of the priorities by the Swiss National Forest Program. However, the question can be raised as to whether or not current financial incentives are sufficient given the importance granted to it⁷⁷. Moreover, biodiversity (or more precisely forest reserves which tend to increase and enhance the level of biodiversity) is also strongly valued by the demand side. Recent studies in Switzerland have shown a very high willingness-to-pay by the population for biodiversity, evaluating the latter to be as important as protection, and more important than recreational activities or wood production. However, in terms of

⁷⁷In 2013, more than 100 millions CHF were invested into protective forests directly or through protection of buildings and infrastructure, over a total subsidies of 140 millions CHF. Less than 10 millions CHF were invested during the same period for biodiversity. *Annuaire La forêt et le bois*, 2014, FOEN.

incentives, especially financial ones, the biodiversity function seems somehow to be the "poor relation" in the context of the Swiss forestry industry, although one of Swiss National Forest Program's priorities. The findings of this chapter show that the function has barely any effect on revenues whatsoever (with or without subsidies). As seen in chapter 3, it is still costly for firms but therefore with basically no benefit. In this regard, there might therefore be a mismatch between objectives and current policies, again especially in terms of incentives for forestry firms which do not seem to pursue the biodiversity objective by themselves.

Regarding their core activities, it is an undoubted fact that the economic function of wood harvesting is a key aspect for the survival of the industry. Still, it is also clear that forests fulfil a wide variety of functions (which are not confined to the functions discussed in this chapter), and only few, if any, are profitable for the forestry industry, at least with the current structure of financial support. These functions are extremely valuable for the society although part of the related costs seems to be currently borne by forestry firms and indirectly public communities supporting them. Whereas at a larger scale and when considering only public firms, this could be considered reasonable, some communities potentially bear more cost than others. An analysis for a better redistribution of costs and benefits could be performed. In other words, analysing whether or not there is any adjustment that could be made for a fairer distribution of costs would be valuable. When discussing the topic of the several public services fulfilled by the forests through the activity of the forestry industry, many firms raise the fact that these are economically unprofitable for them, protection included, even after considering the substantial subsidies that are received. While this chapter does not offer explicit solutions to this problem, it still brings evidence which (along with chapter 3) could be the basis for further discussions and investigations.

A few caveats and shortcomings should be mentioned in this analysis, mostly regarding the functions themselves. First, their number is fairly low. Indeed, there was basically no choice and all available information were used in this chapter. Second, data quality, along with precise definitions, is to some extent disputable. Although the results are fully coherent with expectations and initial assumptions, it is nonetheless important to keep in mind the fact that each forestry firm is responsible for the conceptual separation of its own forestlands, which might lead to bias or lack of coherence. The lack of a centralized categorization for some non-wood related functions (i.e. recreation and biodiversity) could lead to a strong heterogeneity in the data which is hard to overcome.

Direct interactions with forestry firms as well as in depth discussions about the different choices available to them could be an interesting alternative, or continuation, for the analysis of the questions raised in this chapter. Creating surveys for the overall industry would be a valuable starting point, among others in order to challenge the findings of this paper and give a chance to forestry firms to express their voices. The results of the survey could then be the foundation for further discussions, in order to get a deeper understanding of the considerations the industry gives to the multifunctionality and the role of the latter in the overall forest management.

5.6 Appendix A

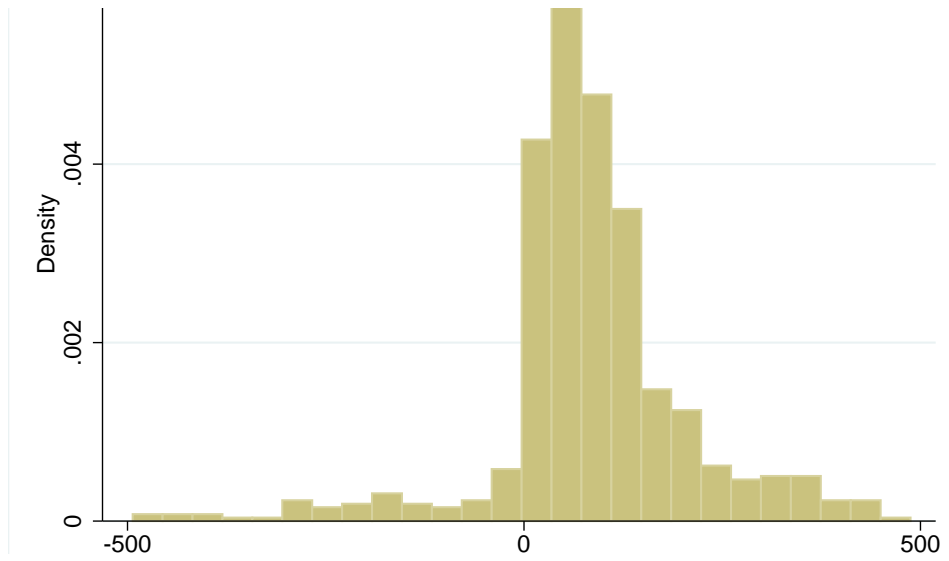


Figure 11: Model 1 : Shadow price - Protective area (CHF/ha)

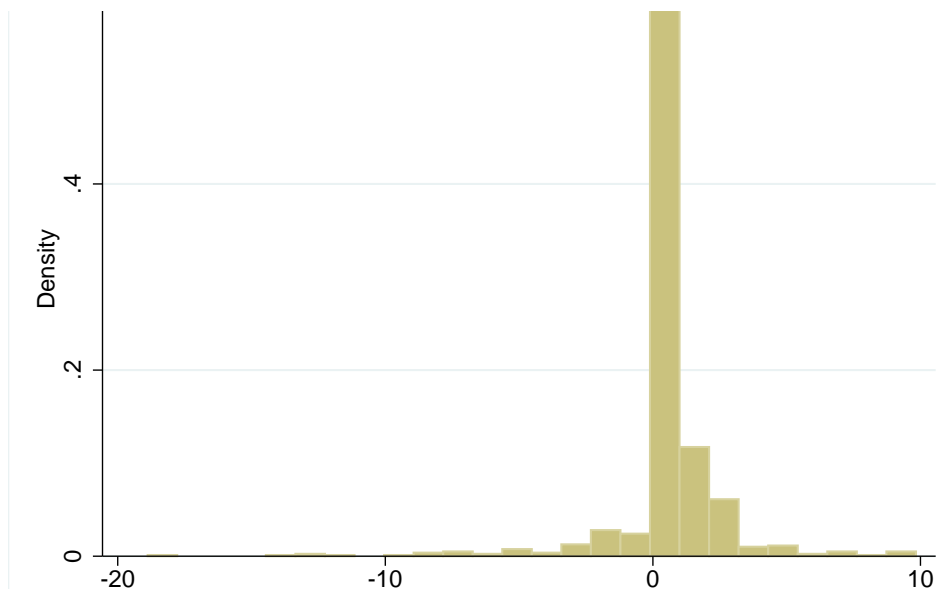


Figure 12: Model 1 : Shadow price - Protective area (m^3/ha)

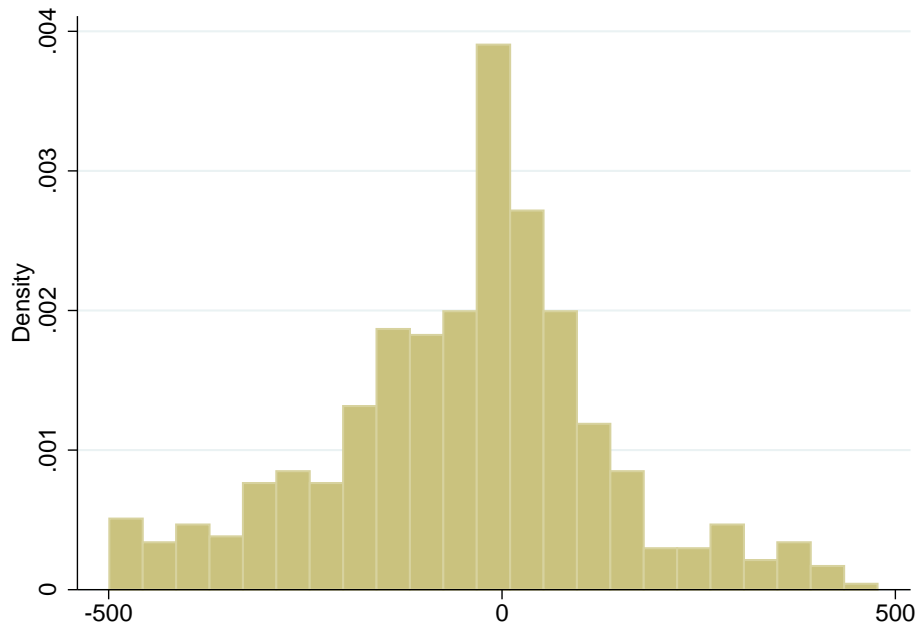


Figure 13: Model 1 : Shadow price - Biodiversity area (CHF/ha)

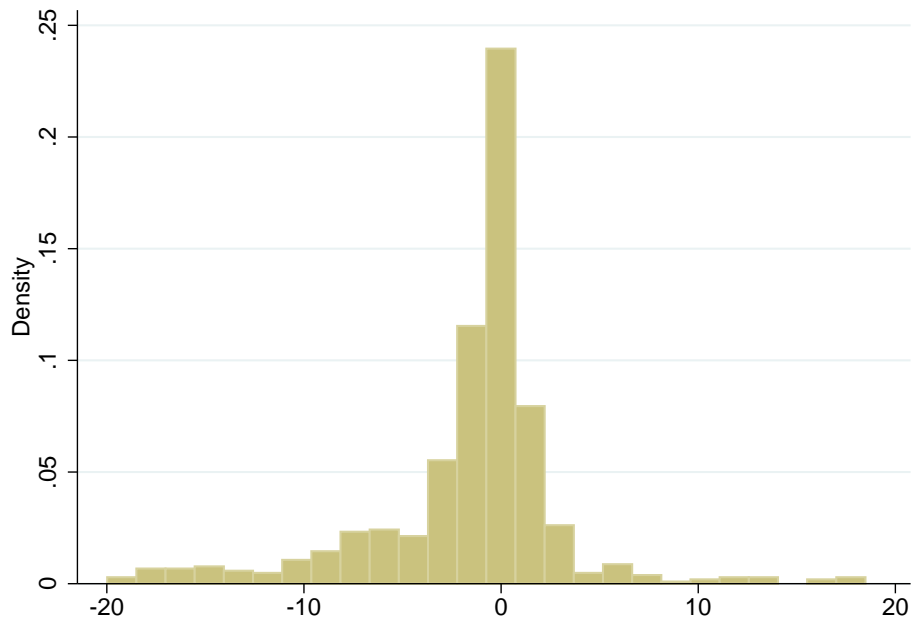


Figure 14: Model 1 : Shadow price - Biodiversity area (m^3/ha)

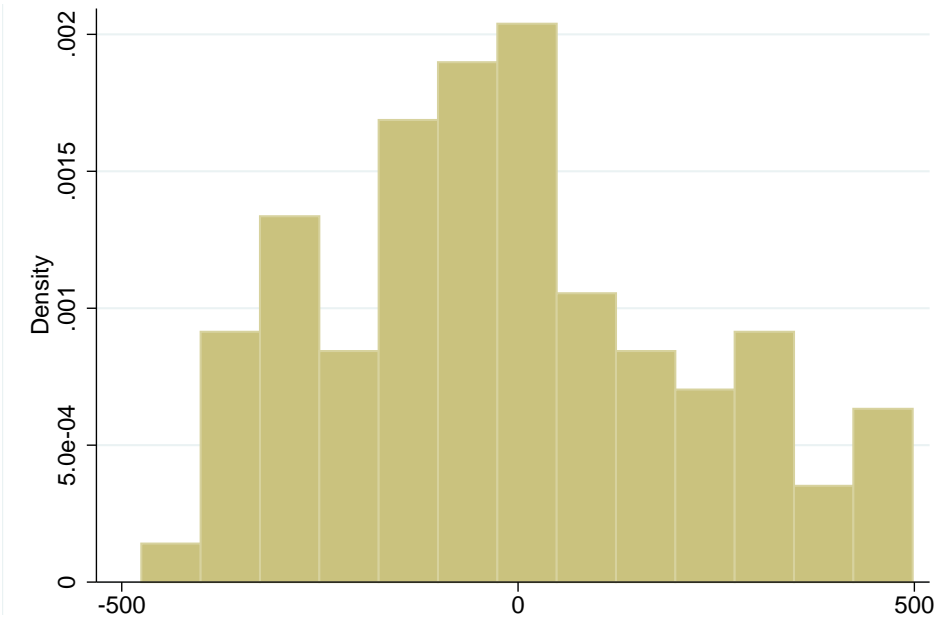


Figure 15: Model 1 : Shadow price - Recreation area (CHF/ha)

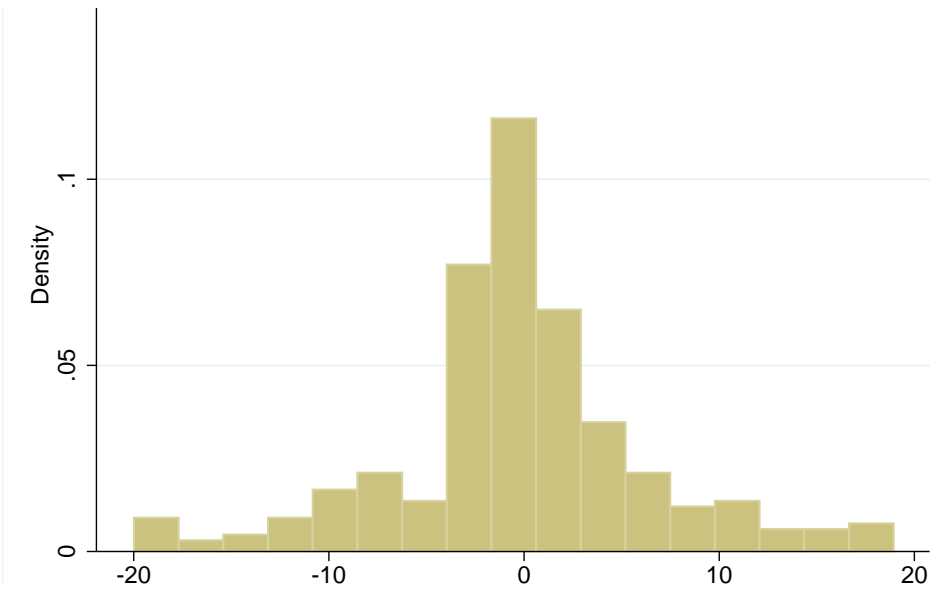


Figure 16: Model 1 : Shadow price - Recreation area (m^3/ha)

6 Conclusion

This dissertation brings insights on several aspects of the behaviour and economic structure of forestry firms in Switzerland. The objective of this general conclusion is to summarize the main findings and discuss them all together in a more general framework and from a policy perspective. I will conclude by discussing the limitations and recommendations for further researches.

The general situation of the Swiss forestry industry is interesting by more than one aspect. First, the structure of the industry is highly fragmented and firms face very heterogeneous environments, restrictions and challenges. Also, forests are multifunctional on many aspects and do not only provide wood, going far beyond timber production. Water purification, recreation, biodiversity, protection are all examples of valuable services forests provide to the human society and the reasons why we should take care of them if we want to take care of our own kind. The government is sensitive to these aspects and therefore the forest policies in Switzerland include many aspects of this multifunctionality. While accepting the fact that economic activity in forests is important, the government also values non-economic functions with three out of the five priority objectives that have been set to be non-economic in the strict sense.

On more economic terms, the industry has been for several decades showing recurrent deficits at the industry level. Although some firms are able to continuously make profits, most of them cannot. This situation is worrying and requires specific attention in order to find potential solutions, if any should be found. The valuation of forests, including all non-timber goods and services, are often estimated in billions. Assuming this to be true, this could support the fact that the costs associated with these deficits are fully acceptable, as the related benefits largely outweigh them. The question could then simply be to find out who should bear them and integrate the appropriate mechanisms (taxes, subsidies) for

the perfect redistribution. Nevertheless, even assuming that this can be true, the situation is definitely not perfect and the performance of the industry can still surely be improved. This has been the focus of the thesis and will remain for this conclusion.

Empirical analysis

Three subjects have been tackled: the analysis of production costs of raw wood and the formation of prices, the estimation of a supply function for raw wood, and the analysis of the firms' behaviour in a multifunctional environment through a restricted revenue function. These econometric analyses were all done using data at the forestry firm level.

First, the costs of the forestry industry were analysed. While the deficits of the industry have become the norm over the last decades, the firms seem to be powerless in facing the costs from core activities that are steadily raising. At the same time, the core revenues are barely stagnating, if not decreasing over the same period of time. The most important change in the Swiss industry has surely been the non-core activities that have increased more than threefold in the last 25 years (see 2.2), without being able to reduce deficits in any way.

In this context, the costs analysis of the forestry firms has been conducted for a better understanding of the drivers of the cost structure in the case of the Swiss forest industry. A multi-output cost function is estimated considering several types of outputs : wood, area and roads. Each of the first two types are then considered using more specific outputs. Wood is subdivided into timber, fire and industrial wood. Regarding areas, only protective and non-protective areas are distinguished. Using a non-linear specification, namely a generalized Box-Cox model, which allows to estimate specific economies of scale for each observation, the number of outputs was restricted for numerical reasons (the es-

timization procedure was not able to handle more than 5 or 6 outputs). Although non-protective areas are not fully similar, this distinction allocates around 50% of forests to each of the two variables. Moreover, when considering subsidies and as such public services offered by forestry firms, the majority are spent for protective and related activities.

Along with the estimations of specific economies of scale, the model also allows the estimation of an "optimal" size. The objective of such an estimate is not to serve as a rigid goal for firms but rather provide a general guideline, as there is an obvious and strong heterogeneity among them, with many different environments and as many realities, leading to different optima. This can still offer a powerful insight on whether the current industry is too fragmented or not, and give an idea for the minimum scale efficiency.

In terms of the general results, the estimations show a strong heterogeneity across the four forestry regions. With mostly protective forests, the Alps are surely a special case with high costs. Marginal costs of outputs also support these findings. But most importantly, the results also reveal a strong potential for cost reductions through economies of scale in small forestry firms. They also show a significant and positive effect of outsourcing on the reduction of total costs. This finding is among the most important ones of this dissertation in terms of implications. Despite the fact that the exact magnitude of potential cost reduction is yet to be determined, the economies of scale are undeniably a strong characteristic of the Swiss forestry industry. Additionally, outsourcing, as a means to decrease profit through the indirect use of another firm's efficiency, has shown significant potential as well in terms of cost reductions.

Pressure on wood prices from international markets is strong and the industry is mostly helpless in facing its consequences. Product differentiation, promotion of Swiss labels, local productions and related measures are without any doubt

good and should be maintained if not strengthened. They certainly can help to some extent but cannot be the answer to all problems. The revenues are difficult to influence as they mostly come from wood sales which are driven by international market. As a consequence, these measures on product differentiation and labelling, as a means to increase the value of firms' outputs and at the end revenues, simply cannot be the only action. It turns out that the solution, in terms of financial performance, can credibly be found in the cost performance of the forestry firms. High wages and general cost level is a reality in Switzerland which leaves the forestry sector no choice but to raise productivity and overall efficiency. As a consequence, policy makers must take any available chance to improve the situation. They should thus work on effective incentives and measures so that the forestry firms can benefit as much as possible from the potential lying under the economies of scale. It can have a strong impact on forestry industry's financial health for years to come and might even bring profitability to the industry. If not a priority, this would certainly not be superfluous. As already mentioned, the economies of scale convey a strong potential which should not be underestimated. In addition to the strict merger of firms to benefit from economies of scale, the different types of collaborations between firms should be highly promoted as they can be very effective. Shared investments, work coordination or externalisation of certain tasks are all possible tools at the disposal of forestry firms, not to mention the outsourcing alternative which seems to convey strong potential as well. In terms of policy, an increased collaboration between forestry firms is difficult to enforce, but specific tools might be offered. The *conditio sine qua non* for successful collaboration is first to have the information that another firm is willing to do it. Platforms, in different forms, could be a first step to increase interactions between firms and help them synchronize each other when planning different works in neighbouring forests as soon as possible and

therefore join workforces, but also share needs for future investments. Numerous firms are without any doubt already utilizing some or maybe even all these methods. Nonetheless, the room for improvement has been shown to be big, and most importantly, significant in terms of cost reduction potential. This is crucial in the current financial situation of the Swiss forestry industry which is and has been in deficits for several decades. Creating such tools could be the first step towards shifting attitude towards more collaboration and, with time, towards mergers and higher structural cost efficiency.

The second paper of the dissertation focuses on the supply of raw wood. By doing so, the goal is to determine the main drivers and factors affecting the quantity of supply at the firm level, and better understand their competitive behaviour. Two main hypotheses were formulated and tested in this first analysis. The first focused on profit maximization of the forestry firms. It was tested using the price response estimated with an econometric model, using the wood supply at the firm level as the dependent variable. It was then regressed on several characteristics of firms such as hectares of productive and non-productive areas and other information on subsidies and outsourcing, among others, in addition to prices. It appears that the magnitude of the different price response estimations vary with the several econometric approaches. However, the conclusion about the test of the profit maximization behaviour of the forestry firms is unambiguous among all estimations. It is rejected without exception. In other words, the estimates of the price elasticities are always negative or insignificant (even though mostly small in absolute values), meaning that prices and quantities vary in opposite direction, which directly contradict profit maximization behaviour, as shown in the theoretical part. Different magnitudes are still found with respect to ownership and firm size. For example, private and bigger firms tend to be more competitive than the others. Although there is no consensus in the literature, there are sev-

eral authors that have found or suspected similar results, such as Bürgi and Pauli (2013) who suggest that the high production costs compared to current prices might lead to a non-competitive behaviour. The general result here is that there are strong arguments against the hypothesis formulated above that there is a competitive market in which forestry firms are maximizing their profit. If this model does not fit the current market, what could? A potential explanation, also given in a way or another by Swiss forest experts, is that forestry firms are rather targeting a given revenue level and not seeking profit. The multifunctional nature of the industry and of the forests and the numerous public objectives could also be related to this non-maximization of profit, as forestry firms are more concerned about other non-financial considerations. Finally, the fact that most firms are also public only strengthens this potential explanation.

As a second hypothesis, the market power of the forestry firms was estimated and tested. For this second part, the dependent variable was the price itself. Regressors include specificities of firms and most importantly the two hypotheses that were tested, concerning the size of the forestry firm in terms of hectares under management, and the level of subsidies each firm receives. The firm size is fairly clear as general economic theory states that a larger size generally increases the market power. The second hypothesis that was tested is that subsidies might increase market power (hence prices) as higher subsidies mean that a higher share of costs is covered by non-wood related activities. In other words, the pressure is less intense for forestry firms to get sufficient revenues, and therefore the latter can themselves put more pressure on wood buyers in order to increase prices. The results indeed show some market power for bigger firms. However the subsidy hypothesis was fully rejected as the estimate is even significantly negative, meaning that the relation between subsidies and price is going in the opposite direction. Two assumptions could be raised here in order to explain it. First,

higher subsidies mean a larger part of non-wood related activities, with wood production as a by-product. The latter is potentially of lower quality and thus sold at a generally lower price than the wood produced as an economic activity. Second, the fact that subsidies are higher gives indeed the forestry firms a bigger margin to operate as the pressure is lower. Rather than taking advantage of this situation, the forestry firms can decide to sell their wood at lower prices in order to dispose of it more easily or, indirectly, help the other market players.

The third and final empirical analysis puts the multifunctionality of the forests at the center of interest. All non-timber goods and services provided by forests and forestry firms are extremely valuable to society in general, although it is difficult to put a precise price on them. As an example, Rauch-Schwegler (1994) values aggregate services provided by the forests in general in Switzerland at as much as CHF 9 billion. Out of this huge number, timber production only accounts for a few percentages, more than 95% being non-timber goods and services.

The analysis provides an estimation of a restricted revenue function in order to estimate shadow prices of non-economic functions, using the same procedure than Baardsen (2003). The concept of shadow price can be defined as the monetary value of a non-marketable good or service (and even any negative externalities, which is not the case here). In other words, it assesses the value of the constraint for the forestry firms of each service provided. The functions considered include protection, as in chapter 3, but also recreation as well as nature and biodiversity combined in a single variable. Using firm-level data, the econometric estimations can then be compared to a survey at the national level also conducted in the context of the National Research Program 66.

The shadow price is a very effective tool for empirical analysis as it enables to evaluate what is not directly observable and is more than ever justified in pres-

ence public and non-marketable services and in a context of multifunctionality. Also, others methods need additional data, such as survey or creation of simulated markets which were not within the scope of this dissertation. In addition, many authors have used or suggested similar approaches, such as Shobayashi et al. (2003) for the case of public goods or in Romstad (2010) when considering land management.

In terms of results, the protection function is the only function with positive and significant, yet small, shadow prices. On the other hand, the two others (recreation and biodiversity) do not show any significant estimates, meaning that forestry firms are not substantially affected, or constrained, by these types of forests areas. In terms of shadow prices, the main finding is therefore that only protection shows a binding constraint from the firms' perspective. This is somehow not unexpected given the nature of the protection function which is imposed at the federal level whenever needed. This is however not the case for the other functions. The general findings are in line with other studies in Europe such as Górriz-Mifsud et al. (2016). In this case, the use of subsidies is considered to be a crucial tool. However, the discussion about biodiversity functions and recreational services is an important to conduct, and further researches might be needed. The present analysis suggests that the constraints of these public services are not binding for forestry firms, or insignificant. It is however very difficult to draw further conclusions without more information. Especially, the existence of a gap between supply and demand cannot be inferred based on the previous findings. The latter might also come from the data which hold a few drawbacks. As an example, the definition and the division of forestland into the four main categories in a arduous and hazardous task. These categories are closely intermingled with one another that their strict separation might be a mistake. Furthermore, whereas protection is defined at the federal level, the three

others are let to the discretion of forestry firms, which could create a higher level of heterogeneity and distort or favour non-significant results.

On the other side of the market, the survey conducted at the national level bring some interesting insights along with the results of the shadow prices. For example, it shows a willingness-to-pay in Switzerland of more than CHF 20,000 per additional hectare of forest reserve in Switzerland. Even if we interpret this amount as a one-shot payment (which is not what it is meant to be), it is a huge amount of money for the forestry industry. In terms of policy, it is worth noting that the Swiss National Forest Program contains 12 long-term objectives, out of which 5 are considered priorities. And out of these 5 objectives, biodiversity (along with protection and economic activities) would be one of the direct beneficiaries of an increase of forest reserves. On the other hand, forestry firms have no direct revenues from these functions. Whereas both Swiss population and policies tend to strongly value biodiversity, there seems to be no financial incentive for forestry firms in that perspective. This gap between demand and supply is worrying and should surely be closely looked after. A stronger implication of the government might be beneficial for the biodiversity function, potentially along with subsidies, either with new ones or through a better redistribution of the current ones.

Limitations and further research

First of all, the lack of well defined prices is definitely a problem in the case of this dissertation. It has been dealt with in the best possible way, but more specific and precise results could surely be drawn with more available data.

The multifunctionality and more precisely its modelling through extensive and reliable data is one of the most important challenges faced by this type of analysis. This dissertation tried to make the best out the available data but every

database has its limitations. Therefore, further research and new data collections could be carried out with additional objectives. For example, as already mentioned, the proxies for the different public and non-marketable services is an important issue. Creating better (both in qualitative and quantitative terms) and more reliable proxies, based on sound theoretical foundations, could be the subject of a further research.

As it is now clear to the reader, multifunctionality is a crucial part of forestry sector. As a consequence, the analysis of the economies of scope would be very valuable in addition to the results regarding economies of scale. The current Swiss model leans towards a strong interrelation between the different public services as well as the private function of wood harvesting. At first sight, it seems difficult to imagine anything else. But other models could be interesting to analyse. As an example, could specialisation be a solution to increase wood production on one side and public functions on the other (assuming they are separated) and thus decrease overall inefficiency?

Finally, beside the limitations from the sole econometric point of view, this dissertation has not formally given voice to the market players, who might have important and interesting insights to the different findings of the precedent chapters and in order to increase the overall understanding of the behaviour and the performance of this complex industry. While working on this dissertation, informal discussions, among others with owners, have been conducted several times in order to get insights on the underlying mechanisms of the forestry sector, get a feeling of the general context and mostly get feedbacks on results of the analyses presented in this dissertation. However, formal interactions with those people working directly in the forestry industry could be a valuable extension to this dissertation. In particular, the use of surveys for the forestry and sawmill industries would allow to evaluate the current situation from a new viewpoint and poten-

tially get new perspectives to find the best tools to bring in order to increase the general performance of the industry. As an example, better understanding how forestry firms can most effectively benefit from economies of scale, or what are the true roots of the non-competitive behaviour in light of multifunctionality. Also, differences in the behavior and the objectives of private and public firms could be evaluated. Aspects of public and non-marketable services, such as biodiversity and recreation, could well be brought to the table as well. In general, it could allow to better assess the behaviour of the industry and understand their decision making processes.

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