Illegal Logging and the Productivity Trap of Timber Production in Mexico

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Abstract: This paper uses two approaches to estimate illegal volumes and provides arguments to show that timber production in Mexico is largely defined by the presence of significant volumes of illegal logging, which supply the market with a volume equivalent to that of the legal harvest. Estimated illegal volumes are closely linked to the growth rate of the construction and manufacturing sectors, which suggests these sectors trigger demand for illegal volumes, while a lower supply of illegal volumes is kept for making rustic furniture and wooden handicrafts. Illegal logging reinforces the productivity trap through several mechanisms throughout the value chain, from timber production to sawn wood retailing. These mechanisms, in conjunction with certain features of the domestic sawn wood market, contribute to keeping the forest sector in a productivity trap. Illegal logging is a complex socio-environmental problem, which requires the participation of society as a whole to reverse the effects of this activity in every component of the forest value chain.

Keywords: laundering of illegal logging; wood balance analysis; productivity trap; organized crime

1. Introduction

Forest areas in Mexico comprise approximately 65 million hectares of tropical (49%) and temperate (51%) forest [1]. Nevertheless, forest cover with the potential for timber production is estimated at 15 million hectares, mostly temperate forest, with an estimated yield of over 45 million cubic meters (Mm³) a year [2]. Current timber production is authorized in only 5–6 million hectares with harvest rates in the 2.5–4.2 Mm³/ha/year range [3]. However, over 45% of this legal felling is not harvested [4] due to problems linked to the market, harvest costs, and governance within forest communities [5]. Despite the availability of timberland not yet under production and the high productivity of certain forest lands [6], timber production in Mexico has stagnated in the past 20 years at levels of 6–7 million cubic meters (Mm³) per year. This is below the annual legally allowable timber harvest estimated at 14 Mm³ [3] and far below the demand for wooded forest products, whose roundwood volume is approximately 30 Mm³ per year [7].

Several factors have been associated with the stagnation of Mexican timber production, which negatively affects not only the commercial balance of timber products but also the welfare of forest producers, incentives for forest conservation, and the vulnerability of certain forest areas. The most cited drivers associated with these low production levels are lack of infrastructure, absence of financial mechanisms, inefficient forest management practices, low technology at every stage of the value chain, and the presence of illegal logging and wood laundering [2,8]. This last driver not only reduces the competitiveness of the timber sector but also produces various environmental, social, economic, political, and cultural negative impacts [9,10], a vicious circle in the forestry sector.

Illegal logging, defined as the unauthorized harvesting of timber, has been reported since the late 1920s [11,12]. However, illegal activity increased after the 1940s (after the disappearance of cooperatives), when legal restrictions on logging, as well as forest conservation policies (extensive bans throughout the country), and logging through large
concessions \[13,14\] reduced the local supply of basic timber products (sawn wood and firewood), creating a black market for them \[11,12,15\].

Although the existence of illegal logging has been recognized, it was not until 1997 that the Mexican Government first acknowledged that the illegal timber volume absorbed by the forest industry was in the order of 7.7 Mm\(^3\) \[16\]. Since then, several estimates of the illegal volume placed on the timber market have emerged, ranging from 3 to 4 Mm\(^3\) a year \[12,17\] through 7–8 Mm\(^3\) a year \[18\] for the period 2007–2010, up to 13.3 Mm\(^3\) a year \[19\]. Most of these estimates have been based on experts’ knowledge.

Because of its nature, there are no statistics for illegal logging. As a result, most estimates have no solid basis as they rely on limited supporting information. In most cases, estimates refer to timber in the sawn wood market since timber absorbed by the pulp and board making (plywood, MDF/HDF, particle board) industries is properly supervised, while the firewood market, although large, is diffuse and atomized \[20\].

Most methods used globally to estimate illegal logging rely on discrepancies between timber flows and market balances \[21\]. These differences could obviously be the result of causes not necessarily linked to the presence of illegal activities. However, all methods assume that if these differences are significant and consistent, they could provide a suitable proxy for estimating illegal timber volumes introduced in the market \[22–24\].

Against this background, the aim of this paper is to estimate the volume of illegal logging, not only to gauge the scope of the problem but also to estimate the extent to which it depresses the forestry sector in Mexico. In addition to estimating the volume of illegal logging, this paper provides arguments to support the hypothesis that illegal logging is one of the main drivers maintaining the productivity trap \[25\] in the Mexican timber sector.

2. Materials and Methods

Two approaches for estimating the volume of illegal timber laundered in Mexico were used. The first relies on the acknowledgment of the discrepancy between the growth rate of the apparent demand (AD) for sawn wood and the rate of growth of the AD for all wood products except sawn wood. This approach will be referred to as the “differential rate of growth of AD” (DRGAD). The second approach resembles a wood balance analysis \[26\], which estimates illegal logging by using the gap between domestic consumption and supply (production plus imports). This approach will be referred to as wood balance analysis (WBA) \[10\].

2.1. Differential Rate of Growth of Apparent Demand (DRGAD)

To illustrate the approach, compare Figure 1a, which shows the trend in imports, exports, and production of all wood products calculated in roundwood equivalent volumes (RWE), with Figure 1b, which shows the trend in the same variables but just for sawn wood. All data come from FAOSTAT \[27\] for the period 1960–1989 and from SEMARNAT \[28\] for the period 1990–2017. Equivalencies for the conversion to RWE were obtained from INFOR \[29\], and apparent demand (AD) is estimated as production + imports − exports.

The AD trends show a higher rate of consumption for all wooded products than for sawn wood over time. We suggest that this discrepancy in the consumption rate is the result of illegal harvesting since the structure of forest products resulting from timber production has not substantially changed over time. We realize the discrepancy could be attributed to other processes. However, we left the set of arguments and supporting material until the discussion section to show that this discrepancy is a suitable proxy for illegal logging.
The DRGAD estimate assumes that the annual rate of growth of the AD for sawn wood each year should be equivalent to the rate of growth of the AD for all wood products except sawn wood in the same year, given the assumption of an invariable structure of products in the forest sector. To illustrate the estimates, let us define the annual rate of growth for the AD for wood products from year \( t \) to year \( t + 1 \) as:

\[
  r_t = \frac{D_{w_{t+1}} - D_{w_t}}{D_{w_t}}
\]

where \( D_{w_t} \) represents the AD for wood products in year \( t \). Then, under the assumption of similar \( r_t \), the expected growth rate for the AD for sawn wood in year \( t + 1 \) can be expressed as

\[
  E_{D_{s_{t+1}}} = E_{D_s}(1 + r_t)
\]

where \( E_{D_s} \) represents the expected AD for sawn wood in year \( t \). Thus, the estimate for illegal logging is

\[
  E_{D_{s_t}} - D_{s_t}
\]

where \( D_{s_t} \) corresponds to the observed AD for sawn wood in year \( t \).

The approach has three obvious shortcomings: (a) we do not know the first year this discrepancy was related to illegal logging. Based on the figures, we can assume illegal logging has been present since the 1940s. However, there are years when this problem was inconspicuous in this estimate, as there is a barely perceptible change in AD for all timber products; (b) it is assumed that the rate of growth of AD for sawn wood is the same as the AD for all other wood products not produced from sawn wood. This assumption could be false for some years, particularly when economic shocks affect industries demanding sawn wood at a different rate from industries demanding other wood products, or because of the effect of technological changes or changes in consumer preferences; and, (c) the usual problem of limited information on illegal logging.

The first shortcoming affects the estimate since the more the years for which the expected and observed rates of growth of the AD of sawn wood are assumed to be similar, the greater the accumulation of discrepancies, which could lead to an overestimation of the volume of illegal logging. To offset this cumulative effect, we estimated different years for the initial discrepancy (every other year beginning in 1962). As a result, we generated different time series of hypothetical AD for sawn wood, each with different years for the onset of a discrepancy between expected and observed rates of growth of the AD for sawn wood. Given all these estimates of the AD for sawn wood for each year, we took the mean value of each year as the expected AD for sawn wood to estimate the discrepancy in that specific year regarding observed AD.
Finally, in order to test if other industries induce the demand for illegal sawn wood, the Granger causality test [29] was used. The test ($F$ test) consists of checking if the time series values of the inducing industries (e.g., construction or manufacture) precede the values of the DRGAD estimate. The test assumes the data-generating processes in those time series to be tested independently. Therefore, precedence is verified by testing if lagged values of the inducing industries explain the variation in the DRGAD estimate. The test just shows precedence, not causality.

2.2. Wood Balance Analysis (WBA)

The most common approach for estimating illegal harvest is the wood balance analysis. The method contrasts timber inputs (the sum of production and imports) with outputs (the sum of exports and domestic consumption) in the territorial unit being analyzed, and the discrepancies between them are assumed to be the result of illegal activities [24]. The approach relies heavily on an accurate estimate of domestic consumption to yield satisfactory approximations since the illegal timber or lumber offered in the informal timber or sawn wood markets is barely detected in the statistics.

Our WBA estimate assumes that statistics for wholesale sales of sawn wood ($S$) include both sales of legal ($S_G$) and laundered sawn wood ($S_L$). A second assumption is that sawn wood sales include volumes produced ($P$) plus imports ($I$), such that an estimate for the volume of laundered sawn wood is

$$S_L = S - S_G = S - (P + I)$$  \hspace{1cm} (4)

Total sawn wood sales were obtained from the economic census conducted every five years by the National Institute of Statistics and Geography from 1999 to 2019 [30]. The census database provides information on sales of economic units according to the North American Industry Classification System (NAICS) at various levels, including wholesale. Sales were transformed into roundwood equivalent volumes (RWE) by using the lumber price of the reference year [27,31], and equivalencies were mined from INFOR [32].

This approach has evident shortcomings, such as (a) the retrieval of the RWE from sales requires assumptions, such as the weighted price and the distribution of quality classes from the mill, which could vary by regions; (b) the approach does not consider sawn wood products sold without a record (such as a receipt or an invoice) at the point of sale; and (c) the usual problem, unreliable trade information.

To offset the effect of the first shortcoming, we used a weighted price, where the price for each lumber quality class was weighted by the average volume share of each lumber quality class (Class 5 was not included in the estimation of the weighted average since it is considered waste.) [33]. Since we were unable to find a mechanism to offset the second shortcoming, we expect illegal volumes to be slightly underestimated by this method.

3. Results

The estimates of illegal logging obtained through the two approaches are relatively similar. However, the DRGAD estimates enable the retrieval of a time series estimate for annual illegal logging volumes (Figure 2), in which four periods of interest can be observed. The first period, in the late 1980s, shows the rise of the volume of laundered timber, which coincides with the period when the country embraced trade liberalization and significantly increased its exports. Economic growth stabilized in 1994–1995 due to the economic crisis [34], and illegal logging appears to have stabilized as well. The second period of growth of illegal logging began after a phase of economic recovery from 1997 to 1998 until 2000. During this period, the volume of exports and the economy resumed their growth rate, as did illegal logging. This second period coincides with a period of high growth in the manufacturing and construction sectors, the main sectors demanding sawn wood.
The period 2000–2006 saw two events linked to illegal logging. First, between 2001 and 2004, there was a sharp decline in manufacturing linked to external factors such as lack of foreign investment and strict monetary control, which considerably reduced the country’s economic activity [35]. Second, an increase in legal requirements and operational changes for legal timber harvesting was observed, and a new Forest Law was enacted, which imposed temporary bans on timber harvesting. These events significantly reduced timber harvesting, which led to an abrupt increase in the volume of imported sawn wood (Figure 1) to meet domestic demand [8]. The reduction in the illegal volume during this period seems to be not only related to a reduction in economic activity but also to a probable substitution effect of laundered sawn wood by imports, which was short-lived. The recovery of U.S. economic activity and oil prices beginning in 2005 fueled growth in manufacturing and construction until the 2009 economic crisis [36], which also increased demand for imported sawn wood (Figure 1b). During the period 2009–2018, manufacturing and construction activities (see manufacturing index trend in Figure 2) resumed their growth rate [37], which in turn increased demand for inputs, including sawn wood, which seemed to be relatively satisfied by the illegal volume [38], since legal timber production remained stagnant at levels ranging from 6 to 7 Mm\(^3\) per year and imports did not rise significantly after the 2009 crisis. These periods of economic growth are reflected in different rates of demand for timber products, and as noted earlier, they coincide with periods of increased demand for illegal timber.

WBA estimates of illegal logging approximate the laundered volume sold in formal markets (Figure 3). Illegal timber used to make rustic furniture and pallets sold at workshops or directly on the streets or in warehouse sales without an official receipt are not included in this estimate. As expected, our WBA estimates yielded lower volumes than DRGAD estimates for all years (Figure 2). Table S1 in the supplementary material shows the estimates for illegal volumes obtained from both approaches. Interestingly, the WBA estimate for 2004 (3.004 Mm\(^3\)) is extremely close to the one computed in the time series (3.281 Mm\(^3\)). The other WBA estimates fall within a +/− 9–20% range of difference in relation to the DRGAD estimate.

The share of the legal volume of sales of total sales for each economic census year confirms three trends already observed in the previous DRGAD estimates: (a) the volume of legal sales in 1999 and 2019 appears to be similar as total timber production is also similar, which confirms that the structure of timber uses has not substantially changed over the past 20 years; (b) there was a significant volume of legal sales in 2004 compared to 1999 despite the reduction in timber production, which confirms the significant increase in imports in the early 2000s as noted previously (Figure 1b); and (c) illegal logging is entirely driven by domestic demand.
In addition, the five estimates suggest a steady supply of illegal volume below a sawn wood demand threshold (approximately 11 Mm\(^3\)) that competes with legal production and imports (years 1999 and 2004). However, the illegal volume appears to escalate when demand exceeds this threshold, not only flooding the market but also reducing the share of legal products on the market (both domestic and imported). The former observation suggests that imports do not suffice to clear the market when demand skyrockets, either because of price or quality. This observation is in line with authors who show that domestic sawn wood is preferred to sawn wood from overseas despite the lower price, enhanced presentation, and superior finishing of the latter [39,40]. These observations indicate that the supply of domestic sawn wood in high-demand conditions is set by the illegal sector, which suggests a low expansion capacity of the legal sawn wood sector and a ceiling demand for imported sawn wood (See Figure 1b).

Estimates of illegal logging worldwide differ substantially either because of the lack of information or because of the methodological differences between estimates. Our estimates are close to each other despite the different sources of information and approaches used. Based on DRGAD estimates, the average illegal volume in the past 20 years is in the order of 7.091 Mm\(^3\) (+/− 4.6), whereas according to WBA estimates, the illegal volume for the same period is approximately 6.355 (+/− 6.1) Mm\(^3\). Both figures are high compared to the 6.772 Mm\(^3\) of average legal production in the past 20 years. If we consider the WBA estimates, the average annual loss is approximately $270 million USD (base year = 2019), equivalent to 0.213% of the country’s GDP (base year = 2019) and obviously close to the GDP of silviculture.

4. Discussion

Illegal logging estimators provide some idea of the dynamics and features of this activity. The following discussion focuses on three issues: robustness of estimates, the relationship between illegal logging and sectors in the economy, and illegal logging as one of the main drivers of a timber productivity trap [25].

4.1. Robustness of Estimates

Given the nature of illegal logging, the robustness of estimates not only depends on the quality of indirect information used for estimation but also on estimation assumptions. In the case of the DRGAD method, it is assumed that the discrepancy between expected growth rates in AD for all forest products and the growth rate in AD for sawn wood approximate the expected growth rate in illegal volumes. However, discrepancies may be
related to processes such as (a) the substitution of timber used in different products; (b) the shift from sawn wood consumption to other non-wood products due to technological change; (c) the substitution of domestic sawn wood by imported products. However, since the following arguments show that these processes have not been occurring, it is therefore feasible to consider this discrepancy as a proxy for illegal logging.

- No substitution of timber used in different products. The share of domestic timber used in the three groups of products (pulp/paper, boards, and sawn wood) remains relatively constant throughout the observed period [28]. This suggests no substitution in the use of timber volumes between the different groups of wooden products. This production structure can be confirmed by comparing the share of wooden products produced by the harvest in 1999 and 2018 when legal timber harvest volumes were extremely similar [28].

- Limited technological change: Technological change in the various sawn wood products has been limited. Sawn wood in Mexico is mostly used for the construction (60%) and manufacturing sectors [19,38]. The housing industry in Mexico uses a limited amount of sawn wood as a building material since most formal housing is composed of concrete and bricks. The introduction of new building material (apparent, plastic, and recycled) has had a minimal effect on the demand for sawn wood for this sector since it is mostly used in the building process, as supporting material, scaffolding, and as molding and support material for when concrete is poured. Nevertheless, technological change has been evident in the replacement of wooden boxes and packaging to transport certain agricultural products with plastic boxes. This change has taken place since the 2000s, mainly in agricultural export products, although the use of wooden boxes remains important and will continue to do so in the future given their advantages [41], and as a strategy against climate change mitigation [42]. However, the volumes used in this activity are not high enough to account for the reduction in sawn wood demand.

- Substitution of domestic sawn wood by imported products. AD in timber products has steadily risen since the mid-1990s, and the structure of forest product imports, particularly cellulose and paper (88%), boards (7%), and sawn wood (5%), mainly from the USA, Chile, China, and Brazil, has undergone no significant changes since the mid-1990s [27]. Sawn wood imports skyrocketed at the beginning of the century but have remained low since 2005 (Figure 1b). An additional feature of imports is that a high percentage of conifer sawn wood imports from the United States are processed industrially in companies located on the U.S.-Mexico border and free zones with the USA and returned to that country in the form of finished products. These imported woods are used to manufacture wood moldings, bookshelves, furniture, and frames [43–45].

Conversely, there are strong arguments supporting the idea that stagnated apparent demand for sawn wood is an unexpected trend since actual demand for sawn wood should be higher than in the years before trade liberalization in the early 1990s. Some of these arguments are given below:

- Since the early 1990s, the country has increased its exports of many products, mainly autos, auto parts, clinical and agricultural products, making it the ninth-largest exporting economy worldwide [46]. This growth in economic activity is associated with the use of large volumes of paper and cardboard for packing, as well as a significant amount of wooden packing boxes and pallets composed of sawn wood. The statistics clearly show an increase in the demand for paper products, but not for products derived from sawn wood.

- The construction sector, the main destination of sawn wood [8,19], has maintained average annual growth of 3.4% since 2000 [47], but this growth is not reflected in the statistics describing the sawn wood inputs (production plus imports) used in this industry.
Over 35% of the sawn wood produced in Mexico is used in the furniture industry [48]. However, since the turn of the century, this industry has experienced strong growth, particularly in the manufacture of artisanal furniture [49,50]. This largely informal industry has focused the economy of certain small cities on the labor-intensive production of rustic furniture, which has invaded many corners and street markets in most cities in Mexico and even reached overseas markets [51]. This growth in demand for sawn wood is not reflected in the statistics either.

Overseas demand for certain fruits and vegetables has skyrocketed since the early 2000s, which, in turn, has increased demand for posts and other wooden structures to support fruits and vegetables used in traditional and intensive agricultural systems, such as protected agriculture and vertical farming [52]. This rise in demand for sawn wood is not reflected in the statistics either.

All these features of the sawn wood market suggest that this product should have a high AD growth rate beyond what is suggested by domestic production and import statistics since the demand for sawn wood has increased beyond traditional products for the construction and manufacturing industries. Accordingly, the discrepancy in the rate of growth of AD could be used as a proxy for illegal logging. WBA point estimates appear to be more robust since they rely on a simple discrepancy between the volume sold and the volume available from production and imports.

4.2. Relationship between Illegal Logging and Sectors in the Economy

One result of the estimates derived from the WBA method is that the volume of laundered sawn wood increases during periods of high demand. This means that a strong relationship is to be expected between the growth of the construction industry and the manufacturing industry and the estimated volume of illegal logging.

To test this relationship, a simple linear regression fit between the illegal volume and the manufacturing index reported by INEGI [47] was run. The fit shows that the latter variable accounts for 79% of the variation in the estimated illegal volume (R-squared = 0.79; n = 23). This value increases to 84% when the economic activity index for the construction sector is added to the fit (all estimates proved statistically significant). This simple test shows the relationship between these sectors and the estimated illegal timber volumes (Figure 4) but fails to show whether economic activity triggers the demand for those volumes. For this purpose, a simple pairwise Granger causality test was run to identify the existence of precedence between both time series. The test showed statistical evidence that Granger causality runs one way from the manufacturing sector to the illegal volume time series estimate (Pr > F = 0.0201) when using one lag, and there is no apparent Granger causality with more lags. When the pairwise Granger causality test is run with the index of economic activity for the construction sector, results show that there is statistically significant evidence that Granger causality runs one way from the construction sector to illegal volume (Pr > F = 0.0418), while statistical significance increases as more lags are added, up to four lags. Beyond this number of lags, there is no Granger causality.

These tests therefore not only show the close relationship between manufacturing and construction sectors and estimates of illegal DRGAD volumes but also suggest that these sectors create demand shocks to trigger more intense illegal logging activity. It should be noted that the heavy reliance of the sawn wood market on these two industries reduces the likelihood of a spurious relationship between the DRGAD estimates and the growth of these two industries.
4.3. Illegal Logging as a Driver of the Timber Productivity Trap

The persistence of an unchanging level of sawn wood production over many years, associated with an allowable cut volume 40–50% higher than the harvest volume [4] and the presence of growing AD for sawn wood, is evidence of a stagnant forestry sector. This stagnation has several drivers:

- **Low timber yields and high stumpage:** Harvest rates range between 2.5 and 4.2 m$^3$/ha/year [3,3]. These harvest volumes are uncompetitive and limit investment in the forest (silvicultural practices) to enhance labor capacities and to improve machinery and equipment. These low timber yields seem to be perpetuated as production forests are maintained with low stocks and the implementation of traditional timber management techniques with natural regeneration, scarce intermediate treatments, and poor harvesting planning [54]. These factors also contribute to increasing stumpage, particularly in smallholdings [50], making sawn wood production less competitive.

- **Lack of economies of scale:** In several parts of the country, forests under production are in the hands of forest communities or private producers with small forest areas. The average annual harvest area ranges from 12 ha for private owners to 185 ha for forest communities [4]. The size of these harvest areas and volumes increases harvest costs and limits the possibility of making investments to increase productivity [55]. One means of overcoming the problem is the association of communities and small private producers to achieve scale, reduce costs, diversify, and gain market power. There are few examples, however, of long-term associations between forest communities seeking competitiveness [56].

- **An outdated industry:** Although the sawn timber industry has increased its number of sawmills, its capacity and productivity have decreased [8,47,57]. This result is usually attributed to low timber production (which implies higher idle capacity), an absence of organization among producers, lack of equipment maintenance, and low efficiency of operators [58]. Overcoming these deficiencies requires investment in machinery, capacity building, and product and market development. Nevertheless, investment also requires incentives and a low-risk planning horizon, which cannot be generated with the presence of illegal logging.

- **Low vertical integration in the forest production process:** Most timber harvesting in private or communal ownership is undertaken by contractors, whether independent or attached to an industry [8,59]. In addition, most of the industry does not hold forest land, and most forest owners (whether private or communal) do not own sawmills [4]. These
features of the timber forest sector result in a timber industry with low vertical integration and severe efficiency problems [53].

Despite this low productivity, the sawn wood industry survives for three reasons: (1) nearly 75% of timber production comes from community forests [3] whose production adapts rapidly to seasonal demands, price changes and has no labor problems [60]; (2) the harvest rate in certain production areas (old forest stands) is higher than the growth rate [53], reducing inefficiency through the elimination of excess harvest volume, and (3) domestic sawn wood prices are higher than international prices and domestic sawn wood is more highly prized than international sawn wood by the construction and manufacture industries [39,40]. These features of domestic production confer a degree of market power on domestic sawn wood.

As Figure 5 shows, these features create a vicious circle in which low forest productivity appears to be perpetuated by low investment in the forest itself, human resources, machinery, equipment, and industry. This low productivity makes forest producers and forests less competitive since every additional cubic meter of timber to be produced takes longer to be produced by the forest, has increasing extraction costs, and has limited value added. The low competitiveness of the forest industry has contributed to the lack of diversification routes to add value to sawing or develop support markets to make production more efficient, reduce costs through economies of scale and scope, or renew or adapt technology. These components of the production environment amplify the effect of low productivity while keeping production levels unchanged. All these ingredients form what is called a productivity trap, characterized by low productivity, low investment, little diversification, and a lack of productive chains [25].

Illegal logging is present in all the components of the productivity trap shown in Figure 5. At the forest level, low productivity is exacerbated by illegal logging because of the way it operates by cutting small forest tracks or isolating suitable quality trees within timber stands with suitable accessibility, leaving the high-cost, low-quality harvest for forest owners. Sometimes, loggers cut down seed trees left to regenerate the forest stand or large trees left as snags. These practices obviously do not allow for the best post-harvest practices to ensure the health of the stand or reduce the risk of fires and pest dispersion. Illegal logging therefore contributes to perpetuating low yields, increases fragmentation and damages wildlife habitat in forest areas with suitable accessibility, increases the risk of wildfires and pests, and raises maintenance costs for forest owners. This last feature contributes to increasing stumpage, which in turn increases the profit margin of illegal logging.

At the harvest level, illegal logging with lower extraction costs (no authorization costs, road construction and maintenance, area regeneration, and protection) has a broad
margin for setting the selling price of logs to sawmills, increasing its profits, and leaving legal log producers out of the market. Although illegal logging is widely distributed throughout the country, it appears to be more frequent in regions with a large market for sawn timber products, semi-finished products, or firewood; in regions with land disputes, including those in natural protected areas with tight forest management restrictions [61]; in areas where there are obviously absentee owners (particularly private owners); or groups of forest communities with internal difficulties, low social cohesion and accountability problems in the elite [60], an absence of timber harvest permits, and located either just inside and outside the perimeter of natural protected areas (NPA) [62,63].

At the industry level, the formal sawn wood industry cannot compete with informal industries or shops/warehouses selling illegal sawn wood [9] estimated that illegal wood product prices are 16–20% lower than those on the legal market, a three times larger margin than the price difference between domestic and imported sawn wood prices [38]. Illegal logging therefore indirectly creates incentives for formal firms to gradually incorporate illegal timber volumes into the processing and sale of lumber to keep them on the market, which ultimately contributes to the persistence of an industry willing to combine sales of laundered and legal wood (a quasi-legal industry), creating few incentives to improve equipment or streamline processes, given that (a) the nature of illegal activity turns it into a risky business as well, meaning that there is less incentive to be more efficient, and (b) greater efficiency is somehow linked to higher sales. However, laundering illegal volumes is constrained by the supporting legal documentation, making it less attractive to become more efficient. The presence of illegal logging therefore reduces the incentives to invest in the maintenance and improvement of the industry, which also perpetuates industry inefficiency.

Lastly, it is worth mentioning that the presence of criminal gangs in the wood market has substantially changed the scale and power of illegal logging activity. This intervention alters the legal market of wood products, triggering greater substitution of legal volumes by illegal ones, reducing the profits of formal establishments, and causing many others to leave. The increased participation of organized crime in illegal logging reinforces the productivity trap while changing the way society perceives it. The existence of entire towns dedicated to the logging and processing of clandestine material (with a passive, corrupt authority), and the perception of powerlessness to address the problem on the part of owners, are symptoms of a society that seems to have assimilated the problem and a production sector that tacitly accepts the status quo.

This productivity trap, exacerbated by illegal logging, has severe side effects, ranging from forest degradation and the perpetuation of low timber yields to the reduction in the rate of expansion, modernization and diversification of formal industries, limited diversification of products and markets, the expansion of the informal and quasi-formal industries and, social and institutional decomposition arising from the constant violation of norms and social rules. This causality can clearly be seen in the statistics, which show a high correlation between the growth of the manufacturing and construction sectors and the volume of illegal logging; the stagnation of legal timber production, which has been unable to recover despite the continuous increase in domestic wood product sales; an annual authorized allowable cut over 80% higher than the annual harvest [3]; the critical condition of the sawn wood industry in terms of machinery, efficiency, and technology [58]; and the extremely low growth rate of new formal warehouses and sawmills [64].

This dynamic is typical of a path-dependent process, whose evolution does not depend on the forces that were responsible for the original production of the process [65] and is, in fact, self-reinforcing. Moreover, each evolutive step makes that path more attractive for the next round, creating a vicious cycle of self-reinforcing activity, typical of traps [66]. This dynamic suggests that the stagnating legal forest production in the country is mainly driven by this trap, which is aggravated by illegal logging.

Against this background, the best strategy for breaking out of the trap is to disrupt the reinforcement components of the process [61]. Several mechanisms have been widely
discussed, such as the improvement of information to foster sustainable forest management and market forest products; implementing a targeted chain-of-custody certification; targeted law enforcement actions; reducing costs and increasing the efficiency of legal timber production by implementing public policy instruments; dealing with corruption and organized crime; and improving surveillance activities, particularly in privately owned forests [9,18,61,67–69]. The implementation of these mechanisms is a step toward mitigating the problem. However, unless indirect driving forces related to poverty, the lack of human, social and environmental capacities of forest owners, the deficiency of institutions, and the presence of corruption are addressed, there will always be incentives to continue engaging in illegal business. Likewise, if there is not enough information on the demand side on different market types, or the socialization of the problem and its economic, social, and environmental consequences, there will be less interest in using certified products, reporting illegal activities, and collectively pressing the authorities to correct the problem.

5. Conclusions

The estimates of illegal logging presented in this paper are consistent with and close to the traditional estimates provided by experts. The time series estimate is closely related to the economic activity in the manufacturing and construction sectors, which, in addition, has a causal effect on the illegal logging pattern. The high volume of illegal wood laundered in the sawn timber market suggests that this activity is one of the main reasons behind the productivity trap into which the forestry sector in Mexico has fallen in the past 20 years. The mechanism for maintaining stagnated production operates at several stages of the value chains and appears to be triggered by the sawn wood demand shocks driven by the construction and manufacturing industries. Illegal logging is a complex socio-environmental problem, which requires the participation of all members of society to reverse its effects at every stage of the forest value chain.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/f12070838/s1, Table S1: Estimates of illegal logging volumes from two approaches.

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