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1 Introduction

This paper highlights the role of palm oil expansion at the expense of global forests. Deforestation is a well-known issue playing a role in the global warming problematic. Recent debates about palm oil products show palm oil production could be a major cause of deforestation.

Indonesia is the perfect country to learn about the possible effect played by palm oil on deforestation because it has major issue with deforestation and, at the same time, it is the main palm oil producer. We then use the Indonesia Database for Policy and Economic Research (found on the World Bank's website) where palm oil production and area are listed for each district between 1976 and 2013.

In our thesis, we make an important review of the literature on global deforestation and also on its link with poverty. Three main theories (the poverty-environment hypothesis, the environmental Kuznets curve and the *Limits to growth's* theory) differ on the link between resources scarcity and income. Evidence shows that, at a macro scale, the poorest countries are more likely to deforest compared to high-income countries. However, the debate is much more divided at the micro scale. Even if the poor rely more on natural resources for their income, the rich tend to collect more firewood due to the low opportunity cost of time to collect wood.

Theoretical predictions are then made to better know the relationship between property rights and deforestation. This is still an open debate as well. On the one hand, people argue it is better to apply coercive laws or taxing devices to protect the commons rather than allow free access to them. On the other hand, credible institutions (smaller than the state) are better to preserve the commons because, by collective action, people are more likely to follow their own rules.

The many uses of palm oil and its comparative advantages compared to other vegetable oils (higher yield, no specific soil required and higher profitability for their owners) soar a lot the demand for palm oil. However, we will see this is no without consequence on forests and especially on primary forests which are those with the most biodiversity.

The most often cited factor to explain palm oil expansion is the rising price of palm oil. Higher prices increase the profitability of the crop and are thus expected to increase production. However, a rising production does not necessarily imply an increase of area but could be the result of a more intensive use of existing plantations. Furthermore, the perennial nature of the crop and the fact that 4 to 8 years are necessary for a new plantation to come into production preclude short term adjustment of area to prices. Our research studies effects of price changes on palm oil production and area, taking these elements into account. The focus is on the different types of palm oil plantations (private, smallholder or state owned enterprise) as they may respond differently to an increase in profitability of the crop (due to an increasing investment capacity, incentives and objective). Will an increase of the palm oil price lead to more or less production of palm oil? Will we observe differences between the different kinds of palm oil plantations' ownership? Will the price make bigger changes on immature palm oil plantations (3 years or less), on mature palm oil plantations (4 years or more) or on already damaged palm oil plantations?

The remainder of this paper is organized as follows. Section 2 shows the importance of worldwide deforestation. Section 3 provides theoretical predictions regarding deforestation. Section 4 explains the role of palm oil production in deforestation. Section 5 highlights our main data, investigates the price elasticity of production depending on contract types and shows our empirical analysis. Section 6 describes our empirical results. Section 7 highlights the limits of our thesis. Section 8 concludes.

2 Deforestation: levels, causes and the role of institutions

In this section we first make the general state of deforestation in the world and then, we develop services supplied by forests and the link between forests and poverty. Finally, we show some causes of deforestation.

2.1 Deforestation in the world today

There is no longer any doubt in the literature about the role played and still playing by deforestation on global warming. Forests are known for storing biomass carbon (Malhi et al., 2008) which, when released into the atmosphere, lead to significant changes in climate (Cox et al., 2000). Deforestation such as tropical forest conversion, shifting cultivation or clearing of secondary vegetation makes significant contributions to global emissions of greenhouses gases (Fearnside, 2000). The more we deforest, the more the mean surface temperature will increase and the more the annual evapotranspiration, the precipitation and the runoff will decrease (Nobre et al., 1991). The total net emission of carbon from tropical land uses seems to have a major global warming impact, equivalent to approximately 29% of the total anthropogenic emission from fossil fuels and land-use change (Fearnside, 2000).

Forest area change is a process, a dynamic of gain (forest expansion) and loss (deforestation). If the notion of deforestation is used, it is because the loss is bigger than the gain in term of forest area. Indeed, over the past 25 years, the extent of the world's forests decreases from 4128 million ha (in 1990) to 3999 million ha (in 2015). This net loss of 129 million ha of forest, about the size of South

Africa, represents an annual loss rate of 0.13%. However, the annual rate of deforestation was halved between the periods 1990-2000 and 2010-2015. This rate has stabilized over the past decade (Table 1). It results of a combination of reduced forest area loss in some countries and increased gains in others. Some countries like Brazil (984 thousand ha)[1], Indonesia (684) and Myanmar (546) lost a lot of their forests between 2010 and 2015. Nigeria has the highest decrease rate (-5%) for the same period. On the other side, China (1542), Australia (308) and Chile (301) increased the most their forest area between 2010 and 2015 where the Philippines knew the highest increase rate with +3.3%. Figure 1 shows gain or loss of forest between 1990 and 2015 for each country (FAO, 2016). Lower-middle and low income countries deforest the most but they only own 25% of all forests while high and upper-middle income countries own 75% of all forests. (Keenan et al., 2015). If we have a look to stocks rather than flows, ten countries account for more than two thirds of global forest area (Table 2) which is quite impressive when we know that 30.6 percent of global land area is covered by forests in 2015[2]. Five of these countries (by descending order of percentage: Democratic Republic of the Congo, Brazil, Peru, Indonesia and Russian Federation) are covered by forests for half or more of their land area (FAO, 2016).

Changes in forest area are uneven across sub-regions but also across climatic domains: for example Southeast Asia (to which Indonesia belongs) witnessed a decreasing trend for the period between 1990 and 2015 (Keenan et al., 2015). Indonesia is also located in the tropical domain (Figure 2) and we will see below (point 2.2) that tropical forest really matter for biodiversity. Tropical forest area shows the most dramatic rate of deforestation with a net rate of loss of 5.5 thousand ha from 2010 to 2015. However, it comes from much higher with a decrease rate of 9.5 thousand ha in the 1990s (Keenan et al., 2015).

Indonesia is not the easiest country to observe tropical forest change because of the persistence of cloud cover obscuring the land surface. Therefore, the method of image composites appears to be less efficient than time-series approaches examining all good land observations to map forest cover change. Another problem is that deforestation is not observed all the time because forest change in Indonesia is really transient and cleared forests are rapidly replaced by timber plantations and oil palm estates. However, some evidence of forest cover loss for Sumatra and Kalimantan (two Indonesian provinces) was found. This loss reached 2.86% of the land area or 2.86 million ha from 2000 to 2005, with the highest concentration having occurred in Riau and Kalimantan Tengah provinces (Broich et al., 2010). Between the mid-1980s and late 1990s, logging, plantations, human migration and infrastructure reduced forests in Sumatra by 61% (Sheil et al., 2009). As a result,

[1] All the following numbers are in thousand ha.
[2] The percentage of forests covering global land area was 31.6% in 1990.

Indonesia exhibited the largest increase in forest loss (1021 km²/year) from 10 000 km²/year between 2000 and 2003 to more than 20 000 km²/year in 2011 to 2012 (Hansen et al., 2013). Section 4.2 will show further evidence of deforestation caused by Indonesian palm oil plantations.

In 2015, primary forests accounted for 33% of the world's forests, or about 1.3 billion ha, half of which are located in the tropics where we have seen there is the most deforestation. 26% of natural forests are reported as primary forests while the remaining 74% is into the category of "other naturally regenerated forests". Since 1990, 31 million ha of primary forest have been reported by countries as modified or cleared (FAO, 2016). Globally speaking, forest resources can be divided into three categories: natural forests, semi-natural (disturbed or partly developed) forests, and plantation forests (Perman et al., 2003). The majority of the world's forests are natural forests with 93% of global forest area. However, the trend is downwards because reported natural forest area decreased by a net 6.5 million ha per year from 2010 to 2015.[3] Planted forest area has increased by over 105 million ha since 1990. Natural forests contribute to conserving the diversity of genotypes and to maintaining the natural tree species composition, structure and ecological dynamics. In other words, they preserve biodiversity. Planted forests are often established for the purpose of production and/or protection of soil and water. Well-managed planted forests can provide various forest goods and services and help to reduce the pressure on natural forests (FAO, 2016).

Reducing deforestation is not the panacea though; forest degradation, when trees are used but not cut, also needs to be taken into account. The canopy cover[4] which measures the density of foliage seems to be a good proxy for forest quality. Other measures such as basal area (the total area covered by the cross-sectional area of tree trunks per hectare) or lopping (the proportion of a tree trunk that has been lopped) are also used (Baland, 2009). A way to observe forest degradation is by the PCCL method which is the acronym for Partial Canopy Cover Loss. The total area of PCCL was 185 million ha for 2000-2012. Again, these losses are unevenly distributed across climatic domains and sub-regions. The tropical climatic domain leads with more than 84% of all PCCL while South and Southeast Asia and South America are sub-regions for which the most PCCL was detected with respectively more than 50 million ha and about 47 million ha of PCCL (FAO, 2016).

[3] This is a reduction in net annual natural forest loss though. For the period 1990 to 2000, the net forest loss was 10.6 million ha per year.

[4] The canopy cover is the amount of ground area covered by the canopy through which direct light passes.

2.2 Biodiversity

The main use of forest is for woodfuel and will be discussed in point 2.4. However, another important aspect is the biodiversity provided by forests. Indeed, the issue of deforestation goes further than the only problem of global warming. By the action of deforestation, biodiversity is threatened. If palm oil plantations do have an impact on deforestation, it would thus be harmful for biodiversity as well. If it is not the case, palm oil companies have the argument that their plantations are more profitable and, at the same time, sustain as much biodiversity as primary forests. However, we will see in section 4.2 that palm oil plantations are very bad for owning biodiversity.

Biodiversity loss is defined as a change due to human interventions, as natural changes of biodiversity are a much slower and longer-term process. The two main causes of biodiversity loss are conversion of natural ecosystems into agricultural or other land use (loss of ecosystem quantity), and the decline of species distribution and abundance in ecosystems due to degradation processes such as logging, pollution, disturbance, and fragmentation (loss of ecosystem quality) (Kessler et al., 2007).

Human-driven land-use changes increasingly threaten biodiversity, particularly in tropical forests where both species diversity and human pressures on natural environments are high. If we compare biodiversity from primary forests (with little or no human disturbance) and from disturbed forests, we easily observed that biodiversity values are much higher for the former. Most forms of forest degradation have an overwhelmingly detrimental effect on tropical biodiversity. When compared with different land use systems, tree species richness declined gradually from primary forest to forest gardens, secondary forests, and cacao plantations which are tree crops like palm oil. Figure 3 shows these results. Trees listed are those with more than 5 or 10 cm dbh (diameter at breast height) according to the MMMeans richness estimator, which was found by Herzog et al. (2002) to be the least biased and most consistent estimator. Forest gardens differed from primary forests by a much lower density of understory trees, while secondary forests had fewer species of commercial interest. Comparative studies of birds and butterflies demonstrated parallel declines of species richness, showing the importance of trees in structuring tropical forest habitats and in providing resources. It appears there is no substitute for primary forests in order to preserve tropical biodiversity (Gibson et al., 2011; Kessler et al., 2005).

Furthermore, the CO2 emissions reduction will be bigger with reductions in deforestation rather than expanding plantation agriculture. However, the trend is for more and more crops because of the high yielding cultivars and improved soil management (Hartemink, 2005). The production of selected agro-commodities[5] in their production countries and areas has been studied. A decline of critical socioeconomics indicators as well as a loss of biodiversity was observed in 54% of the studied production areas. Table 3 provides an overview of the biodiversity impacts per commodity, per country, and for the selected production areas per country for the five selected biodiversity indicators. The total area of expansion due to commodity expansion is also indicated, which is about 67 million hectares, taking all countries into account (column 1). Total biodiversity loss expressed as the ecological claim (indicator B5) shows that in the selected area major biodiversity losses have occurred. These losses are mainly associated with soy and meat in Brazil, soy in Argentina, and palm oil in Indonesia. The total biodiversity loss caused by the four commodities in the selected areas within the study period corresponds to an area of 154 000 km² which is about four times the surface area of the Netherlands (Kessler et al., 2007).

2.3 What are the main drivers of deforestation?

Deforestation is the result of many processes driven by multiple causes. We can distinguish underlying and direct causes of land conversion; underlying causes can include economic development, demographic trends, socio-political factors, institutional and policies changes, and technology factors, and direct causes can include agricultural expansion, wood extraction or infrastructure expanding on, and replacing, forest land (Geist and Lambin, 2001). The underlying causes determine the degree of direct causes resulting in land-use change. These causes and their interaction with deforestation are reported on Figure 4 and Figure 5.

Considering the subject of our thesis, the focus will essentially be made on the palm oil expansion replacing forest land and on the influence of palm oil plantations' ownership which is an institutional factor. On point 4.2, we briefly highlight a policy change started in 1998 by the Indonesian government to cope with increasing monopolies in the sector of palm oil. Few analysis will be carried out later to have an idea about the results of this policy.

Even if the presence of forests could affect household expenditure and welfare in various ways, such as by providing firewood and other forestry products or by providing hunting opportunities, about half of tropical deforestation is commonly explained by the expansion of traditional agriculture (shifting cultivation) (Angelsen, 1995). In Indonesia, research highlighted the role of the expansion of cash tree crop cultivation (among others rubber and palm oil) in deforestation. The presence of large tree-crop estates in Sumatra and Sulawesi particularly seemed to have a strong association with deforestation (Table 4) (Chomitz and Griffiths, 1996; Miyamoto, 2006). Road construction (rural and

[5] Soy in Argentina and Brazil, palm oil in Indonesia and Malaysia, beef in Argentina and Brazil, and coffee in Honduras and Vietnam.

urban) which reduces transportation cost and time and raises profitability of tree crop is a significant determinant of forest clearance (Miyamoto, 2006; Panayotou and Sungsuwan, 1989). Roads in rural areas obviously appear to be more significant than urban roads. However, such roads are important and necessary to improve the standard of living of rural people. It will not make sense to stop building new rural roads in order to reduce forest clearance but rather by increasing the availability of off-farm employment.

Beyond land clearance and building road, an increase in population can play an important role in forest loss because it increases demand for logging, then, demand for fuelwood[6], and finally leads to convert agricultural land. Various measures of population pressure have been used to evaluate the impact of this factor. Population growth (Baland, 2009), population density (Panayotou and Sungsuwan, 1989), agricultural population density (Miyamoto, 2006) or urban population growth (DeFries et al., 2010) have been used to show the positive relationship between forest loss area and local resource use. The latter, unlike Miyamoto's (2006) results, showed that forest loss is positively correlated with urban population growth. Rural population growth is not associated with forest loss, indicating the importance of urban-based and international demands for agricultural products as drivers of deforestation.

However, evidence showing a negative effect of population growth on forest loss area was also found. Population growth can also lead to forest growth in a specific case of well-defined property rights (Foster and Rosenzweig, 2002). The debate about property rights will follow on the next section (3.2). Even level of education can play a role. Higher level of education seems to help reducing deforestation. Together with non-farm business assets, their elasticity related to firewood collection is equal to 0.06. This means that if the level of these assets double, firewood collection will be reduced by 6% (Baland, 2009). However, we have to be careful because this study was made in a very specific context and cannot be generalized. The importance of labor market with or without off-farm employment does matter as well. The agro-forestry system seems to be sustainable when off-farm employment is provided while forest instability occurs for the alternative model where there is no off-farm labor market (Bluffstone, 1995). Public policies to improve education access and to help the shift from agricultural to non-agricultural occupations look like a good way to reduce household's demand for firewood (Baland et al., 2010b).

This short part is quite useful for our analysis later. It allows us to better understand which variables may be used as controls for our regressions. Palm oil sector is listed as a rural sector so its development will lead to have more people employed in the rural sector. Therefore, variables like

[6] Baland (2009) mainly highlighted the role of firewood collection.

level of education, income, employment rate in rural sector, lengths of rural roads or total population seem to be useful controls for the following[7].

2.4 Deforestation and its link with poverty

This section shows that deforestation appears mainly in poor countries (like Indonesia which is a lower middle income). It is thus interesting to know what we can expect in terms of deforestation if Indonesia becomes richer. Knowing that palm oil plantations are, in part, accountable for deforestation in Indonesia (see section 4.2), maybe an increase or decrease of deforestation will have an impact on the palm oil sector.

Three main theories are developed in the literature to explain the link between deforestation or natural resources scarcity and income.

First, the poverty-environment hypothesis (PEH) asserts that poverty forces households to rely on environmental common property resources for their survival. The poor are both the agents and victims of environmental degradation (Angelsen, 1997). While the nonpoor tend to earn more nonfarm income like urban jobs, the poor have to count on land-based activities like farming. Thus, they are more likely to deforest when they clear the land for agriculture, when they cut wood for shelters or when they cut firewood for sale. In general, poor people can lack either the means (capacity factors are at fault) or the desire (incentives are at fault) to protect natural resources (Swinton et al., 2003). Reardon et al. (1995) made a distinction between types of poverty for their impact on environment. Those who are "investment poor" are less likely to be able to make critical investments or follow key land use practices to maintain or enhance their natural resource base. However, they might be better off than the "welfare poor" (those who are below the welfare poverty line). In any case, the important measure for poverty in the analysis of links with environment is "investment poverty". However, the main critic to this theory is that distorted incentives are equally if not more responsible for natural resource degradation than poverty alone (Swinton et al., 2013). According to the PEH, mitigating of environmental degradation must be achieved through reduction of poverty.

Then, the environmental Kuznets curve (EKC) shows relationship between per capita income and environmental degradation. It is named for Kuznets (1955) who hypothesized that income inequality first rises and then falls as economic development proceeds. The EKC proposes that indicators of environmental degradation first rise, and then fall with increasing income per capita. Degradation of

[7] However, we will see we will not be able to implement all these controls in our regressions due to poor data or lack of them.

environment will thus increase until a threshold point where use of natural resources will start decreasing. However, there is no agreement in the literature about the exact place of this turning point at which environmental degradation starts to improve (Dinda, 2004). The EKC literature points to an inverted-U between economic development and environmental degradation. Possible explanations for this EKC are seen in the progress of economic development, from clean agrarian economy to polluting industrial economy to clean service economy and the tendency of people with higher income to have higher preference for environmental quality (Dinda, 2004). The EKC-hypothesis only differs with PEH for medium stages of development (Baland et al., 2010a).

The third theory about a link between development and environmental is less developed in the current literature but has to be taken into account. According to this theory, developed in *The Limits to growth* (written by Meadows et al., 1972), the more economic growth increases, the more natural resources suffers and are degraded. It deconstructs the idea that we will need fewer natural resources (in absolute terms) with higher income. It is called the absolute decoupling by Jackson (2010). There is only evidence for relative decoupling which is the fact that usage of materials increases less and less when income increases. Pressure on natural resources keeps growing, though, with relative decoupling. Higher income in many cases increases the pressure on the environment. This will in particular be the case when investments and purchased inputs are used to increase the capacity to exploit natural resources, and where pollution is related to the use of fossil fuels (Angelsen, 1997). Here, economic growth is seen as a threat to the environment and exponential growth cannot be sustainable in a finite world. This is the exact opposite of the previous theories.

Therefore, depending on the theory, an increase in the Indonesian GDP will have a different impact on natural resources and therefore on deforestation. Expectations for policy implications are thus harder to plan. A policy going in the wrong way could have dramatic effects for forest area.

At the macro scale, low-income countries seem to deforest more than high-income countries with deforestation rate by year of +0.5% and -0.1% respectively (World Bank, 2007). For the period between 2010 and 2015, the poorest countries deforest the most with almost 2500 thousand ha of annual area change. However, they reduced their annual loss compared to 1990-2000 where the loss was a bit less than 3000 thousand ha. Lower middle income countries followed the same trend with a current loss of almost 2000 thousand ha between 2010 and 2015. Upper-middle-income countries did better because they succeeded to rule out annual forest area change to reach a slight gain for the period 2010-2015 while the forest area change among the richest countries has been positive over the last 25 years, following an upward trend through years.

By coming back to the countries listed at 2.1, we only see one country (Brazil), among the three main countries (with Indonesia and Myanmar) which lost forest area, is an upper-middle income country while the three countries (China, Australia and Chile) which gains the most forest are between 2010 and 2015 are at least upper-middle income countries. It is also reassuring to observe that eight countries among the ten countries which own the most forests (Table 2) are at least upper-middle income countries. The remaining two are the Democratic Republic of the Congo (low income country) and India (lower-income country).

Globally about half of total removals are woodfuel, but the share of woodfuel varies significantly by income category (Figure 6). The less a country is rich, the more the share of woodfuel use increases. The share of woodfuel is 93% for low-income countries and goes down for higher income categories: 86%, 40% and finally 17% for high-income countries. At the same time, forestry and logging sector is really important for low-income countries. Its contribution on the GDP of these countries is close to 1.4% while it reaches roughly 0.1% for high-income countries. Taking an aggregate measure, some 12.7 million people were employed in forestry and logging (full-time equivalent) in 2010, about 79% of whom were from Asia (mainly Bangladesh, China and India) (FAO, 2016).

The link between poverty and environment at a micro scale is much more difficult to find. Local natural resources do matter a lot for the welfare of the poor. On average, poor rural households (in India) derived 9 to 26% of their income from common property natural resources while it only reaches 1 to 4% for rich households (Jodha, 1986 in World Bank, 2007). In general, environmental income contributed most to the incomes of the poor (32%), compared to 17% for the rich (Vedeld et al., 2004). However, in the absence of policy reforms, economic growth is likely to increase resource use in the short to medium term, and both poor and nonpoor households contribute to resource degradation. Evidence from across Latin America suggests that the nonpoor and the poor are both at fault. While the poor lack the means to invest in protecting natural resources, both the nonpoor and the poor often lack the incentives for good resource stewardship (Swinton et al., 2003).

Something disturbing is that the impact of slow and small changes in resource availability on welfare is small, which may encourage resource degradation. As degradation occurs, households use alternate resources or obtain their resources from alternate areas. The low opportunity cost of time in poor households implies that the welfare impact of degradation is likely to be small (World Bank, 2007). Indeed, in a study made in rural Nepal (Baland et al., 2010a), authors found no evidence of a reduction in firewood collection when consumption increases. The relationship between both was rather positive and concave. Forest degradation and income are not the kind of variables which are easy to find, especially for the remotest poor households. Some proxies are thus used to analyze the link between them. Firewood collection seems to be a good proxy for forest degradation because wood is not a renewable resource in a so short period of time. Therefore, the more households collect firewood, the more forests are degraded. On the other side, consumption is used as a proxy for income because it seems logical that consumption is part of income and will move in the same direction than income changes.

Forests can also be a provider of natural insurance during times of need. While some agricultural yield risks or unexpected production shocks increase, forest-production collection increases as well to serve as insurance. For example, rural households in Indonesia compensated the loss of agricultural income by increasing forest use (Sunderlin et al., 2000).

Some improvements like development of primary education, growth of nonfarm occupations or drop in fertility can mitigate the level of firewood collection though (Baland et al., 2010a). Therefore, growth does not seem likely to curb local resource use. It is more likely that local resource use will grow in the short to medium term with economic growth unless significant policy measures to increase welfare by taking environment into account are put in place.

3 Institutions and deforestation

In this section, we explain how the actors (have to) handle externalities for the thematic of the commons. We also exhibit theoretical predictions on economics of deforestation. The point is to show the impact of property rights on the commons[8]. Differences in their design may have diverse impacts according to the literature. Finally, we discuss the potential issue of governance in relation to deforestation.

3.1 The role of externalities

Externalities are unlikely to be fully taken into account by the owner of the commons (or here the forest). Issues of deforestation or global warming are hard to internalize and consider a greater extent than the mere exploitation of a smallholder. This section discusses how to best internalize these externalities.

Politician and policies are important elements in the debate about deforestation for both the best and the worst. Without taking the property rights issue into account, some action plans have to be provided by the governance to deal with externalities issue. We cannot exclude people from

[8] Commons are resources like forests, water, fishes, etc for which exclusion is infeasible in the sense people cannot be denied access but use by any one user precludes use of some fixed quantity of a good by other users (Ostrom and Ostrom, 1977).

consumption when they are in front of commons. Therefore, if an actor is not able to internalize the cost of its usage of wood, this cost would be supported by the rest of the community. Government regulation is requisite to solve this problem.

Externalities issue appears when the forest owner's non-timber benefits (in our case) cannot be appropriated by the landowner. In the absence of government regulation, we would not expect them to be brought into the owner's optimizing decisions. Decisions would be privately optimal but socially inefficient. On the other side, if the forest owner is able to appropriate compensation for these benefits, those benefits would be factored into his or her choice and the forest should be managed in a socially efficient way (Perman et al., 2003). A rate of 2.4% is suggested to supply all of the world's timber and fibre needs but the annualized rate of increase in area of planted forests only reached 1.2% in the 2010-2015 period (Payn et al., 2015). We see that costs of deforestation are not totally internalized and offset. It could be explained by the existence of a wedge between privately and socially efficient incentive structures for privately owned forests whenever forests serve multiple uses. Forests are multi-functional, providing a wide variety of economic and other benefits. Private foresters are unlikely to incorporate all these benefits into their private net benefit calculations, as they often have very weak or no financial incentives to do so. Non-timber benefits may be very substantial. Where plantation forests are being managed, the presence of these benefits is likely to cause the length of socially optimal rotations to diverge from what is privately optimal (Perman et al., 2003).

3.2 The property rights factor

Property rights are usually considered as a nice tool to protect individual goods and to preserve natural resources. However, they do not fully guarantee that all externalities will be properly addressed. Some failures could appear, especially if they are badly designed. Moreover, the literature also rips on the question: there is no single solution on how we can best manage the commons.

Usually, forests are roughly split in three different categories in terms of ownership: village commons (village ownership), state-owned forests (state ownership) and open-access resources (no ownership). To summarize boldly the literature on this topic, two main theories differ to know which kind of ownership is better to implement for preserving the forest area.

On the one hand, Hardin (1968) with his paper *Tragedy of the commons* demonstrates there is anything to do to preserve commons when there is an open access to them. They are dedicated to be overused by definition. This is what he means by "tragedy": something controlled by "the solemnity of the remorseless working of things". It thus seems futile to try to escape it.

To explain his point, he takes the example of an open pasture shared by many herdsmen. Each herdsman seeks to maximize his gain so what would be the problem of adding another animal to his herd? The herdsman will receive the benefits of his animal's sale. However, the effects of overgrazing are shared by all the herdsmen. A rational herdsman will conclude that it is best for him to add another animal to his herd. And another; and another…But this is the conclusion that each herdsman is making and it will lead to a "tragedy" for the commons because the pasture shared by everyone cannot be expanded indefinitely. According to Hardin, freedom in a commons brings ruins to all. He disclaims the continuance of the laissez-faire policy (at that time) which was based on the "invisible hand" of Adam Smith (1776[9]). This is the idea that an individual who intends only his own gain is led by an invisible hand to promote the public interest. Hardin showed that people will protect their own private property but without really taking the others into account. However, the air and waters (for example) surrounding us cannot readily be fenced, and so the tragedy of the commons as a cesspool must be prevented by different means, by coercive laws or taxing devices that make it cheaper for the polluter to treat his pollutants than to discharge them untreated. Therefore, his solution to preserve the durability of commons would be to nationalize the commons with the possibility to allocate the right to enter them or to sell them of as private property (Hardin, 1968).

On the other side, Ostrom and Ostrom (1977) argues that characteristics of non-exclusion and jointness of consumption or use (so the commons) create situations in which market arrangements may fail to meet individual demands for public goods. Special forms of governmental or quasi-governmental organization are required to deal with these contingencies. The problems, however, occur largely in relation to the organization of collective consumption. As long as appropriate collective consumption units are organized, several alternative options (such as private or governmental agencies serving as suppliers) can be used for the production and delivery of public goods and services.

In presence of competition with effective mechanisms for conflict resolution, public choice theory suggests that public service industries characterized by multiplicity and overlap will be more efficient and responsive to user demands than highly integrated governmental monopolies. Public economies that are open to competitive supply of public services by private enterprises are likely to be more efficient than public economies which foreclose such competitive opportunities.

As we have seen, a collective action increases the beneficial outcomes so individuals are motivated to make a set of rules and therefore form an institution. However, problems appear when we try to create these institutions to make collective action viable. We have to address how a new institutional

[9] With his book *The Wealth of Nations*.

arrangement can come about (1), how credible commitments can be made (2), and why monitoring must be supplied (3). Ostrom (1990) solved these problems by establishing trust and establishing a sense of community which are mechanisms for solving the problem of supplying new institutions (1), by monitoring and sanctioning people who would benefit in breaking the rules (2), by ensuring the monitoring because without monitoring, there can be no credible commitment and without credible commitments, there is no reason to propose new rules (3).

In conclusion, it would be better, according to her, to clearly defined boundaries and to make it congruent with local specificities. In smaller contexts, the participants should be able and are better in establishing their own rules. Therefore, neither the state nor the market is the best way to sustain long-term, productive use of natural resource systems (Ostrom, 1990).

However, there is evidence for both theories. For example, Burgess et al. (2012) defends the hypothesis of Hardin who would not give property rights to localities. Incentives that local politicians and bureaucrats face are a key determinant of rates of tropical deforestation. The number of jurisdictions within a provincial wood market increases deforestation and makes prices down. Rents from oil and gas exploitation which can be used as substitutes for forest extraction do only work in the short term. It seems to be a similar reaction as developed in a standard Cournot model: as competition increases (due to more districts so more jurisdictions), extraction increases as well to maximize rents in response to the fall of wood prices. This case where political jurisdictions are large enough to have some market power in wood markets and where the political heads of these jurisdictions obtain rents from allowing illegal logging, leads to more and not less deforestation when these jurisdictions are subdivided.

Evidence from Baland (2009), Baland et al. (2010b) or Somanathan et al. (2009), on the contrary, support Ostrom's view which is that small-scale of commons are best managed than state management ones. In Nepal and India, they have started for several years to transfer part of the rights relating to state forest management and use to local communities. They hoped it will provide suitable incentives to rural households for rational and sustainable management. Differences will be observed for the three different types of common property management regimes currently using in Uttarankhand, province in the Indian Himalayas and in Nepal: state forests, open-access forests and local forest management structures (also known as Van Panchayats). These Van Panchayats increased a lot in Uttarankhand, India, from 429 in 1947 to 12 089 in 2006. Studies showed that, on average, the crown cover of Van Panchayat (VP) forests is significantly higher than that of open-access forests (12% for broad-leafed forests), and similar to that of state-management forests. However, forest management costs are on average 13 times higher per hectare of forest for state management than those for VP management. Therefore, the collection of firewood is less affected when the forest is managed by a VP. Subsidies on gas which is the main alternative source of wood are really efficient. For a subsidy of Rs 100 which is 1.2% of the total consumption expenditure per year, the amount of wood collected decreased by 22%. In comparison, an increase of one hour of collection time reduces firewood consumption by 14% but implies a direct household welfare loss of 1%. Subsiding gas thus appears to be more efficient and avoids all the external costs linked to deforestation (Baland, 2009). For the same area, VP forests are found to be 20-30% less lopped, and similar on other dimensions compared to state and open-access forests. The lopping differences are greater the longer the forest has been under a VP showing management differences rather than selection effects. Furthermore, benefits of VP could be underestimated because local communities are more motivated to form a VP and to manage forest areas when these forests are more degraded. For an average of lopping of 66%, a reduction of 13 percentage points of the incidence of lopping when it's managed by VP in Uttaranchal does matter a lot (Baland et al., 2010b).

Another study made in India (Somanathan et al., 2009) provides such same conclusions. Decentralized management of forests has been at least as well managed than centralized ones but at much lower cost. Even if state forests are on average further from villages than council forests, the plan to transfer them towards council control will not change these conclusions because costs' differences are wide enough. We do not even know if this transfer will cost more (because watchmen have to travel further) or less (because of less anthropogenic pressure) than the current costs of managing council forests. More generally, these studies support the idea that rules of the commons have to be fitted to local conditions and should not be decided from a general perspective on developing countries with limited financial resources.

Despite the debate to know which kind of ownership is the best to preserve the commons, there is no doubt about the importance of them. In other words, (well designed) property rights are better than no property right at all. These are an institutional factor which might lead to deforestation by their absence.

The absence of clearly defined and enforceable property rights must at least partially explain the fact that less than 0.1% of tropical logging, the area where there is the most deforestation, is currently being done on a sustainable yield basis (Perman et al., 2003). When property rights are not really well defined, it could lead people to develop their crop tree and expand it into primary forest which is a reason of deforestation (Angelsen, 1995).

Property rights are used as a kind of regulation. People know who owns some specific land and if it is well defined, the land would not be seen as an open access land and will be better handled. It is thus capital to know who owns the forest and who has forest management rights to implement policies going in the right way and to highlight sustainable management of forests. It helps us to better understand who benefits or loses from the variety of products and services provided by forests.

The majority of forest area is publicly owned. In 2010, 76% of global forest area was publicly owned, 20% was private and 4% were still of unknown ownership. Africa and Asia (except East Asia) are the regions reporting the highest proportion of public ownership with 90% or more while the highest proportion of private forests is found in East Asia and Oceania (42%), followed by North America (33%). However, the current trend is for more private forests. Between 1990 and 2010, forest area under public ownership decreased by about 120 million ha, while privately owned forests showed an increase of 115 million ha. It is mostly due to China which implements a reform of collective forest ownership in 2008. This single country accounted for an increase of 85 million ha, a reason why the upper-middle-income category almost doubled its area of private ownership. A majority of publicly owned forests are managed by public administration. However, between 1990 and 2010, the share administered by public administration has decreased from 95% to 82% while private business gained 12 percentage points to reach 15% in 2010 (Figure 7). Considering now the distribution of private ownership of forest, both private business (from 39% to 29%) and communities (from 19% to 15%) have seen their share of ownership decrease (Figure 8). Even though the relative proportion owned by local, tribal and indigenous communities has decreased; its absolute level in forest area gained 4 million ha to reach 64 million ha in 2010. On the other side, the share of individuals who own private forest area has increased from 42% to 56% for the period 1990-2010 (FAO, 2016).

3.3 Governance

The governance is the traditions and institutions by which authority in a country is exercised. This includes (1) the process by which governments are selected, monitored and replaced, (2) the capacity of the government to effectively formulate and implement sound policies, and (3) the respect of citizens and the state for the institutions that govern economic and social interactions amongst them (Kaufman et al., 1999 in Baland et al., 2010). A country with bad governance can lead to many variations in development experiences if they are badly managed.

Indeed, electoral competition and democratization can both surprisingly lead to more deforestation. By changing incentives and by clumsily modifying the actors who have to support the externalities, the previous equilibrium does not hold anymore. The introduction of multi-party elections in Kenya in 1992 raised political motives to allow district access to previously government forest land. More deforestation was observed in loyal districts rather than in opposition districts. This forest transfer was to the detriment of public use like building schools for the preferential private use (to individuals/communities). Finally, higher votes for the ruling party were noted for the next election in swing districts where that greater access to forest land appears (Morjaria, 2012). It could be related to what we have seen previously about property rights. In this specific case, state management was better in terms of forest protection compared to communities/districts management.

4 Why do we focus specifically on palm oil?

Few agricultural developments generate as much controversy as the rapid expansion of oil palm into forest-rich developing countries which is highly discussed in the public debate. With 40% of the global deforestation, the planting of palm oil monocultures seems to be one of the main drivers of this issue (European Parliament, 2017; Koh and Wilcove, 2007; Stone, 2007). This industry plays also a significant role on Indonesian forests which is the main producer of palm oil in the world. In this paper, we are only going to focus on palm oil plantations and their impacts on deforestation. Concerns about the nutritional qualities and health effects of eating different types of palm oil products is another debate and will not be detailed here. Considerable research is already being conducted on these issues (see Colon-Ramos et al., 2007; Karsulinova et al., 2007; Ladeia et al., 2008; van Rooyen et al. 2008).

Moreover, the world production of palm oil is unlikely to decrease because of its many uses (in chemical industry, biofuels, for food production and consumer goods), its higher yield and its soaring demand. We thus have to care about this growing sector.

4.1 Usage and market of palm oil

The palm oil market is a really recent one. It started around the 60's. Then, it knew a fuliginous increase. It is essentially due to the many products we can get from both the fruit and the seed of palm oil, the growing sector of biofuels, its ability to grow on various soils and its higher yield compared to the other vegetable oils.

4.1.1 The palm oil product

Oil (triacyglycerols) can be extracted from both the fruit and the seed, crude palm oil (CPO) from the outer mesocarp and palm-kernel oil from the endosperm (Figure 9). Most crude palm oil is used in foods. In contrast, most palm-kernel oil is used in various non-edible products, such as detergents, cosmetics, plastics, surfactants, herbicides, as well as a broad range of other industrial and agricultural chemicals (Wahid et al., 2005). The derivatives of oil palm fruit are noted on Figure 10. The main one is the palm oil itself with a global production of 66.8 million tons, accounting for 65% of all palm products. By decreasing order, other products are palm-kernel oilseed (18 million tons), palm-kernel meal (9.3 million tons) and palm-kernel oil (7.8 million tons). Cultivation of the oil palm is thus the first major source of the world supply of oils and fats. Taking together, both oils (palm and palm-kernel) are dominating the soybean production (73 million tons) with 74.6 million tons (FAS USDA, 2017). Growth rates of palm kernel oil and palm oil were the highest of all vegetable oils for the period between 1988 and 2000 allowing them to close the gap with soybean oil (Table 5).

4.1.2 The palm oil market

World production of palm oil is unlikely to decrease and knows a spectacular growth from the sixties until now (Figure 11). Where it was initially for its use in the chemical industry, food production or consumer goods, the soaring demand for biofuels[10] explains the more this recent boom. It started at 1.24 million tons in 1965 to reach 10.85 million tons in 1990, 21.76 in 2000, 46.37 in 2010 and 66.8 currently in 2017. The main producers of palm oil are Indonesia and Malaysia, accounting for 85% of global production, with respectively 36 and 21 million tons (Table 6). They were already dominating the world trade in palm oil in 1966 (Sheil et al., 2009). The small decrease we can observe in 1998 on Figure 11 can be explained by the Indonesian economic crisis in 1997. CPO production declined for the first time since 1969 and reached only 5 million tons in 1998. This was a 7% decline in production from 1997. At the same time, the government revised downwards its estimation for new plantations of palm oil for 1999. They estimated at 177 197 hectares which is still a large area but nothing compared to the 266 565 hectares planted in 1997 (a 33% decline). Some of the key reasons for this slowdown are the restrictive government's export tax policy, reform policies that targeted the oil palm sub-sector, a precipitous decline in the world price of crude palm oil or the 1997/98 El Nino Southern Oscillation phenomenon and consequent drought and fires. However, this new availability of land cleared through El Nino drought and related forest fires stimulated future plantation development (Casson, 2000).

Though Malaysian yields are higher on average, Indonesia benefits from abundant land resources and lower wages. Production costs in Indonesia are around $185 per hectare, compared to $226 per hectare for Malaysian palm oil. As a result, Indonesia overtook Malaysia in 2007 as the world's largest oil exporter (Naylor et al., 2007). Sharp increases in global production are mainly driven by these both countries (Figure 12). Furthermore, all the countries producers of palm oil (except Mexico and China) are situated in the tropical domain area (Figure 2 and Figure 13). The main importers of palm oil are India (20.8%), European Union (14.6%), China (10.9%) and Pakistan (6.8%) while exportations are obviously dominated by the main producers. More than 90% of palm oil exported is

[10] It is further developed in point 4.1.4.

from Indonesia or Malaysia with respectively 54.1% and 36.7% of global exportations (FAS USDA, 2017). In terms of global area harvested, palm oil (20.76 million ha) is well below other crops such as wheat (222.24), corn (180.64), milled rice (161.83) or barley (47.25) for 2017. However, this is the yield which differs a lot as we will see below (point 4.1.3). Area harvested follows a steady growth for decades. From 0.142 million ha in 1975, this market expanded a lot to reach 3.66 in 1984, 9.82 in 2000 and still more than doubled until its level of 2017. Forecast show both Malaysia and Indonesia are those who will expand the most their area harvested of palm oil for the following years. Again these countries are leading on the area harvested domain with 9.3 million ha and 5.2 million ha for respectively Indonesia and Malaysia. Thus, they account for almost three quarters of the global harvested area of palm oil (FAS USDA, 2017).

4.1.3 Why this success?

It could be interesting to know why palm oil became the first vegetable oils sold in the world and why almost all the production is concentrated in Southeast Asia. Something we know for sure is that soils do not matter at all. There are no specificities from palm oil plantations which only fit with a typical soil. On the contrary, according to the land suitability assessments, the requirements for cultivation of oil palm are not exclusive. It means that these areas are also suitable (depending on the soils) for rubber, paddy, coconut or cacao cultivations, among other crops (Ritung et al., 2007). Two answers can be provided: climatic factors and high yield of palm oil.

The influence of climatic factors such as visible light, temperature and water vapor partial pressure deficit in the air can influence palm oil's yield. Thanks to a better combination of these elements, Southeast Asia can reach a bunch production (where fruits have grown) of 35 t fresh weight/ha/year while it is only 23 t fresh weight/ha/year in West Africa which has lower solar radiation. These favorable factors may explain the variations in maximal yield between West Africa and Southeast Asia (Dufrene et al., 1990).

Oil palm has a superior oil yield for two main reasons. First, it produces oil not only in its seed but also (and rather unusually) in the fleshy part of its fruit, known as the mesocarp. Second, the crop plant is a large perennial tree that is able to grow year-round thanks to its tropical habitat, whereas the temperate oilseeds only live for a single year and do not have the opportunity to become very large during their brief 4-6 month growing season (Murphy, 2007). Compared to other major oil crops, oil palm has at least a 4 times higher yield (Table 7). To give an example, from 1994 to 2003, the northern region of South America added oil palm plantings to produce 0.6 million tons of oil. This palm oil yield is equivalent to the oil yield from 5 million hectares of soybeans, or one sixth of the entire US soybean area (Murphy, 2007). Even if palm oil's yield is still ahead, data from United States

Department of Agriculture are a bit lower. Easily computed from the division of global production divided by global harvested area, global yield for palm oil would only reach 3.22 MT/HA[11] for 2017 knowing a slow growth for years. However, if we only take the two main countries for palm oil production into account, we note a yield of 3.87 MT/HA for Indonesia and even 4.04 MT/HA for Malaysia. While the yield for Malaysia stays around this level since 2000, Indonesian yield increased a lot for the same period from 2.86 MT/HA in 2000 (FAS USDA, 2017).

The direct profitability of smallholding is a main driver of farmer's choices. The greater profit of palm oil over other cash crops (traditional rattan gardens, intensive rubber plantations, traditional rubber plantations or rubber plantations) seems mainly driven by reduced labor needs (Belcher et al., 2004; Feintrenie et al., 2010). During the mature period of plantations, the maximum area one smallholder can manage is 1.34 ha of rubber monospecific plantation, or 2.94 ha of rubber agroforest, or 3 ha of palm oil plantations (Feintrenie et al., 2010). Rubber is the main competitor and substitute crop in Indonesia. While rubber monoculture has a higher return to land[12] compared to oil palm (Figure 14), the opposite comes true concerning the return to labor[13] (Figure 15). Oil palm plantations employ cheap labor and, unlike annual crops, provide work throughout the year. Thus, oil palm can be an attractive crop for smallholders if they can "survive" the 2-3 unprofitable years before their first harvest. As observed on Figure 14 and Figure 15, profitability of palm oil falls down to 0 after 25 years because it is around this threshold that trees become too tall to harvest and are replaced (Sheil et al., 2009). To extract the most yields of their plantations, farmers have to take care of the life cycle of their oil palm plantations. It can be characterized by three phases:

1) The young immature (0-3 years)
2) The young mature (4-8 years)
3) The mature phase (over 8 years)

Each phase requires particular management for optimum growth and production (Hardter et al., 1997) and the full production of palm oil is reached when oil palm trees have between 8 and 10 years (Larson, 1996).

In official Indonesian statistics, the mean yield of smallholders (2.5 t CPO/ha/year) is half that of large-scale producers (4-6 t CPO/ha/year) (Goenadi, 2008). These differences are probably due to a better access to good planting stock and fertilizer, and low intensity maintenance for larger producers (Sheil et al., 2009).

[11] MT/HA = metric ton (=1000kg) per hectare
[12] It is the net added value generated by one hectare of land during one year (Feintrenie et al., 2010).
[13] It is the return to land divided by the number of working hours for one hectare during one year (Feintrenie et al., 2010).

Increasing prices of the commodity at the global market in conjunction with increasing petroleum price, shortage in supply of vegetable oils, and/or vast area available for development are main factors triggering the fever of oil palm growing specifically in Indonesia (Goenadi, 2008).

4.1.4 The growing biofuels sector

Palm oil is not only used for food, as we have seen above, but more and more as biofuel as well. A growing number of industrialized and developing countries have introduced policies to increase the proportion of biofuels within their energy portfolio. Following the Kyoto Protocol's policies, biofuels will probably quadruple to account about 10% of world motor fuel. Countries such as Japan, South Korea and the United States, and some in Europe, will not have the domestic capacity to meet national demand and are therefore looking to other countries to fill the gap and meet their ambitious targets. Indonesia and Malaysia are already expanding oil-palm plantations to meet this growing demand. They made a commitment to set aside nearly 40% (6 million MT) of their crude palm oil output for biodiesel production (Dufey, 2007; Naylor et al., 2007). Together, they are currently supplying 23% of biofuels consumed in European Union and 46% of the total palm oil imported by EU is used for biofuel's production (European Parliament, 2017).

Biofuels offer significant opportunities to pursue environment and development goals. This new interest in biofuels has already translated into rapidly expanding international biofuel markets. Currently, bio-ethanol is the most widely used biofuel and acts as a substitute for gasoline (Balat and Balat, 2009). It is produced by fermentation from a number of crops, including sugarcane, maize, cassava, wheat, sugar beet, and sweet sorghum. Biodiesel, widely used in Europe, is made from extracted vegetable oil using crops such as rapeseed, soybean, oil palm, and sunflower. As of 2005, leading bio-ethanol producing countries include Brazil (16.5 gigaliters per year), the United States (16.2), China (2.0), the European Union (1.0), and India (0.3). Major biodiesel producers include Germany (19 gigajoules per hectare), France (0.5), the United States (0.3) and Italy (0.2) (Naylor et al., 2007).

Indonesia promotes the use of biofuel for its domestic use as well in order to reduce its dependency on fossil fuels by 25% by 2025. The Indonesian government already provided few incentives to support the biofuel development program, including the allocation of Rp 10 trillion from the state budget for infrastructure related to biofuel development and tax incentives (30% reductions on net profits and interest rate subsidies (10%) for smallholders). The government also allocated 1 trillion per year to subsidize loan interest rates for companies investing in the biofuel industry. Several companies are taking advantage of these subsidies and are establishing biodiesel plants to process

CPO throughout Indonesia (Table 8). The capacity of these plants can go from 300 tons to 1 050 000 tons (Casson et al., 2007).

Already leading in terms of yield for their plantations (see the above section), palm oil also have the biggest biofuel energy yield (gigajoules per hectare) among the major feedstock crops. On average, the energy yield per hectare from Malaysian oil palm was 1.4-fold greater than the energy yield from Brazilian sugarcane, 2-fold greater than the U.S. maize, 4-fold greater than Brazilian cassava and 10-fold greater than Brazilian soybean which has the smallest energy yield (Table 9). It should be noted, however, that these figures represent gross biofuel energy yields; they do not account for energy expended in the cultivation, harvesting, and processing of the crops, which would reduce their net energy yields (Naylor et al., 2007).

Palm oil for biodiesel is also placing the spotlight on land access, ownership and use. Some evidence from Southeast Asia suggests that biofuels production is making improvements in land administration (particularly overlapping customary and formal titling) increasingly important. In some cases where land rights are not recorded, palm oil expansion could strengthen claims to land by poor people and create an increased drive towards equitable land tenure arrangements (Peskett et al., 2007).

4.2 Palm oil and deforestation: overview

The palm oil industry is generally badly seen for its implication in the deforestation (the purpose of our thesis) and its dangers on our health (not covered here). Land cover data suggest that between 1990 and 2005, some 55-59% of oil palm expansion in Malaysia (that is 834 thousand -1 109 thousand ha of a total of 1 874 thousand ha), and over 56% of that in Indonesia (1 313 thousand -1 707 thousand ha of a total of 3 017 thousand ha) occurred at the expense of natural forest cover (Sheil et al., 2009). Even if they are not the only producers (and then not the only accountable for deforestation), some palm oil companies have been accused of clearing or burning lands filled with primary forests without even planting their palm oil plantations. Furthermore, degraded forests abound in Indonesia but are also not used by the palm oil industry for their plantations (Casson, 2000; Casson, 2003; Casson, 2007).

If economic impacts of palm oil are still debated (among others Gyamfi, 2017; Korkeala and Obidzinski, 2012; Rist et al., 2010; Sheil et al., 2009; Susila, 2004), its environmental effects do not make any doubt according to the literature (among others Margono et al., 2005). Beside impacts on deforestation, palm oil plantations are very bad in terms of biodiversity. As a complement to Figure 3, any kind of land use can reach the biodiversity level of primary forests. Even logged forests recorded much more biodiversity than palm oil trees (Figure 16).

In Indonesia, palm plantations seem to be the major cause of degradation and loss of forest habitats. The area of forest lost is greater than the area of plantations that replace them. Ministry of Forestry statistics indicate that close to 70% of the oil palm plantations located in Indonesia were planted on land that formally fell within Indonesia's forest estate between 1982 and 1999. This totaled close to 2.5 million hectares of forest land, most of which was within the provinces of Riau, Jambi, Aceh, West Sumatra, Central Kalimantan and South Kalimantan (Casson, 2000). Since it is easier to obtain a land clearing permit rather than a logging permit, some investors use oil palm as a means to gain access to timber. This explains why location permits covering 5.3 million hectares of land for oil palm developments have been issued in West Kalimantan, while less than 1 million hectares of land have actually been planted with oil palm (Casson et al., 2007). According to the Indonesian government, only 1.4 million hectares (16.5%) had been realized from the 9 million hectares of forests licensed for plantation estates since early 1990 (Casson, 2000). In 2003, although 12.5 million hectares of degraded land was available, most oil palm plantations were established in forested areas (Casson, 2003), showing close relations between oil palm companies and logging companies (Casson, 2000). However, many in the Indonesian biofuel industry and even many in government deny any links between oil palm and forest loss. For many pro-oil palm commentators, oil palm plantations are forests (Sheil et al., 2009).

After the resignation of the Indonesian president, Suharto, in 1998, the new government decided to reform the forest sector and to mitigate corruption. Three main politics were implemented in the following years altering the palm oil's sector (Casson, 2000):

1) All provincial forestry and plantation offices were instructed to revoke the forest use and conversion permits of estate crop companies that were only interested in cutting timber from their concessions and had failed to develop their estates. The Ministry of Forestry and Plantation Estates went further by stopping issuing new licenses to open up conversion forest land for plantation estates because many investors had neglected their projects.
2) The same Ministry decided in 1999 to limit plantation concession sizes. In this regulation, tree crop plantation development area was set at 20 000 hectares in any one province, and up to a maximum of 100 000 hectares in the whole country for a given company. Some financial analysts were concerned about the fact that this policy will more hurt the efficiency and productivity of the sector than preventing the build-up of monopolies. However,

conglomerates succeeded to bypass the legislation by starting up new companies in order to obtain more land.

3) The third element was about making this industry closer to the people. Thus, the Indonesian government has encouraged investors to cooperate with local farmers and cooperatives in the ownership and operation of palm oil plantations. In this way, this encourages the local people to protect plantation areas from looting, theft and damage.

Palm oil industry also suffers from a bad public image for years. It got worse in June 2005 when the business plan of an oil palm mega-project in a 5-10 kilometer band along the border of Kalimantan and Malaysia was made public. The 1.8 million hectare oil palm project would have trashed the primary forests of three National Parks, cut through rugged slopes and mountains utterly unsuitable for oil palm cultivation and annihilated the customary rights land of the indigenous Dayak communities in the border area (Wakker, 2006).

However, this atrocious public image really started with the worst fires worldwide which occurred in Indonesia in 1997 and 1998 (Wakker, 2006). The fires burnt 11.6 million hectares of land of which a third of them was to prepare land for plantations while the Indonesian government banned the use of fire in relation to the clearance of land in…1997 (Sheil et al., 2009). The economic costs of forest loss, degradation and smoke haze pollution of this event were estimated at $2.3-3.5 thousand million, with an additional $2.8 thousand million in carbon release (Tacconi, 2003). Health damages of the population were also evaluated. The haze had an immediate deleterious impact on physical functioning as measured by self-reported difficulty carrying a heavy load. The effect dissipates quickly for prime-age males, persists until the haze clears for older adults, and persists several months after the haze has cleared among prime-age females. The haze has also a substantial negative effect on respiratory health (Frankenberg et al., 2004).

On the contrary of Malaysia where strict no-burning policy for land clearance was established in the 1990s to development the palm oil industry, forest and other fires are an annual occurrence in Indonesia. In one month in 2007, some 5108 fire “hotspots” were recorded in Kalimantan. Burning is still widely regarded as the quickest and cheapest method to clear land for plantations. However, it is only true for large areas of forests and forests on peat soils because the costs to manage and handle heavy machinery are high. Zero burning becomes more cost effective for existing large-scale plantations, secondary vegetation or heavily logged forest. Oil palm companies are even suspected of setting fires to degrade forest intentionally to gain land use permits (Sheil et al., 2009).

Deforestation, degradation, and tropical peat fires contributed to almost half of global fire emissions of CH_4 between 1997 and 2009 (van der Werf et al., 2010). Fires leading to deforestation were the dominant contributor of any kind of fires to carbon emissions present in Indonesia (Figure 17).

Beside companies, individual farmers also engage in palm oil cultivation at the expense of forest. Rather than planting oil palm at the place of their former plantations, farmers prefer extending their cultivated land at the expense of forests. They sell the most remote parts of their holdings to companies and keep the most accessible plots for individual plantations. However, they have no incentives to pressure the forest and its diversity. Indeed, if smallholders usually apply less chemicals and fertilizer than estates, they may also lack the knowledge about environmentally friendly agricultural practices (Feintrenie et al., 2010).

4.3 The palm oil industry

The elasticity to price will probably not be the same for all the actors selling palm oil. Therefore, it is necessary to care about the palm oil industry by better understanding who dominates it and by highlighting the expected trends of the industry. In this section, we will not talk about the negative social impacts of palm oil and the possibility that palm oil do not always comply with the RSPO (Roundtable on Sustainable Palm Oil) principles (Gyamfi, 2017). We will not go further neither on the conflicts appearing between palm oil companies and communities because of unclear land tenure and a recurrent lack of leadership in smallholders' cooperatives (Feintrenie et al., 2010; Naylor et al., 2007).

Along with the fast-growing plantation area the structure of ownership is shifted from the Indonesian government-owned state enterprises to private sectors and/or smallholders. In the early 1970s the so-called PT Perkebunan Nusantara might have owned about 80% of the total areas, whereas the private sectors and smallholders had the rest. In contrast, for about two decades, the latter occupies almost 90% of the total area of oil palm in the country (50% is owned by large private plantations and 40% by smallholders) (Goenadi, 2008; Korkeala and Obidzinski, 2012). In 1997, the Indonesian private estate sector was dominated by ten conglomerates which accounted for 64% of the total planted area owned by private companies. They owned land banks[14] totaling approximatively 2.9 million hectares (Table 10). This was basically 400 000 ha more than the total planted area of palm oil plantations in Indonesia (Casson, 2000).

During the period 1997-2007, the area devoted to oil palm cultivation grew fastest among smallholders, whose annual growth was 12%, compared to 3% for public plantations and 6.7% for private plantations. Over this period, also the level of palm oil production grew fastest among

[14] Area of land agreed to be developed in principle by the governor of a given province.

smallholders. As land constraint limits expansion in Sumatra, future growth is projected to occur predominantly in Kalimantan and Papua. There were 477 palm oil mills in Indonesia in 2006, of which majority were located in Sumatra. Palm oil does matter a lot for the Indonesian economy. It contributed 1.5-2% to Indonesian GDP in the early 2000s, rising to 4.5% in the late 2000s. There are no accurate statistics in the palm oil industry, but approximatively 1.2 million laborers are supposed being employed in this industry in the early 2000s (Korkeala and Obidzinski, 2012).

Smallholder palm oil production has expanded rapidly over the past decade. It is estimated that around 30% of smallholder production is produced by individual farms and the remainder is by joint partnerships with large plantations. National data do not distinguish between independent smallholders and joint partnerships, but according to available estimates the recent growth can be largely attributed to independent smallholders (Korkeala and Obidzinski, 2012).

5 International prices and production in Indonesia

Our research studies the price effect on palm oil production and area. The focus is made on the different kinds of ownership of palm oil plantations (private, smallholder or state owned enterprise) to observe any difference. It might be useful for policy applications to know which property rights generate the most deforestation in reaction to price changes as we listed on point 3.2. Will an increase of the palm oil price lead to more or less production of palm oil? is another interesting question for future policies wanting to play a role in the management of the forests. Finally, will the price put more pressure on immature palm oil plantations (3 years or less), on mature palm oil plantations (4 years or more) or on already damaged palm oil plantations? By knowing the effect of price on total production or area of palm oil, we could go further by investigating which kind of palm oil plantations responds the most to price.

The following of this section will be as follows. First, we describe our data and provide describe statistics. The explanation for our choice to use international prices rather than domestic (Indonesian) prices of palm oil is present in this section. Next, we make a short review of the literature on price elasticity of supply and our specific context of perennial crop. Finally, we estimate the response of Indonesian producers to changes in international price, distinctly by type of producer and type of palm oil plantations' condition and perform regressions.

5.1 Data

Our database was found on the World Bank's website and is called the Indonesia Database for Policy and Economic Research (World Bank, 2017b). Burgess et al. (2012) used this database in their paper on the impact of an institutional change (an increase in the number of political jurisdictions) on deforestation. They found that it leads to more deforestation because of the higher concurrence between the jurisdictions.

The dataset includes 224 variables for 546 different Indonesian districts for each year between 1976 and 2013. They are 20 748 observations[15] due to lots of missing values. A main drawback of the database is that variables are poorly defined especially for early years. The variables on palm oil cover the period 1996 until 2010. We have eleven relevant variables related to palm oil. All of them will be used as dependent variables. To be clear, we have the total production of palm oil (in tons), the total area of palm oil (in ha), the area of palm oil depending on the condition (damaged, immature or mature) in ha, the area of palm oil depending on the property rights (private sector, public sector or smallholders) in ha and the production of palm oil depending on the property rights (private sector, public sector or smallholders) in tons.

The differences between property rights are basically depending on who owns the palm oil plantation. State-owned enterprises are part of the public sector, companies are listed in the private sector while households are rather in the smallholders sector. In the absence of a clear definition in the database, we refer to the literature presented above to interpret the distinction in term of maturity. In line with the literature presented in 4.1.3, the immature plantations are those younger than 4 years. Mature phase begins from 4 to 8 years until 25 years so it is really imprecise. We assume that our variable "Mature" takes the plantations from 4 years and more. However, the biggest effect should be observed for plantations around age 8. Finally, damaged plantations are those in situation of post-production (Sheil et al., 2009).

Total production (area) of palm oil is the sum of the production (area) of palm oil for each district by year.

Table 11 reports the number of observations for each dependent variable from 426 for the production of the public sector to 2119 for the total area of palm oil. Due to the large number of missing variables, these numbers are low compared to the total number of observations of our dataset.

Table 11: Descriptive statistics for each dependent variable.

Variable	Obs	Mean	Std. Dev.	Definition
Damaged	865	1.651.613	3.685.886	The palm oil land area damaged (in ha)
Immature	2032	18208.41	44435.17	The palm oil land area immature (in ha)

[15] An observation is by district for a specific year.

Mature	1916	45693.56	118969	The palm oil land area mature (in ha)
POLAprivate	853	66181.46	112359.4	The palm oil land area of the private sector (in ha)
POLAsmallholder	1874	29492.28	71797.52	The palm oil land area of the smallholders (in ha)
POLApublic	473	24046.03	49638.33	The palm oil land area of the public sector (in ha)
totPOLA	2119	59437.03	152358.8	The total land area of palm oil (in ha)
PPprivate	801	157715.2	307029.6	The production of palm oil from the private sector (in tons)
PPsmallholder	1653	68815.97	184096	The production of palm oil from the smallholders (in tons)
PPpublic	426	80200.04	185434.3	The production of palm oil from the public sector (in tons)
totPP	1844	148724.5	432173.1	The total production of palm oil (in tons)

One of our main data, the international price, was collected on the website of the World Bank (World Bank, 2017a). Because our dependent variables are in year, we simply take the international price for each year between 1976 and 2013.

To analyze the price elasticity of the Indonesian palm oil supply, we decided to take the international prices of palm oil (in $ per ton). These prices were easier to find and, in our opinion, less exposed to miscalculations than for domestic prices. However, we are not naïve and we know that, because Indonesia and Malaysia control 85% of the global production of palm oil (see 4.1.2), both domestic prices (and especially the Indonesian one alone) should have a direct impact on international prices.

However, in practice, the world price does not seem to be determined by the domestic price. To study the effect of biodiesel demand on the Malaysian palm oil market, Applanaidu et al. (2011) explained the influence of both prices. While the domestic price is significantly affected by world palm oil price (as well as for Malaysian ending stock of palm oil, biodiesel demand and lagged domestic price), the opposite does not seem to be right[16].

[16] The world price of palm oil is not determined by the domestic price. This equation can be specified as follows:

$$POWP_t = \alpha_0 + \alpha_1 PSB_t + \alpha_2 WGDPN_t + \alpha_3 WSTOCK_t + \alpha_4 POWP_{t-1} + \mu_t \quad (1)$$

Where $POWP_t$ is the real world price of palm oil (USD/tonne), PSB_t is the real world price of soybean oil (USD/tonne), $WGDPN_t$ is the world GDP at 2000 prices (USD billion) and μ_t is a random residual term.

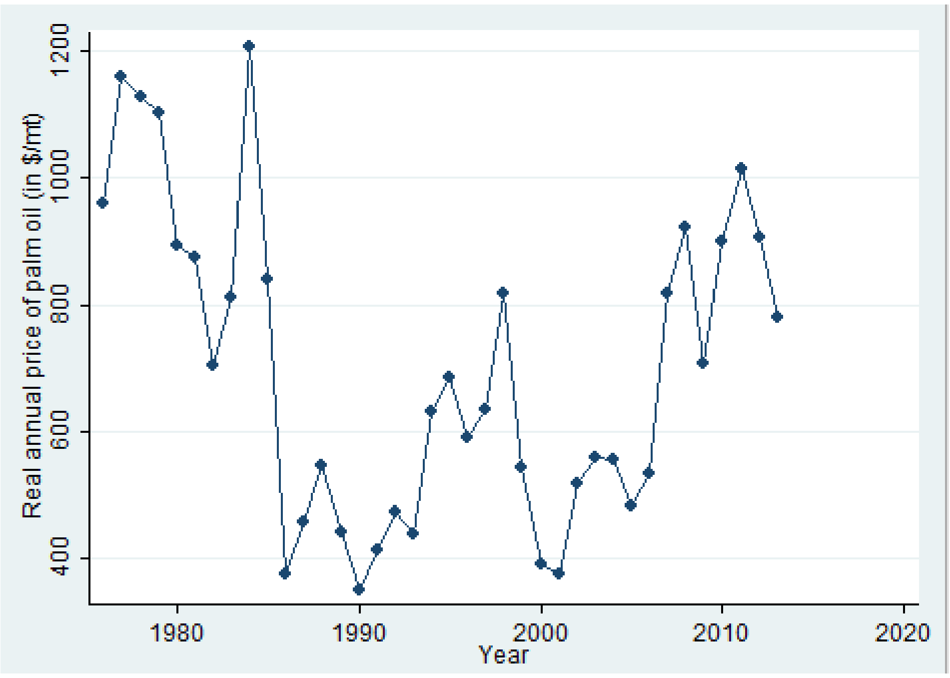
With the so-called "combined marketing strategy" between Malaysia and Indonesia to increase the world price of CPO (crude palm oil), we may worry there are some effects of domestic prices on world price though. In 1999, Indonesia decided to decrease its export tax on palm oil from 60% to 10%[17]. However, few companies have taken advantage of the government's new export tax policy because domestic price for CPO is still higher than the world of CPO. They thus decided to start cooperation but being careful not to act as a cartel. Therefore, Malaysian producers have been encouraged to engage Indonesian producers and exporters in talks to improve the price situation. Once CPO prices increase, we can expect to see further expansion and planting programs occur in the palm oil sector. A price increase will also encourage companies to increase CPO exports which will gain from the new export tax on CPO (Casson, 2000).

Indonesian refinery system is dominated by five large refiners organized into two alliances which influence more than 60% of the refining capacity and control the most popular name-brand cooking oils. There are called the Big Five Refiners. If they collude, they may be able to increase domestic prices above competitive levels because monopolistic pricing is frequently characterized by stable but high prices. Evidence shows a domestic price of 26-31% above competitive levels. However, these results were not conclusive. Therefore, even with potential for oligopolistic pricing, the statistical evidence is not concluding (Larson, 1996).

To conclude, we know that there are doubts that domestic prices may influence the world price. However, evidence showed above does not seem to support this hypothesis. We think international prices will be as much effective as Indonesian domestic price, even with the high volatility we can observed on Figure 18, to analyze supply response of palm oil (and even more for people worrying about their palm oil exports) but avoiding possible miscalculations.

[17] The IMF still imposed Indonesia not to set export tax on palm oil higher than 10%.

Figure 18: Evolution of real annual price of palm oil between 1976 and 2013 (in $/ton).



Source: World Bank Commodity Price Data (2017a)

The inclusion of some controls is quite difficult due to a lack of data decreasing a lot our observations once we regress them. We make a review of the controls developed earlier (point 2.3) to know which one(s) we can use for our regressions without losing too many observations[18]. Table 12 listed all these variables with their number of observations. The revenue and the literacy rate will be our only controls.

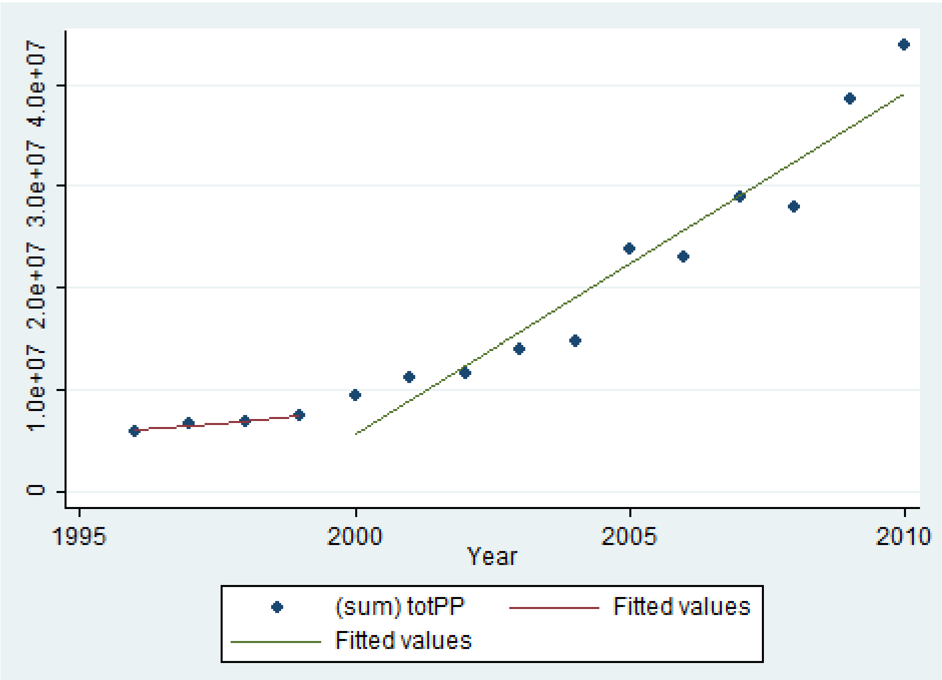
[18] The number of observations for the average score of the national exam for the primary level (Primary), the junior secondary level (Junior) and the senior secondary level (Senior) do not even reach 500 observations. Idem for the length of road in good shape per district (road) with only 226 observations. The GDP for each district (gdp) gets only 812 observations. We have 1880 observations for the percentage of a district population in urban areas (urban) and the employment rate (Employmentrate) we can compute thanks to our dataset ((number of people employed/number of people in the labor force)*100) has 3777 observations. We drop all these controls of our regressions due to a lack of data because it does not match really well our dependent variables. Indeed, we have less than 1000 observations in our regressions. Total population of each district is also dropped because we fear a kind of miscalculations in the original database. For example, the population of Bali in 2000 is equal to 3 111 402 people but reaches 3 197 107.89 in 2011. What does the comma mean? By security, we prefer to not take the population into account.
However, the revenue of each district (revenue) counts 8064 observations and will be used as a proxy for GDP or income while the literacy rate for population age 15 and over (literacy15), in % of total population of a district, reaches 7553 observations. It will be the control usually played by education.

5.2 Descriptive statistics

We start with describing in depth our data and how they evolve over time. Our main variables are those dealing with production and area of palm oil plantations. In short, we have both acreage and production for the three kinds of ownership (private, smallholder and public). We also have the acreage depending on the condition of palm oil plantations (immature, mature and damaged). Moreover, we get the total production and area of palm oil.

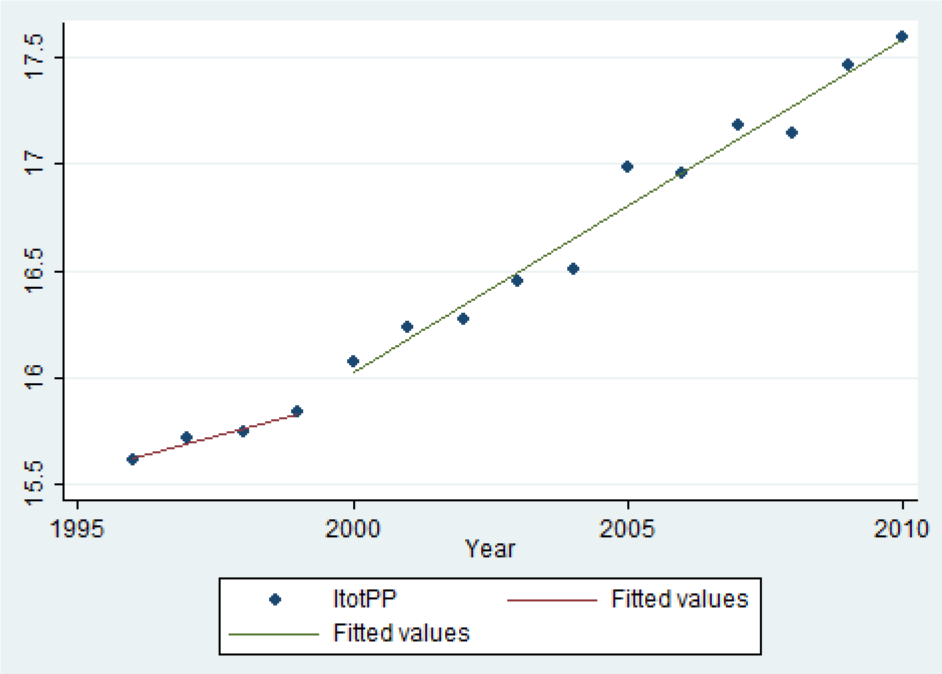
We present two trends on Figure 19: one before 2000 and one after 2000. This is because we would like to observe the effect of the legislation made by the Indonesian government in 1998 and 1999 to prevent the growth of monopolies (see 4.2 for the policy made the Indonesian government, and 4.3 and table 10 for the ten conglomerates dominating the private sector). We can note these two trends do not have the same slope at all. However, it is not really convincing considering this graph with level values.

Figure 19: Total production of palm oil between 1996 and 2010 with trend lines for periods 1996-1999 and 2000-2010 (in tons).



Therefore, we use the logarithmic scale (Figure 20) because the data values are spread out better with this method. It allows us to better observe differences and represent increase rate of production. The private sector worried about the difficulty to invest with the new legislation (Casson, 2000). However, the graph suggests that the increase in competition has led to an increase in the total palm oil production after 2000.

Figure 20: Total production of palm oil between 1996 and 2010 with trend lines for periods 1996-1999 and 2000-2010 (in log of tons).



The 90's celebrated the beginning of the end of the public's predominance in palm oil's production (Figure 21). After this, its volume of production in this industry stays constant, while private and smallholder sectors kept growing, reaching only 10% of the total production in 2010. The three different kinds of ownership produced more or less the same with a quantity around 2 million of tons in 1996. The production of the public sector "only" doubled in our dataset to reach 3.8 million of tons in 2010. The production of smallholder is more subject to variation with a sharp decrease in 2008. However, this sharp in 2008 can be explained by the surprisingly lack of data for this year and for this variable. Production of the smallholder is thus not supposed to decrease so much in 2008. Though, they have raised their production sevenfold between 1996 and 2010. Private sector produced far more compared to the two other sectors in 2010. It also appears to react a lot to the new legislation implemented in 1998 and 1999 even if the increase of palm oil produced by the private sector from 2000 is much more obvious with a logarithmic scale (Figure 22). For the period of our database, the production of the private sector had jumped tenfold from 2.1 million in 1996 to 23 million of tons in 2010.

Figure 21: Production of palm oil between 1996 and 2010 depending on property rights (in tons).

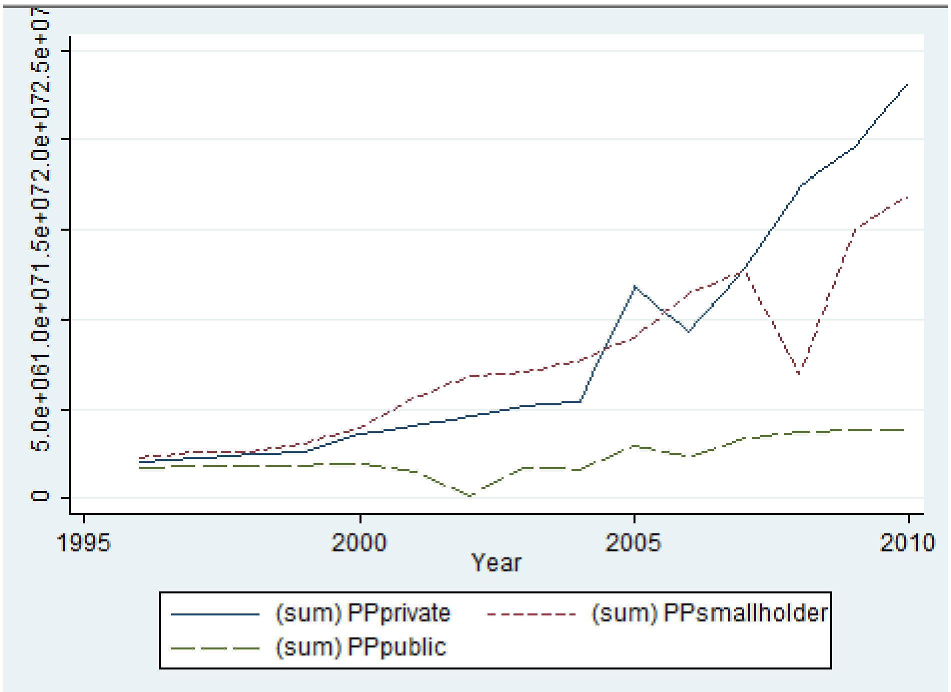
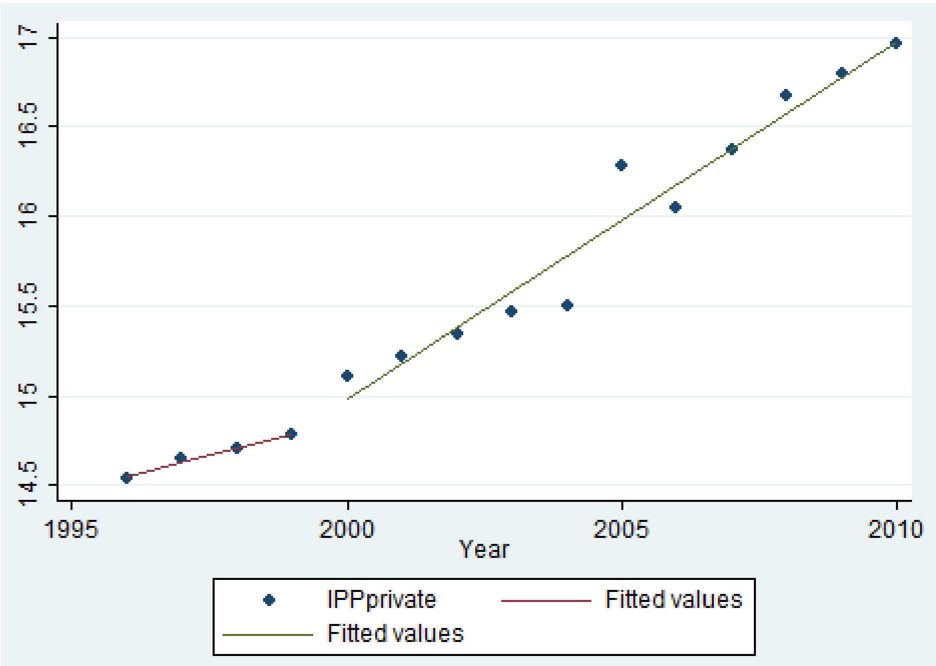


Figure 22: Production of palm oil from the private sector between 1996 and 2010 (in log of tons).



We would like to know if the break in trends is similar for the acreage. However, we can see on Figure 23 there is no significant difference between both trend lines. Even if the total acreage does not stop increasing over time, the increase of palm oil production was stronger from 2000. It could be explained by the fact that companies, knowing they will be limited in their new expansion of plantations, preferred to produce palm oil more intensively. Therefore, they produced more on the same area.

Figure 23: Total area of palm oil between 1996 and 2010 with trend lines for periods 1996-1999 and 2000-2010 (in log of hectares).

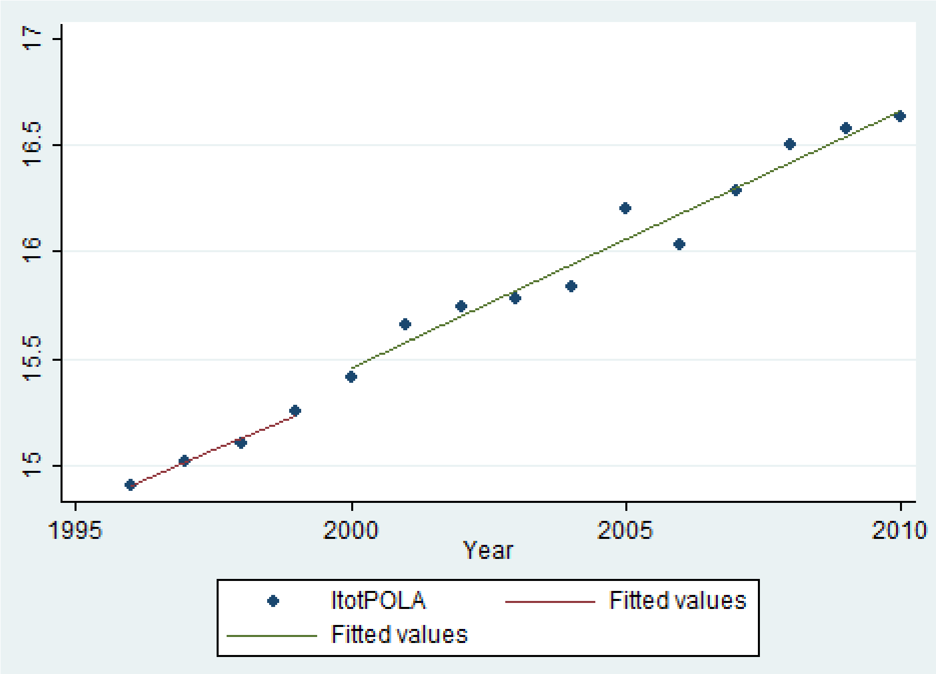
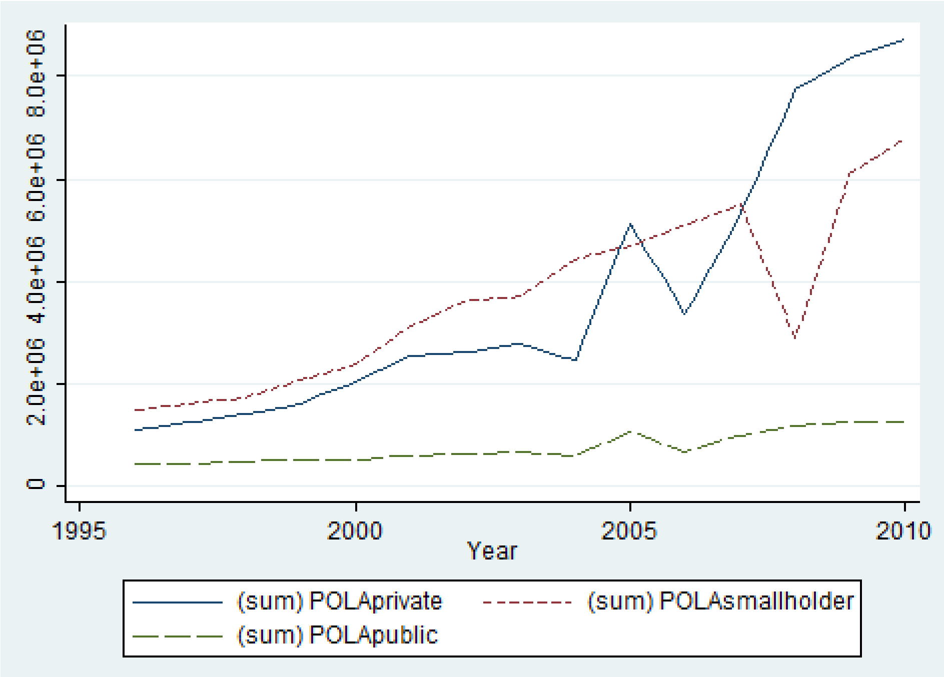


Figure 24 is pretty similar to the one showing production for each type of ownership. It means yield of plantations does not differ a lot between each category. The mean of yield across time and taking all the districts into account is equal to 4.3 tons/ha for the private sector, 3.3 for the public sector and 3.9 for the smallholders. The area owned by public plantations does not increase as much as others. It started from 427 000 hectares in 1996 to reach 1 300 000 hectares in 2010. The increase of the land area handled by smallholders is much impressive because it rose by more than fourfold from 1.5 million of hectares in 1996 to 6.8 million of hectares in 2010. However, the same drop appears in 2008, as for the production (Figure 21). This is also for the same reason: lots of observations are missing for the area owned by the smallholder in 2008. As for the production from the private sector, the total area had almost eightfold from 1.1 to 8.7 million of hectares for the same period.

Figure 24: Land area of palm oil between 1996 and 2010 depending on property rights (in hectares).



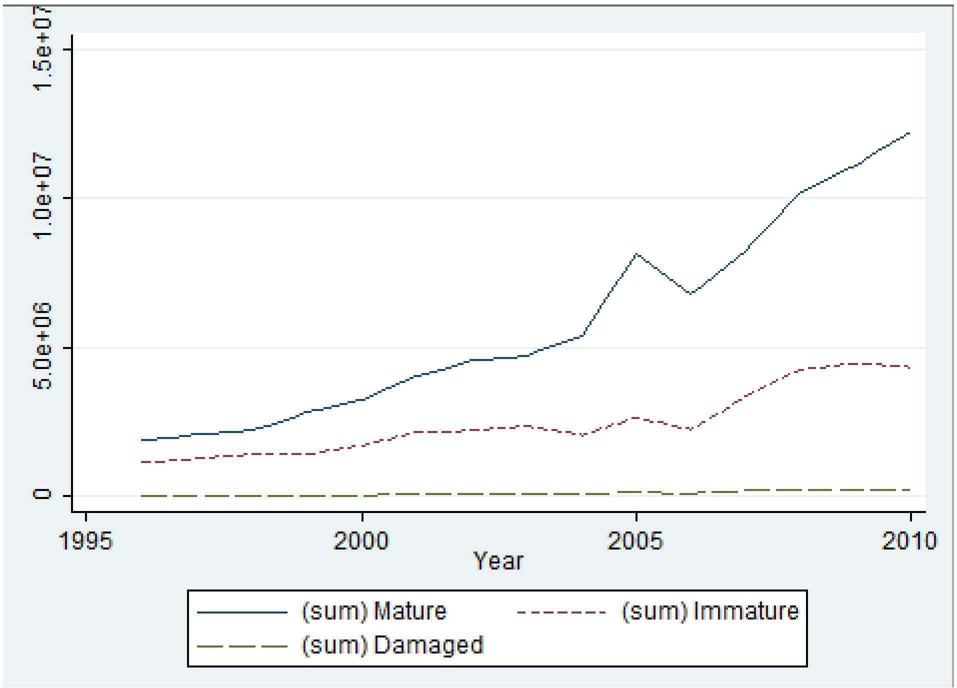
Before turning to estimation, we may already discuss our expectations regarding the response to the price for each kind of ownership. We expect that the public production will not change a lot with prices. The politician initiative to plant more plantations may take time and prices variation will not be the major element which will determine their final decision. On the other side, we expect the private sector to respond more to price increases because the main objective of private firms is to maximize their profit. It is more difficult to expect the smallholder's reaction. We know that they are typically more risk averse than companies, that they may pursue other objectives than the profit maximization and that their production decision may be influenced by their labor endowment if the labor market is not perfect. However, other factors will also influence this decision like the financial situation of the household, their current investments (other crops, tuition fees if they have children, etc.), life cycle of the household (if the head of household is old or close to retirement, he/she will be more reluctant to make investments with long and risky returns).

Since palm oil needs around 8 years to be very productive, the choice to plant depends on price expectations and expected profitability of the tree crop.

Reactions to price for the acreage will be more or less the same than explained for production. However, it is possible that all elasticities for acreage will be lower compared to those for production because acreage is less volatile. Indeed, while it is possible to "play" with the production (harvested more in period of high prices or harvested less in period of less prices), acreage will react more slowly due to the time to get permits, to reclaim current forests, etc.

The first observation we can make on Figure 25 is that damaged plantations stays constant over time, approximatively 1% of the total plantations. We thus expect a low elasticity to price for damaged palm oil trees. Immature trees (younger than 4 years) rose almost fourfold for the period of our dataset (from 1.1 to 4.3 million of hectares). Its elasticity to price should be bigger than for damaged trees because prices are part of the decision to plant. Therefore, production of immature trees will increase when low lag of prices increases. Mature trees (from 4 to 8 years until 25 years) are obviously the predominant element in palm oil production. Its production reached 12 million of hectares in 2010 from only 1.9 million of hectares in 1996. Its elasticity to price has to be bigger than immature trees but with longer lag of prices because it takes more time to have productive trees.

Figure 21: Production of palm oil between 1996 and 2010 depending on condition of palm plantations (in hectares).



5.3 Review of the models to estimate price elasticity of supply

The supply function is an upward sloping curve. Based on the theory of profit maximization, the quantity of goods supplied increases in reaction to a price increase of this good, holding everything else constant, for a competitive market (Gale, 1955). This is the same for the agricultural sector. For an individual farmer, if the whole price distribution shifts upwards, then presumably he will wish to supply more (Newbery and Stiglitz, 1979). When we aggregate crops, farmers do respond to changes in the aggregate price index as well (Bond, 1983).

On the individual farm, substitution among crops is relatively easy. This means that on typical farms small changes in the relative prices of crops may make large changes in the cropping practices profitable. However, agricultural prices are among the most volatile in the economy. Therefore, if farmers always react to the last year's price, they would probably find themselves with lower incomes when extensively revising their production plans in response to the wide swings that take place in the relative price of various crops (Nerlove, 1956). Especially since the fixed cost of crops switching does not have to be neglected (time to plant the new crop, time for the new crop to be mature, cost of new seeds and waste of old seeds, etc.). Turnovsky (1974) analyzed the gains from price stabilization. He found that price stabilization provides an overall welfare gain that is higher (because supply decisions are made before the actual market price is known and so are based on price expectations) than when supply depends upon actual prices .

Most of supply elasticities were identified as the elasticity of acreage with respect to price. However, producer's decision to open up more land for his/her land does not react directly to price increase because time is required to purchase more land, clearing land or planting. There is thus a lag between price increases and reaction of the supply side (Lau, 1999). In addition, farmers will not react directly to last year's price but rather to the price they expect, and this expected price depends only to a limited extent on what last year's price was.

The famous model of Nerlove (1956) shows this relation between the acreage (as the dependent variable) and the expected price:

$$x_t = a_0 + a_1 P_t^* + u_t \ (2)$$

Where x_t is the acreage this year, P_t^* the price expected this year and u_t a random residual term.

Price expectations are, of course, shaped by a multitude of influences, so that a representation of expected price as a function of past price may merely be a convenient way to summarize the effects of these many and diverse influences. But how should we use past prices to represent expected price? Each past price represents only a very short-run market phenomenon, an equilibrium of those forces present in the market at the time. It is for precisely this reason that farmers may not react only to last year's price. This does not mean, however, that the past has no relevance for the future. More recent prices are considered as a partial result of forces expected to continue to operate in the near future: the more recent the past price, the more it expresses the operation of those forces relevant to expectations. Hence, the influence of more recent prices should be greater than the influence of less recent prices (Nerlove, 1956). Consequently, we expect to observe higher elasticities for the long-run compared to the short-run (Bond, 1983).

To help motivate our econometric analysis, we will describe the Nerlove's model which is the most often used to estimate expected price (or at least to start with a basic model) and how he gets equation (2). One hypothesis to make is that each year farmers revise the price they expect to prevail in the coming year in proportion to the error they made in predicting price this period:

$$P_t^* - P_{t-1}^* = \beta\,[P_{t-1} - P_{t-1}^*] \quad (3)$$

Where $P_{t-1}^*$is the last year's price expected, P_{t-1} is the actual price last year and β the coefficient of expectation ($0 < \beta \leq 1$).

If we consider β as the proportion of the error by which farmers revise their constant, their expected price would be represented by a weighted moving average of past prices where the weights are functions solely of the coefficient of expectation (β). In equation, it results as:

$$P_t^* = \beta\,P_{t-1} + (1-\beta)\beta\,P_{t-2} + (1-\beta)^2\beta P_{t-3} + \cdots \quad (4)$$

Where P_t is the actual price in period t.

Since the coefficient of expectation,β, is between zero and one the weights will decline toward zero as we go back in time. Although in theory all past prices must be included, the fact that the weights decline means that practically we can safely begin to ignore all previous prices depends on the size of the coefficient of expectation: the closer is the coefficient of expectation to zero, that is, the greater the tenacity with which farmers cling to their previous expectations, the greater will be the number of past prices we cannot ignore.

However, the coefficient of expectation in equation (4) is hard to know and to aggregate from one farmer to another. Thus, it is impossible to estimate equation (2) because we cannot observe P_t^*. We must represent P_t^* in terms of variables we can observe. Equation (2) means we can write any expected price, P_t^*, as a linear function of acreage x_t. In particular, last year's expected price, P_{t-1}^*, can be represented by last year's acreage, x_{t-1}, because the expected price this year is a function of actual price last year and expected price last year (see equation (3)). We can replace last year's expected price in equation (3) by a linear function of last year's acreage. If we now substitute this new expression for expected price into the acreage function, equation (2), we obtain a new relation between acreage this year and last year's actual price and last year's acreage as follows:

$$x_t = \pi_0 + \pi_1 P_{t-1} + \pi_2 x_{t-1} + v_t \quad (5)$$

Where v_t is a random residual different from u_t. π_0 represents $a_0\beta$, $\pi_1$equals $a_1\beta$ and $\pi_2$equals $1-\beta$. We cannot, in practice, observe expected price, but we can observe last year's price and last year's acreage. Therefore, we should observe a correlation between acreage this year and actual last price and acreage last year if acreage does respond to expected price.

However, the Nerlove's model was originally applied to field crops. Our case with palm oil is somewhat different. Longer lags are expected for tree crops because time between planting and cropping is longer.

For perennial crops, we will have an enhanced version of Nerlove's model as follows:

$$x_t = a_0 + a_1 P^*_{t-g} + u_t \quad (6)$$

Where x_t is the acreage of mature trees in period t, P^*_{t-g} is the expected price of the farmers when planting decision is taken and u_t is a random residual term. The subscript g takes the time required for the palm oil planted to grow into account because we assume that the acreage response function will not depend anymore of the price expected this year, as developed in the Nerlove's model (equation (2)), but rather with the price expected when the farmer decided to plant his/her palm oil trees.

The production of palm oil may be considered in two parts: potential production (so the forces which motivate the farmer to plant) and the proportion of potential production that is harvested (so the relationship between acres planted and output harvested). Decisions relating to the former are primarily long run whereas the harvesting decision is short run. The principal factor determining potential production is the level of past investment. It may be conjectured that both the investment and the harvesting decisions are mainly determined by expected prices (Wickens and Greenfield, 1973). New plantings and removals depend on the existing age structure of the crop and expected values for future prices and other exogenous variables. Acreage in individual age categories evolves depending upon existing acreage, new plantings, and removals (Knapp and Konyar, 1991).

The literature proposes various types of model to address the question of estimating the elasticities of supply for perennial crops with both production and acreage as the dependent variable. There is no really one model supplementing the others and each author defends its own model by criticizing the previous ones. Two main reasons explained this diversity in the literature:

1) The available data

Most of the authors elaborate a sophisticate model but can't really apply it in practice because of a lack of data. Some data are hard to find like the existing age structure of the crop, the mature acreage, the plantation area or the area harvested and most of them suffers from imprecision because sometimes rudimentary ways are used on the spot to compute the acreage or the production. Estimation of the future supply curve is also used to estimate elasticities. However, it is really difficult because many factors may play a role and change the supply side. Results do not seem very robust with this method neither. Therefore, authors have to go a bit backwards by using a more generic model which captures less the price's effect.

2) The complexity of the farmer's decision

When we observe the current output of a perennial crop, the farmer's decision to plant was made a long time ago. Thus, we can't analyze the current situation but rather what happened in the past and why and how does the farmer take his decision several years ago. According to the risk-aversion theory, a farmer will prefer the less risky choice compared to another one for the same output. A farmer has to think about the long run when he plans to plant and in a certain way where and how he will be in a few years later without taking the current situation into account because the output will not appear directly. This question of long term investment for a farmer is complex by nature to analyze because many factors will probably enter in the final decision. History will, without a doubt, play a more important role than for annual crops. The farmer will for example take the previous prices of the market into account to make an expectation of the future ones to know if his perennial crop will be profitable.

We are going to present main models used to predict how production and acreage respond to price change. Then we will discuss what we can estimate in the case of palm oil, given the limited data available.

In a simple model developed by Stern (1965), output depends on current price, mature acreage, and a trend variable for unspecified factors like changes in productivity.

$$PP_t = \beta_0 + \beta_1 price_t + \beta_2 mature_t + \beta_3 others_t + u_t \quad (7)$$

Where PP is the production of palm oil, $others$ the trend variable for unspecified factors and u_t a random residual term.

While mature acreage is unknown (depending on available data), planting is postulated to be a function of the current price. Thus, taking first differences, the change in output depends on the change in current price and the change in mature acreage, which is a function of the price lagged by the gestation period. It may be more realistic to assume that planting decisions depend on expected future price rather than on current price: this is done in Bateman (1965). Low price elasticities of supply were found with these models and the only one significantly different to 0 is from the Nerlove's model with a coefficient of 0.22 (Ghoshal, 1975).

Different models were used to analyze the acreage response in the literature. Ekaputri (1996) is an example of a more sophisticated model compared to the previous ones. He made his work on Malaysian palm oil.

First, he made moving averages of his independent variables. He decided to take two different years of prices into account (in t-2 and t-3) but not the last year's price to capture grower expectations. Then, he not only implemented prices of palm oil but also of coconut oil which is another Malaysian major commodity and the second main vegetable oils imported (after palm oil) in Malaysia (FAS USDA, 2017). Therefore, coconut oil is a substitute of palm oil. As seen in the Nerlove's model, he also put the lag of the dependent variable as an independent one. However, he used longer lags with the moving average in t-2 and t-3. Finally, he wanted to implement the weight of Malaysian production. Since Malaysia and Indonesia are the two main producers in the world (see 4.1.2), he inserted the proportion of Malaysian production over production of both countries.

His model is as follows:

$$HA_t = \alpha_1 + \alpha_2 MHA23_t + \alpha_3 MPP23_t + \alpha_4 MPC23_t + \alpha_5 MMP23_t + \alpha_6 MIMP23_t + \alpha_7 GI_t + \varepsilon_t \quad (8)$$

Numbers 2 and 3 in each variable mean it is a moving average of these variables in t-2 and t-3.Thus, HA is the harvested area, $MHA23$ the moving acreage, $MPP23$ the moving average of palm oil price, $MPC23$ the moving average of coconut oil price, $MIMP23$ the proportion of Malaysian production over Indonesia and Malaysia, $MMP23$ the moving average of Malaysian production and GI a dummy variable which takes value 1 if t ≥ 1990, as Indonesian government stopped controlling domestic palm oil prices in 1990.

The elasticity with respect to palm oil price was found to be very small, 0.358, which indicates inelasticity. Total oil palm area planted was also found to significantly respond to its own and rubber prices in the study of Talib and Darawi (2002). However, the degree of response is inelastic[19] which is consistent with the perennial nature of the oil palm. Perennial crops are slow to react to changing market forces.

Other models can be found such as those made by Bateman (1965) or French and Matthews (1971) but we think the three models developed above (Nerlove, 1956; Stern, 1965 and Ekaputri, 1996) are representative enough of the global literature about supply elasticities.

As we note, computing price elasticity of supply will not be easy and the precision and robustness of the estimates are often low. By using time-series data, changes in production are attributable to

[19] The short-run own-price elasticity is 0.055 while the long-run own-price elasticity is 0.292.

prices whereas effects of other variables may play a role as well. The estimation difficulties are more pronounced on the supply side (compared to demand side), particularly because of dynamic responses that imply lags between observed prices and their realized impacts. These aspects are particularly pronounced for perennial crops where the production cycle is multi-year and the dynamics are long term.

5.4 Empirical analysis

Therefore, we will take the remarks made above into account to do our best with our limited data.

5.4.1 Model specification

Our choice of model will be simple. It will be a mix of the Ekaputri's and the Nerlove's model because Nerlove is a reference in acreage response to price (for annual crops) and Ekaputri found some evidence with his moving-average of price for perennial crops.

First, we remove the lagged dependent variable from the Nerlove's model (see equation (5)) on the left side (with the dependent variable) to get a first difference as a dependent variable. Then, we implement the moving average used by Ekaputri, and not only the price of the previous period, in the new Nerlove's model. Ekaputri choses to make a moving average with prices in t-2 and t-3 but, in our opinion, it does not make a lot of sense. A palm oil tree needs between 4 and 8 years to become mature and so productive. He should use at least lags for 4 years because he will not see any effect of prices on production before 4 years in the past. Consequently, in all our regressions, we use a moving average (*ma_price*) of three consecutive prices in t-8, t-9 and t-10 to take the price of years before the investment (so before the act of planting) into account. Furthermore, we put a dummy variable to care about the trend of the price (*price_up*). If the price increases during this period (so if price in t-8 is bigger than price in t-9 and this latter bigger than price in t-10), the value will be equal to 1, otherwise it will be 0. Some controls will be used to get the best and the most comprehensive model possible without losing too many observations. The global revenue of the district (in Indonesian Rupiah) and the literacy rate for population age 15 and over (in % of total population of the district) are these controls.

For this thesis, we want to study the impact of price on both acreage and production. The acreage's reaction will be analyzed for each type of ownership (in 3 separate regressions) and for each condition of palm oil plantations (in 3 separate regressions). The production's reaction will be studied for each type of ownership (in 3 separate regressions). We also have the total production and the total acreage of palm oil so it can be interesting to study their effect as well. It thus makes 11 different regressions. In order to make it clear and to be concise, we will only write the general model.

In mathematical form, this gives us:

$$Dep.var_{it} - Dep.var_{it-1} = \beta_0 + \beta_1 ma\_price_t + \alpha_i + u_{it} \quad (9)$$

Where $Dep.var_{it-1}$ is the depedent variable lagged by one year for each district, ma_price_t is the moving average of prices in t-8, t-9 and t-10, α_i represents the district heterogeneity (factors influencing the dependent variable that do not change over time) and u_{it} is a random residual term.

The general model with controls added is as follows:

$$Dep.var_{it} - Dep.var_{it-1} = \beta_0 + \beta_1 ma\_price_t + \beta_2 price\_up_t + \beta_3 revenue_{it} + \beta_4 literacy15_{it} + \alpha_i + u_{it} \quad (10)$$

Where $price\_up_t$ is a dummy variable taking the value 1 if $price_{t-8} > price_{t-9} > price_{t-10}$ or 0 otherwise, $revenue_{it}$ is the revenue (in IDR) for a district *i* in time *t*, $literacy15_{it}$ is the literacy rate for those being 15 or over (in % of the population of the district) for a district *i* in time *t*,

We can make some predictions of our coefficients. We expect β_1 will be positive to confirm the law of supply but it will not be surprising if it is not significantly different to 0 as it appears to be in the literature. β_2 should show a positive sign as well. We expect β_3 will be bigger than 0 because it could be interesting for companies to set up in richer districts to make use of economies of scale. However, some problems of endogeneity can arise because more production leads to more wealth. With this loop of causality between the dependent variable and an explanatory variable, endogeneity will occur. Finally β_4 should be positive as well because more educated people are more productive. These data for people employed in palm oil industry would give us a sharper coefficient. However, we do not have this kind of data.

5.4.2 Our method

We regress our 11 dependent variables on the moving-average of price by using the simple OLS method and then, a second time with the controls. To estimate properly by OLS, we have to include clusters. This means observations are related with each other within certain groups. Here, these groups are the districts. We are assuming independence across clusters but correlation within clusters. Standard errors will probably be higher with clusters because we are allowing for correlation between observations. Thus, our coefficients will be less significant but our model will be cleaner.

As a reminder, our dependent variables are, in the same order as our regressions, the total land area of palm oil (totPOLA), the land area mature (Mature), the land area immature (Immature), the land area damaged (Damaged), the land area of the private sector (POLAprivate), the land area of the smallholders (POLAsmallholder), the land area of the public sector (POLApublic), the total production of palm oil (totPP), the production of palm oil from the private sector (PPprivate), the production of palm oil from the smallholders (PPsmallholder) and the production of palm oil from the public sector (PPpublic). Do not forget we have to take the first difference as a dependent variable. This is why there is a "d" in front of the variables' name[20].

Table 13 and Table 14 show the results we get by doing OLS and clustering the standard errors of all regressions with and without controls.

Table 13: Clustered OLS estimation (no controls).

	(1) dtotPOLA	(2) dMature	(3) dImmature	(4) dDamaged	(5) dPOLApr~e	(6) dPOLAsm~r	(7) dPOLApu~c	(8) dtotPP	(9) dPPpriv~e	(10) dPPsmal~r	(11) dPPpublic
ma_price	1.657 (0.21)	-2.078 (-0.44)	4.071 (0.86)	1.126 (1.46)	15.95 (0.83)	-4.973 (-1.31)	-5.823* (-2.50)	-36.79*** (-3.40)	12.77 (0.20)	-0.857 (-0.13)	27.19 (1.79)
_cons	5850.9 (1.17)	6803.8* (2.05)	-619.4 (-0.24)	-522.5 (-1.26)	-1110.8 (-0.13)	5607.6* (2.17)	3639.7** (2.69)	42572.1*** (5.50)	13517.9 (0.48)	9990.1* (2.26)	-14721.9 (-1.81)
N	1858	1668	1755	643	571	1472	343	1570	541	1297	289

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 14: Clustered OLS estimation (with controls).

	(1) dtotPOLA	(2) dMature	(3) dImmature	(4) dDamaged	(5) dPOLApr~e	(6) dPOLAsm~r	(7) dPOLApu~c	(8) dtotPP	(9) dPPpriv~e	(10) dPPsmal~r	(11) dPPpublic
ma_price	9.105 (0.67)	3.643 (0.39)	6.909 (1.11)	2.338* (2.38)	0.199 (0.01)	-9.387 (-1.74)	-10.78** (-3.24)	-53.79 (-1.67)	-76.25 (-1.68)	-17.02 (-1.90)	-1.692 (-0.17)
price_up	-11850.5*** (-3.43)	-10181.0*** (-3.70)	-2656.2 (-1.96)	-698.5** (-3.10)	20533.2** (2.79)	-525.5 (-0.74)	5307.9*** (3.45)	-7656.7 (-0.44)	90779.8** (2.68)	3534.9 (1.44)	34569.3* (2.38)
revenue	6.54e-09 (1.45)	5.66e-09 (1.32)	6.65e-10 (1.46)	2.10e-10** (2.65)	9.56e-10 (0.73)	3.68e-09* (2.07)	5.93e-11 (0.42)	2.63e-08 (1.39)	7.38e-09 (1.27)	1.20e-08 (1.90)	2.13e-11 (0.05)
literacy15	313.0 (1.45)	336.7 (1.79)	-1.950 (-0.03)	11.24 (1.17)	300.6 (0.77)	251.5* (2.27)	27.46 (0.76)	2187.8** (2.86)	2178.6* (2.20)	963.5* (2.41)	186.9 (1.51)
_cons	-29008.7 (-1.57)	-29301.7 (-1.86)	-1787.4 (-0.28)	-2317.9* (-2.06)	-24181.4 (-0.57)	-17147.5* (-1.99)	2803.6 (1.08)	-167469.0* (-2.53)	-162644.2 (-1.48)	-78179.3* (-2.21)	-21703.3 (-1.78)
N	1719	1547	1620	602	562	1336	336	1453	532	1180	283

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Analysis of our results will be discussed in the next section (see point 6). For the moment, we would like to see if there is a more intensive production for shorter lags. In other words, do the coefficients

[20] Table 11 listed properly the name of our dependent variables.

of our dependent variables related to production become positive when we take a more recent moving-average of prices? Therefore, we rerun our regressions with the moving-average of prices in period t-4 to t-7 (*ma_price2*). With *ma_price2*, we will see if a more intensive production is present on young mature plantations (between 4 and 8 years). We only make these regressions on production variables and not on the acreage because we consider the acreage is less volatile and flexible in the shorter run. To be consistent, we also have to modify our price trend. It thus becomes related to the same year of the moving-average. Therefore, *price_up2* takes into account the increase of price in 4 years in a row (from t-7 to t-4). However, none of these observations takes the value 1 (meaning the price does not increase 4 times in a row[21]) so we drop this variable of our regressions with *ma_price2*. Table 15 and Table 16 listed the results both with and without controls.

Table 15: Clustered OLS estimation for our dependent variables related to production with the moving-average of price in t-7 to t-4 (no controls).

	(1) dtotPP	(2) dPPprivate	(3) dPPsmallho~r	(4) dPPpublic
ma_price2	-19.32	14.46	-9.957	-102.9
	(-1.46)	(0.35)	(-1.50)	(-1.58)
_cons	33082.0***	12199.4	14925.4**	53413.9
	(3.82)	(0.46)	(3.05)	(1.58)
N	1570	541	1297	289

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 16: Clustered OLS estimation for our dependent variables related to production with the moving-average of price in t-7 to t-4 (with controls).

	(1) dtotPP	(2) dPPprivate	(3) dPPsmallho~r	(4) dPPpublic
ma_price2	35.43	37.65	11.28	-112.8
	(1.29)	(0.98)	(1.36)	(-1.58)
revenue	2.64e-08	7.98e-09	1.18e-08	8.15e-11
	(1.42)	(1.22)	(1.90)	(0.14)
literacy15	2154.5**	1635.9	928.0*	-238.0
	(3.03)	(1.96)	(2.39)	(-1.30)
_cons	-213865.4**	-161869.6*	-89311.3*	80466.1
	(-2.66)	(-2.36)	(-2.26)	(1.56)
N	1453	532	1180	283

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

[21] To take the value 1, prices had to be as follows: price in t-7<price in t-6<price in t-5<price in t-4.

We also make a third moving-average of prices in period t-1 to t-2 (*ma_price3*) to capture the effects of price and to take care of the flexibility in the intensive production in the very short run. We also change the price trend to become a dummy variable when the price in t-1 is bigger than the price in t-2 (*price_up3*). Table 17 and Table 18 show the results of these new regressions.

Table 17: Clustered OLS estimation for our dependent variables related to production with the moving-average of price in t-2 and t-1 (no controls).

	(1) dtotPP	(2) dPPprivate	(3) dPPsmallho~r	(4) dPPpublic
ma_price3	62.85*** (4.72)	-32.95 (-1.04)	2.191 (0.37)	2.685 (0.25)
_cons	-15605.3** (-2.81)	43205.9 (1.63)	8253.0* (2.12)	-2829.7 (-0.36)
N	1570	541	1297	289

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 18: Clustered OLS estimation for our dependent variables related to production with the moving-average of price in t-2 and t-1 (with controls).

	(1) dtotPP	(2) dPPprivate	(3) dPPsmallho~r	(4) dPPpublic
ma_price3	30.69* (2.14)	-31.16 (-0.96)	-21.72 (-1.81)	5.900 (0.46)
price_up3	-2544.9 (-0.44)	-36672.6*** (-4.21)	-9096.1** (-3.08)	-5316.3 (-1.95)
revenue	2.54e-08 (1.35)	7.05e-09 (1.16)	1.28e-08 (1.92)	3.17e-10 (0.66)
literacy15	2039.4** (2.80)	2061.6* (1.99)	948.7* (2.36)	-119.6 (-0.70)
_cons	-201149.9** (-2.94)	-137372.1 (-1.79)	-69262.6* (-2.09)	8487.3 (0.72)
N	1453	532	1180	283

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

We need to make some diagnostics to check if the classical assumptions are met for the OLS estimators to be the best linear unbiased estimator (BLUE) under the Gauss-Markov theorem. The two main assumptions, here, to care about are:

1) The explanatory variables are uncorrelated with the error term. It is essentially for our price variable which needs to be uncorrelated with the production or the area of a district. We do not want to observe that our dependent variables have an influence on price. This is the endogeneity hypothesis.
2) The error terms are uncorrelated with each other so we hope there is no serial correlation.

First, the main method for endogenous variables is to replace them by an instrumental variable. However, in our dataset, we do not have any instrument close to the price (*ma_price*). By allowing some correlation between explanatory variables and the error term, we can get better standard errors. The inclusion of clusters in our regressions is an attempt to reduce this possible endogeneity issue.

Second, we have to check in each of our eleven regressions if there is serial correlation. The classical Durbin-Watson test for AR(1) serial correlation does not work with panel data. However, Drukker (2003) found a nice tool to test serial correlation in regressions on Stata. It gives us directly the F-test with its p-value. As usual, if the p-value is below 5%, we can reject the null hypothesis of no serial correlation. This test is made for all of regressions from Table 13 to Table 18 and the results are listed in the appendix on Table 19 to Table 24. Fairly logically, this is essentially the same regressions which suffer from serial correlation[22].

OLS is no longer BLUE in the presence of serial correlation. Even more importantly, the usual OLS standard errors and test statistics are not valid, even asymptotically. With positive serial correlation, the usual OLS variance understates the true variance of the OLS estimator. Some advanced models are possible to correct the serial correlation and get unbiased estimators. The generalized least squares (or GLS) estimator or the feasible GLS estimation seems to be part of the solution (Wooldridge, 2006). However, we will not go further in this thesis.

A test taking care of our individual effect (the district heterogeneity) could be done though. We use a fixed-effects model to find better results. With this model, we allow the explanatory variables to be correlated with the individual effect. However, a problem could occur if an explanatory variable is related to the error term because the strict exogeneity assumption required for fixed-effects model will not hold anymore. If we suffer from endogeneity, the estimation of our intercept and our coefficient will not be biased and be consistent for a large period of time (which is the case here) but the standard errors of our coefficients and the residuals will not be consistent. Therefore, we run the

[22] The dependent variables in concern with serial correlation are the first difference of the total area of palm oil (in every case), the mature area of palm oil (in every case), the palm oil land area of smallholders (only in Table 14), the total production of palm oil (in every case) and the palm oil production of the smallholders (in every case).

same regressions as for the OLS method. The first two tables (Table 25 and Table 26) are representing the results with and without controls with our original moving-average (*ma_price*).

Table 25: Fixed-effects estimation (no controls)

	(1) dtotPOLA	(2) dMature	(3) dImmature	(4) dDamaged	(5) dPOLApr~e	(6) dPOLAsm~r	(7) dPOLApu~c	(8) dtotPP	(9) dPPpriv~e	(10) dPPsmal~r	(11) dPPpublic
ma_price	4.203	-0.376	4.753	1.220	3.442	-2.311	-7.665	-29.33	-29.27	10.89	28.73
	(0.43)	(-0.04)	(1.04)	(1.51)	(0.21)	(-0.68)	(-1.70)	(-0.68)	(-0.57)	(1.04)	(0.96)
_cons	4479.9	5887.8	-985.2	-574.7	5093.7	4151.5*	4572.2*	38541.3	34479.8	3560.8	-15498.6
	(0.84)	(1.18)	(-0.39)	(-1.26)	(0.63)	(2.19)	(1.98)	(1.63)	(1.32)	(0.61)	(-1.01)
N	1858	1668	1755	643	571	1472	343	1570	541	1297	289

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 26: Fixed-effects estimation (with controls)

	(1) dtotPOLA	(2) dMature	(3) dImmature	(4) dDamaged	(5) dPOLApr~e	(6) dPOLAsm~r	(7) dPOLApu~c	(8) dtotPP	(9) dPPpriv~e	(10) dPPsmal~r	(11) dPPpublic
ma_price	14.12	6.287	8.861	2.735**	-3.274	-4.208	-10.42*	-56.96	-103.8*	-2.764	3.399
	(1.29)	(0.61)	(1.69)	(2.86)	(-0.20)	(-1.11)	(-2.25)	(-1.17)	(-1.99)	(-0.23)	(0.11)
price_up	-13276.3***	-11237.7***	-2986.2*	-784.0***	16302.2**	-948.8	5259.4***	-8667.1	83854.4***	2438.1	37272.3***
	(-4.83)	(-4.38)	(-2.27)	(-3.46)	(3.14)	(-1.08)	(4.19)	(-0.72)	(5.22)	(0.88)	(4.26)
revenue	6.15e-09**	6.76e-09***	-7.78e-10	1.42e-10	5.54e-10	1.56e-09*	4.61e-10	3.57e-08***	1.28e-08*	8.36e-09***	2.35e-09
	(3.16)	(3.87)	(-0.86)	(0.75)	(0.28)	(2.24)	(1.01)	(4.41)	(2.08)	(3.99)	(0.81)
literacy15	-244.3	-443.7	242.4	37.53	826.1	-117.2	-704.8	345.0	3432.2	201.9	-1343.9
	(-0.43)	(-0.82)	(0.86)	(0.53)	(0.57)	(-0.61)	(-1.88)	(0.13)	(0.75)	(0.32)	(-0.54)
_cons	21015.5	41929.3	-24787.6	-4959.3	-71158.1	15737.0	70544.1*	945.6	-271797.6	-12446.5	115012.3
	(0.40)	(0.83)	(-0.94)	(-0.73)	(-0.52)	(0.88)	(2.04)	(0.00)	(-0.64)	(-0.22)	(0.50)
N	1719	1547	1620	602	562	1336	336	1453	532	1180	283

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Then, we use the fixed-effects estimation on dependent variables related to production to analyze the possibility of an intensification of the production. Table 27 and Table 28 reflect the results with our second moving-average (*ma_price2*).

Table 27: Fixed-effects estimation for our dependent variables related to production with the moving-average of price in t-7 to t-4 (no controls).

	(1) dtotPP	(2) dPPpriv~e	(3) dPPsmal~r	(4) dPPpublic
ma_price2	-34.53	-68.47	-15.25	-118.4*
	(-0.56)	(-0.80)	(-1.08)	(-2.42)
_cons	41267.1	56272.3	17800.2*	61596.4*
	(1.24)	(1.23)	(2.29)	(2.37)
N	1570	541	1297	289

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 28: Fixed-effects estimation for our dependent variables related to production with the moving-average of price in t-7 to t-4 (with controls).

	(1) dtotPP	(2) dPPpriv~e	(3) dPPsmal~r	(4) dPPpublic
ma_price2	17.65	-43.94	-5.035	-126.6*
	(0.26)	(-0.49)	(-0.32)	(-2.45)
revenue	3.53e-08***	7.36e-09	8.15e-09***	4.87e-10
	(4.36)	(1.16)	(3.90)	(0.16)
literacy15	259.0	4214.5	183.5	-636.0
	(0.10)	(0.89)	(0.29)	(-0.25)
_cons	-32596.3	-360714.4	-8824.5	124291.3
	(-0.13)	(-0.82)	(-0.15)	(0.52)
N	1453	532	1180	283

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

The last two tables (Table 29 and Table 30) present the results for the third moving-average (*ma_price3*) which takes care of the intensification of the production in the very short run (t-1 and t-2).

Table 29: Fixed-effects estimation for our dependent variables related to production with the moving-average of price in t-2 and t-1 (no controls).

	(1) dtotPP	(2) dPPpriv~e	(3) dPPsmal~r	(4) dPPpublic
ma_price3	76.77*	64.62	-2.078	11.83
	(2.52)	(1.63)	(-0.25)	(0.49)
_cons	-24089.3	-25843.6	10723.2*	-9096.1
	(-1.27)	(-0.91)	(2.17)	(-0.55)
N	1570	541	1297	289

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Tableau 30: Fixed-effects estimation for our dependent variables related to production with the moving-average of price in t-2 and t-1 (with controls).

	(1) dtotPP	(2) dPPpriv~e	(3) dPPsmal~r	(4) dPPpublic
ma_price3	**50.88**	**48.60**	**-15.97**	**13.56**
	(1.49)	**(1.19)**	**(-1.74)**	**(0.52)**
price_up3	**-1875.8**	**-33215.4*****	**-9967.6*****	**-5613.8**
	(-0.21)	**(-3.79)**	**(-4.32)**	**(-0.99)**
revenue	**3.32e-08*****	**7.71e-09**	**8.94e-09*****	**1.10e-09**
	(4.07)	**(1.24)**	**(4.29)**	**(0.36)**
literacy15	**-504.9**	**2873.0**	**309.1**	**-1062.1**
	(-0.19)	**(0.62)**	**(0.50)**	**(-0.40)**
_cons	**19338.3**	**-273176.0**	**-10283.0**	**90184.2**
	(0.08)	**(-0.63)**	**(-0.18)**	**(0.37)**
N	**1453**	**532**	**1180**	**283**

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

6 Empirical results

Before turning to interpretation, we have to keep in mind that our dependent variables are first-differences so it is the variation between two years and not the level we have to take into account.

Table 13 and Table 14 disappoint us a bit because almost none of our main coefficients (those before the moving-average) are significant and only one of the four significant coefficients is in the expected sign (positive). As the moving-average of the price in t-8, t-9 and t-10 increases by 1 dollar/ton, the damaged area increases by 2.338 hectares from one year to another. This is nothing but it means that plantations have already been cleared. However, we should observe a positive coefficient for the mature plantations (which is only the case with controls but it is no significant). Those with a negative sign (the palm oil land area of the public sector (2 times) and the total palm oil production) are surprising because it means that a price increase in more than 8 years (moving average of prices in t-8, t-9 and t-10) decreases the variation of acreage allocated to palm oil by the public sector by respectively 5.823 ha (Table 13) and 10.78 ha (Table 14), and the variation of the total production of palm oil by 36.79 tons which are not the expected results. These results are, however, very low. The supply response to prices seems to be very low or even inexistent which is in conformity with the literature.

The price trend shows surprising results as well (Table 14). The coefficients are positive for variables related to production except for the total production. For example, if the price increases three times in a row, the production of the private sector 8 years later increases by 90 779.8 tons or by 34 569.3 tons for the production of the public sector 8 years later. The palm oil land area of the public (+5307.9 ha) and the palm oil land area of the private sector (+20 533.2 ha) increase a lot but it is not case for the total land area of palm oil (-11 850.5) which is also surprising. The large negative significance of the mature area is also incomprehensible because it means the land allocated to mature (productive) palm oil decreases when the price increases 3 times in a row at the time of the planting.

For the anecdote, the revenue seems to have a very small positive impact in each case but its coefficient is only significant for the damaged area and the palm oil land area of the smallholders. The literacy rate of those above 15 years has also a positive sign as expected. For example, an increase of 1% of the literacy rate of the population (from 15 years) increases the total production of palm oil by 2187.8 tons.

Then, with the new moving-average (*ma_price2*) to capture flexibility in the production, we do not have concluding results. The coefficients for *ma_price2* are never significant (Table 15 and Table 16)[23].

Results are more interesting with the third moving-average (*ma_price3*) because the coefficient on the total production of palm oil is positive and significant (with and without controls). This means that when the moving-average of prices in t-1 and t-2 increases by 1 dollar/ton, the total production of palm oil increases by 62.85 tons (Table 17) and 30.69 tons (Table 18). We thus get our more intensive production. This is, though, a pity that not the other variables are significant as well. The price trend (if price in t-1 is bigger than the price in t-2) has again a negative sign and is significant in two of four regressions[24] (Table 18). This is not the sign we expected.

In addition, we rerun these regressions with the fixed-effects estimation. For the first regressions only with the moving-average (Table 25), we have no significance at all. When we add the controls (Table 26), it is more or less what we observed with OLS (Table 14): the damaged area (positive sign) and the palm oil land area of the public sector (negative sign) are again significantly different to 0. This is thus the same reasoning than before. However, this time the palm production of the private sector is significantly different to 0 as well. It has not the expected sign meaning that when the moving average of prices in t-8, t-9 and t-10 increases by 1 dollar/ton, their production in t decreases by 103.8 tons. The same analysis can be provided for the price trend as what we did for Table 14. The

[23] We did the same for the acreage response to closer prices (*ma_price2* or *ma_price3*) but we got no concluding results as well.
[24] For the palm oil production of the smallholders and the palm oil production of the private sector.

same coefficients are significant, except for the immature area which becomes significant and negative with the fixed-effects estimation, and get the same sign.

Table 27 and Table 28 show we get negative coefficients (except for the total production of palm oil with controls) with a shorter moving-average of the price (*ma_price2*). However, the only coefficients to be significant are those before the production of palm oil from the public sector with respectively a decrease by 118.4 tons (Table 27) and 126.6 tons (Table 28) when the moving-average of price increases by 1 dollar/ton. We do not observe an intensification of the production with prices between t-7 and t-4. These results are again counterintuitive.

Finally, we get more convincing results with the very short run (*ma_price3*). The only coefficients to be negative are those for the production of the palm oil from the smallholders but they are not significant. The only significant coefficient is for the total production of palm oil when there is no control and it is positive (Table 29). Some evidence for an intensification of the production is thus provided even if the effect is not wide. An increase by 1 dollar/ton of *ma_price3* leads to an increase of 76.77 tons for the total production. We are again disappointed by our results with the price trend (*price_up3*). All the coefficients are negative and two of them (the palm oil production of the private sector and the palm oil production of the smallholders) are significantly different to 0 (Table 30).

According to our results and their poor significance, we do not think necessary to compute the price elasticities of the production. We can simply say the sign of these elasticities will be the same than those of the coefficients.

7 Limits

We obviously encounter some problems in our work. Our thesis suffers from few important limits which have maybe biased our results.

7.1 Econometrics

This is probably not the best model to study the price impact on palm oil production and area. We do not implement palm oil substitutes like rubber or soybean for example. We also have a dependent variable reflecting a change while the independent variables are in levels. Therefore, it could generate problems of understanding and interpretation. However, we try to choose the most comprehensive model without being too sophisticated. Our choice to have a first-difference only in the dependent variable was based on two elements: (1) to follow the logic of the Nerlove's model which put the lagged dependent variable in the right side and (2) to avoid this problem of lagged dependent variable in our independent variables which would have complicated our interpretation of the econometrics.

7.2 Data

Even if our dataset was interesting to study the price effect on palm oil plantations, we have to confess that the lack of data on some variables and the poorly defined variables do not help us to make precise analyses.

Interesting controls had to be dropped due to poor data (roads, GDP, employment rate, etc.) and the absence of other variables (age structure of palm oil plantations, acreage of palm oil planted each year, etc.) does not allow us to have the comprehensive model we would have wished.

8 Conclusions

This paper highlights the role of palm oil expansion at the expense of global forests. We make this focus throughout the price elasticity of palm oil's supply to know what will be the reaction of the palm oil plantations' owners with a change in the palm oil price.

Indonesia is the perfect country to learn about the possible effect played by palm oil on deforestation because it has major issue with deforestation and, at the same time, it is the main palm oil producer. We then use the Indonesia Database for Policy and Economic Research (found on the World Bank's website) where palm oil production and area are listed for each district between 1976 and 2013.

In our thesis, we make an important review of the literature on global deforestation and also on its link with poverty. We have shown that three main theories (the poverty-environment hypothesis, the environmental Kuznets curve and the *Limits to growth's* theory) differ on the link between resources scarcity and income. Evidence shows that, at a macro scale, the poorest countries are more likely to deforest compared to high-income countries. However, the debate is much more divided at the micro scale. Even if the poor rely more on natural resources for their income, the rich tend to collect more firewood due to the low opportunity cost of time to collect wood.

We highlighted the relationship between property rights and deforestation. This is still an open debate as well. On the one hand, people argue it is better to apply coercive laws or taxing devices to protect the commons rather than allow free access to them. On the other hand, credible institutions (smaller than the state) are better to preserve the commons because, by collective action, people are more likely to follow their own rules.

The soaring demand of palm oil (through its many uses and its comparative advantages compared to other vegetable oils) is not likely to decrease in the medium term. This has some impacts on forests.

The most often cited factor to explain palm oil expansion is the rising price of palm oil. Higher prices increase the profitability of the crop and are thus expected to increase production. However, a rising production does not necessarily imply an increase of area but could be the result of a more intensive use of existing plantations. Furthermore, the perennial nature of the crop and the fact that 4 to 8 years are necessary for a new plantation to come into production preclude short term adjustment of area to prices. Our research studies effects of price changes on palm oil production and area, taking these elements into account. The focus is on the different types of palm oil plantations (private, smallholder or state owned enterprise) as they may respond differently to an increase in profitability of the crop (due to an increasing investment capacity, incentives and objective). Will an increase of the palm oil price lead to more or less production of palm oil? Will we observe differences between the different kinds of palm oil plantations' ownership? Will the price make bigger changes on immature palm oil plantations (3 years or less), on mature palm oil plantations (4 years or more) or on already damaged palm oil plantations?

Our results show that with both estimations (OLS and fixed-effects), the total production of palm oil do not increase and even decrease with poor significance though. However, we found a positive supply response to prices in the very short run. Total production of palm oil increases by 30.69 tons (with OLS) and by 50.88 tons (with fixed-effects) when the moving-average of prices in t-1 and t-3 increases by 1 dollar/ton. However, this latter coefficient is not significant. This shows some kinds of higher intensification of the production in the short run but these numbers are not that big though.

The poor significance of our results for the different types of ownership does not allow us to make great conclusions about their differences. The little we can say is that both regressions with the public sector (production and area) are the most often significant. However, the sign of the coefficients of the production response to prices are negative which was not the sign expected.

The same reasoning can be made for the different types of plantations. We get very poor significance for these variables (Mature, Immature and Damaged). The only one to be significant and with the positive expected sign is the damaged dependent variable. As the moving-average of prices in t-8, t-9 and t-10 increases by 1 dollar/ton, the damaged area increases by 2.338 ha (with OLS) and 2.735 ha (with fixed-effects). However, these coefficients are not big at all. This means more palm oil plantations are cleared and thus in a post-productive situation when the price of palm oil increases years ago.

To conclude, these results due to their poor significance are close to those found in the literature. Very low elasticities were found when the coefficients were significant. Palm oil plantations' owners tend not to react to prices even when we try to take the year(s) of planting into account. We could however ask ourselves why the price effect is so negligible. It could be due to the bad specification of our models. A first-differed dependent variable and the independent variables in levels are not that common. We do not include substitutes to palm oil such as rubber for example which could have an impact on the supply response to prices for the palm oil sector. Poorly defined and incomplete dataset could play a role as well in our poor results. Another reason might be that the international prices are not the best ones which react to supply response of the Indonesia palm oil production. Furthermore, we have to remind that our observations are on a district-base. Thus, the district production is nothing compared to the world supply and might not fully react to international prices. Maybe, the choice to pick Indonesian would have been more judicious. Another reason, but very unlikely, is that we got really good results which contradict the literature as our results mainly show negative reaction of the supply to prices.

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