FARMERS, TRADERS, AND PROCESSORS: ESTIMATING THE WELFARE LOSS FROM DOUBLE MARGINALIZATION FOR THE INDONESIAN RUBBER SECTOR

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Abstract
Reducing buyer market power over farmers is a key strategy to improve rural livelihoods in emerging economies. This paper focuses on implications for farm income and market efficiency of failure of a supply chain to coordinate vertically to eliminate a second stage of buyer power in the vertical market chain – the so-called "double marginalization" problem. Our specific application is to the Indonesian rubber industry. In the Jambi province production is mainly in the hands of smallholder farmers, who sell via spot transactions to a network of traders who in turn sell in spot exchanges to rubber processors. Processing is highly concentrated, and concentration among traders is also quite high in localized procurement markets. Barriers to buyer coordination are largely absent, and evidence indicates that both traders and processors exercise oligopsony power, a classic problem of double marginalization. We estimate the extent of buyer market power in farmer-trader and trader-processor interactions and then explore the nature of this market failure and quantify the extent of welfare loss and redistribution of income among market participants. We conclude by asking why the market has not addressed the market failure of double marginalization through improved vertical coordination in the supply chain and discussing policy innovations to facilitate better coordination.

Keywords: Double marginalization, market power, oligopsony, rubber, Indonesia.

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1 Introduction

Many authors have emphasized the importance of vertical coordination in modern food supply chains as a way to reduce costs and meet the market's demands for products that are increasingly complex and multidimensional in their characteristics (e.g., Reardon and Timmer, 2007; Reardon et al., 2009; Crespi et al., 2012; Sexton, 2013). Vertical coordination streamlines market channels by eliminating intermediaries, facilitating information exchange and sharing of inputs between trading partners, and setting terms of exchange that maximize joint surplus to the trading partners.

Vertical coordination is commonly achieved through formal or informal (relational) contracts (Wu, 2014) or upstream (backward) vertical integration (Gaigné et al., 2017). Contract exchange mechanisms are common within Western economies, e.g., MacDonald (2015), and are expanding in the developing world, limited mainly by lack of institutions to facilitate execution and enforcement of contracts (Swinnen and Vandeplas, 2010; Swinnen and Vandeplas, 2011; Swinnen and Vandeplas, 2014). Vertical integration within supply chains in developing countries is often impeded by insecure tenure, restrictions on property transfers, and limited enforcement of contracts (Feder and Feeny, 1991; Besley and Ghatak, 2010). Failure of supply chains to fully exploit the advantages of vertical coordination can entail substantial welfare losses through excessive transactions costs, market power of intermediaries, and inefficient input utilization.

Despite a general recognition of the advantages to vertically coordinated supply chains and surplus losses incurred in uncoordinated food supply chains (e.g., Gaigné et al., 2017; Janssen and Shelegia, 2015), there have been surprisingly few attempts to measure these welfare losses and, in turn, quantify the benefits to vertical coordination. This is the task we set out to accomplish in the present paper for the Indonesian rubber supply chain, focusing specifically on production and processing in the Jambi province. Rubber in Indonesia is produced primarily by smallholder farmers, who sell via spot exchanges into a network of traders, who in turn sell through spot exchange to one of a handful of rubber processors located in the Jambi province (Arifin, 2005). The supply chain is, thus, bereft of almost any vertical coordination, and there is considerable evidence suggestive of buyer power exercised at multiple stages of the supply chain, namely trader oligopsony power exercised in dealings with farmers (Martini et al., 2010; Kopp and Brümmer, 2017), and oligopsony power exercised by processors in making purchases from traders (Arifin, 2005; Kopp et al., 2017).

Market power exercised at multiple stages in spot-market exchanges results in what is known as the double-marginalization problem first introduced by Spengler (1950). The problem has almost exclusively been explicated in the context of seller power at successive stages of the market chain (e.g., Katz, 1989; Janssen and Shelegia, 2015),[1] but the principles apply equally well to exercise of buyer power at successive stages.[2] In our context, if rubber processors exercise oligopsony power over traders, traders' demands for raw rubber from farmers are reduced below the efficient level from the perspective of maximizing surplus within the supply chain. Traders' exercise of buyer power over rubber producers introduces a second layer of marginalization, further reducing production below the efficient level and reducing the total surplus generated by the supply chain.

Marginalization at even one stage in a supply chain reduces economic surplus (Harberger, 1954), but the literature has generally considered this result to be an inevitable consequence of market power in the presence of "arm's length" exchanges, to be addressed, if at all, through competition policy. In contrast, double marginalization has been treated as a market failure that is correctable through vertical coordination in the supply chain. The prototype examples involve seller power with a monopoly manufacturer selling to independent retailers, each of whom may have seller power in local retail markets. Common examples of vertical coordination instruments (often called "vertical restraints") to eliminate successive market power include resale price maintenance to control the price set by retailers, quantity forcing whereby the manufacturer imposes a sales quota on the retailer, or franchise fees (i.e., two-part tariffs) wherein the manufacturer sells to the retailer at marginal cost (thereby eliminating a level of marginalization) and collects profits via the franchise or access fee (Katz, 1989).

Empirical analyses of double marginalization are few and focused on seller power. West (2000) provides heuristic empirical evidence for price effects of successive oligopoly in the liquor market in Alberta, Canada. Brenkers and Verboven (2006) estimate welfare effects of liberalization of the European car market from stimulating intrabrand competition that then reduces one layer of marginalization (auto manufacturers' seller power representing the other). Gayle (2013) models "codesharing" agreements among airlines as a double marginalization problem and estimates effects on consumer price and welfare from eliminating the second markup.[3] Cakir and Balagtas (2012) analyze successive seller power in the U.S. milk supply chain and find modest oligopoly power exercised by marketing cooperatives but little seller power for processors/retailers.

Analysts who have studied buyer power have tended to treat it symmetrically to seller power,[4] i.e., buyers are assumed to recognize a marginal factor cost greater than the factor price for any quantity of the input and, accordingly, reduce employment of the input and pay a lower price compared to the

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[1] The term "double marginalization" is based on the idea that a seller with market power recognizes a marginal revenue curve that for any quantity is less than average revenue, and, thus, induces the seller to offer less than the surplus-maximizing volume on the market. Seller power at an additional stage in the supply chain adds an additional layer of marginalization. The same principle applies to buyer power except that we are considering a marginal factor cost curve that lies above sellers' supply curve.

[2] Studies that have addressed the issue of buyer power at successive stages of the supply chain include Sexton et al. (2007), who examined both successive buyer power and successive seller power in analyzing the potential benefits to developing-country producers from trade liberalization, but that analysis focused on potential magnitudes of deadweight losses and redistribution effects of market power, without conducting any empirical analysis. Bjorvatn et al. (2015) recognize the potential importance of buyer power at multiple stages in developing-country supply chains and develop a formal model to show how the problem can be addressed if traders and exporters can execute two-part tariffs as a vertical-coordination device.

[3] Codesharing is the practice whereby one airline can set prices and sell flights that involve segments operated by competing airlines.

[4] This symmetric treatment also applies to the competition authorities in both the U.S. and EU (Mérel and Sexton, 2017).

competitive outcome (e.g., Lopez and You, 1993; Rogers and Sexton, 1994; Kopp and Brümmer, 2017). Such behavior exercised at multiple stages of the supply chain creates a double marginalization problem through buyer power.

Recently, however, authors have questioned the efficacy of this symmetric treatment of buyer and seller power, especially in the context of agricultural products, noting that a substantial commonality of interests exists between downstream input purchasers and their suppliers in the sense that the suppliers' financial viability is critical to the long-term success of the buyers, who could not operate processing facilities efficiently or meet obligations to their buyers without a stable source of the farm product (Crespi et al., 2012; Sexton, 2013; Adjemian et al., 2016).

This work suggests that, under the right market conditions, this commonality of interests could, through vertical coordination, lead to a symbiotic relationship between a downstream buyer and the suppliers of its farm product input such that, even in highly concentrated market settings, the downstream buyer does not exercise market power through marginalization, output exchange is at the efficient level, and farmers receive at least a competitive return on their investments. Sexton (2013) terms these settings "modern agricultural markets" (MAM), but the aforementioned authors as well as others (e.g., Swinnen and Vandeplas, 2010; Swinnen and Vandeplas, 2011) have also noted that the market conditions required for close vertical coordination between sellers and buyer are often unmet, especially in developing countries. For example, farmer side selling of inputs provided by the buyer or selling outputs outside of a contractual agreement represent common problems (Swinnen and Vandeplas, 2010; Swinnen and Vandeplas, 2011).

In what follows we estimate the welfare loss and impacts on farm incomes in the Jambi rubber sector due to successive buyer power. Our approach involves modeling the vertical supply chain consisting of smallholder rubber producers, a network of rubber traders, and rubber processors. We assume processed rubber produced in Jambi is sold competitively into the world market and estimate farmers' supply function for raw rubber using the flexible generalized Leontief form. We rely upon prior work conducted by Kopp and Brümmer (2017) to obtain estimates of traders' oligopsony power and develop original estimates for rubber processors' buyer power by analyzing transmission of changes in exogenous world prices for processed rubber upstream to traders and to farmers.

Our results show farm prices and revenues are depressed by 22.5 percent due to downstream market power, but that most of the impact could be eliminated if the trader-processor stage of the supply chain were vertically coordinated to eliminate the traders' market power over rubber farmers. We conclude by considering policy recommendations to facilitate better vertical coordination within the industry.

2 Rubber production in Indonesia

Agriculture contributes 29.8 percent to the Gross Regional Domestic Product (GRDP) of the Jambi province of Indonesia. Rubber and oil palm are the two main cash crops produced in Jambi (Euler et al., 2016). While the majority of oil palm is produced through large scale plantation agriculture, rubber production is mainly in the hands of over 250,000 smallholder farmers, with 66 percent of farming households depending on rubber as their primary income source (Krishna et al., 2017, Table 1).

Indonesia is the second largest rubber producer in the world, accounting for 3.3 million tonnes, or 23 percent of global rubber output.[5] Rubber contributes 19.8 percent of Jambi's total export value,[6] and Feintrenie et al. (2010) identify rubber production as a promising strategy of poverty reduction for Jambi. Indeed, the prevalence of rubber production among many farming households provides a large potential for broad based increase in economic welfare if improvements in production and marketing efficiency can be achieved.

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[5] This information is based on data for 2016, retrieved from FAOstat (`www.fao.org/faostat/en`) on 08.01.2019.

[6] These numbers are calculated based on data from Statistics of Jambi Province (2018, p. 486, table 7.1.4 and p. 652, table 12.1).

Raw rubber harvest commences with farmers tapping liquid latex from rubber trees (*hevea brasiliensis*) by cutting each tree once or twice a day and collecting the escaping sap (Harp, 2016). The liquid latex is solidified by adding an acid chemical called "coagulant", resulting in slabs of raw rubber of about 50 kg (Peramune and Budiman, 2007). These slabs are transported to processors via a network of traders. The quality of the raw rubber input supplied by traders matters mainly to processors in terms of the conversion rate at which raw rubber is processed into crumb rubber. The processors shred, clean and press the raw rubber slabs to produce crumb rubber according to the international industry standard Technically Specified Rubber (TSR20) and, to a lesser extent, to other quality grades. The biggest share of the world's natural rubber production goes into tire manufacturing.

3 Model of the supply chain

We assume smallholder rubber producers are homogeneous and express their short-run supply function as

$$q = S(p_f|\boldsymbol{W}), \tag{1}$$

where q denotes output for a representative producer, p_f denotes the price received by the farmer for raw rubber, and $\mathbf{W}$ denotes unspecified shifters of the farm supply curve. Although rubber is a perennial crop, supply may be quite price elastic even in the short run because producers can and do modulate the intensity of harvesting (i.e., the frequency in which trees are tapped) in response to price signals. Rubber is also storable in its natural form, and, thus, producers can withhold product from the market in times of low prices (Peramune and Budiman, 2007).

Total supply available in any local village i is found by aggregating across the supplies of village members. Given our assumption of homogeneous producers, village supply is

$$Q_i = n_i q = n_i S(p_{f,i}|\boldsymbol{W}), \tag{2}$$

where n_i denotes the number of rubber-producing farmers located in the village, and $p_{f,i}$ is the price received by rubber producers in village i. It is also useful to express this village supply function in its inverse form:

$$p_{f,i} = s(Q_i|\boldsymbol{W}). \tag{3}$$

3.1 Farmer-trader interactions

Traders are a main source of credit for rubber farmers, which creates a situation of lock-in between a farmer and a trader because credit recipients are obligated to sell production to the trader who provided credit. Although traders are numerous, they focus their purchases within localized market areas or villages, where personalized knowledge of farmers limits traders' exposure to moral hazard behaviors by credit recipients.

Kopp and Brümmer (2017) report survey results indicating that on average 5.8 traders operate in a given village and that there is close communication among these traders as to price paid to farmers, suggesting a loose oligopsony structure in local markets but with the possibility of collusive behavior among the typical handful of buyers operating within a local market area.

Consider a trader j who procures raw rubber within village i, among possibly others. The trader's optimization problem within a given village is:[7]

$$max\{q_{i,j}\} \quad \pi_{i,j} = [p_{w,j} - s(Q_i|\boldsymbol{W})]q_{i,j} - c_{i,j}(q_{i,j}), \tag{4}$$

where $p_{w,j}$ is the price received by the trader from downstream processors (the subscript w is used consistently to denote variables pertaining to traders or *w*holesalers), and $c_{i,j}(q_{i,j})$ is the trader's cost function for acquiring raw rubber from market i, handling it, and delivering it to processing. We

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[7] We assume that traders are perfect competitors in selling downstream to processors and, further, that costs of acquiring and handling rubber in one village, i, are separable from acquisition and handling costs in another village. Thus, we can treat optimization problems independently for traders that operate in multiple villages.

assume $c_{i,j}^{'}(q_{i,j}) > 0$ and $c_{i,j}^{''}(q_{i,j}) \geq 0$ for all i, j. The first-order condition for an interior solution to problem (4) is

$$\partial \pi_{i,j}/\partial q_{i,j} = [p_{w,j} - s(Q_i|\boldsymbol{W})] + q_{i,j}\partial s(Q_i|\boldsymbol{W})/\partial q_{i,j} - c_{i,j}^{'}(q_{i,j}) \overset{!}{=} 0. \tag{5}$$

A trader's market power in procurement is embodied in the term $q_{i,j}\partial s(Q_i|\boldsymbol{W})/\partial q_{i,j}$, which incorporates the trader's perception of the impact of his or her purchases on rubber acquisition price within the village market. A perfect competitor recognizes no impact on price so that the condition (5) reverts to the standard condition of an input purchaser equating marginal value product of the input with its exogenous acquisition cost: $p_{w,j} - c_{i,j}^{'} = p_{f,i}$. Larger values for $q_{i,j}\partial s(Q_i|\boldsymbol{W})/\partial q_{i,j}$ imply a greater perceived impact on acquisition price from the trader's purchases and a greater marginal cost for acquiring raw rubber in the village.

As numerous authors have shown, (5) can be rewritten in the form of a Lerner index as follows (see, for example, Lopez and You, 1993):

$$L_{i,j} = \frac{p_{w,j} - p_{f,i} - c_{i,j}{'}(q_j)}{p_{f,i}} = \frac{\theta_{w,i,j}}{\varepsilon_i}. \tag{6}$$

$L_{i,j}$ expresses the relative markdown of the raw rubber input below its marginal value product. In (6) $\varepsilon_i = (\partial Q_i/\partial p_{f,i})(p_{f,i}/Q_i)$ is the price elasticity of rubber supply in village i evaluated at the oligpsony equilibrium, and $\theta_{w,i,j} \in [0,1]$ is an index of trader j's buyer power in acquiring rubber from village i, e.g., $\theta_{w,i,j} = 0$ if the trader is a perfect competitor, $\theta_{w,i,j} = 1$ if the trader is a monopsonist or if multiple traders are able to collude perfectly, with $\theta_{w,i,j} \in [0,1]$ representing different degrees of oligopsony power.[8] This buyer power can arise from traders noncooperatively recognizing their influence over local prices as in Cournot competition or as a consequence of imperfectly collusive behaviors such as sharing information and discussing product-acquisition strategies with rivals.

It is useful in deriving market equilibria and depicting them graphically, to relate $\theta_{w,i,j}$ to the concept of a buyer's "perceived" marginal cost (PMC) function for acquiring product from upstream suppliers. A trader's PMC function for acquiring raw rubber from a representative farmer under oligopsony is the weighted average of the marginal cost function for the perfect competitor (i.e., the seller's inverse supply function) and the monopsonist's marginal cost function, $\frac{\partial S(p_f|\boldsymbol{W})q}{\partial q}$, with the weights being the estimated degree of trader oligopsony power, $\theta_{w,i,j}$.

$$PMC_{i,j} = (1 - \theta_{w,i,j})\left(S(p_f|\boldsymbol{W})\right) + \theta_{w,i,j}\left(\frac{\partial S(p_f|\boldsymbol{W})q}{\partial q}\right). \tag{7}$$

We rely upon the recent work of Kopp and Brümmer (2017) to derive estimates of traders' buyer power at the village level. These authors estimated traders' revenue functions using a translog specification and information on traders' handling costs based upon a survey of traders, from which they derived traders' marginal value products (MVPs) for farmers' raw rubber. Traders' MVPs were then compared to observed buying prices and utilized to compute Lerner indices (i.e., equation (6)) of traders' oligopsony power. We aggregated their results to the village level by computing quantity-weighted averages of the Lerner indexes, $\overline{L}_{w,i}$, for each trader operating in the village:

$$\overline{L}_{w,i} = \sum_j (q_{i,j}/Q_i)L_{i,j},. \tag{8}$$

These village-level results are summarized in figure 1. Consistent with theory, the Kopp and Brümmer (2017) results indicate that market power is greatest in remote areas and small markets, as well as in areas marked by the absence of formal lending institutions so that informal credit through traders and, thus, producer lock-in with particular traders is prevalent.

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[8] The $\theta_{w,ij}$ can also be interpreted as "conjectural elasticities," i.e., the percent change in rubber purchases from market i that trader j anticipates as a result of a one percent expansion in his or her own purchases (Karp and Perloff, 1996; Perloff et al., 2007).

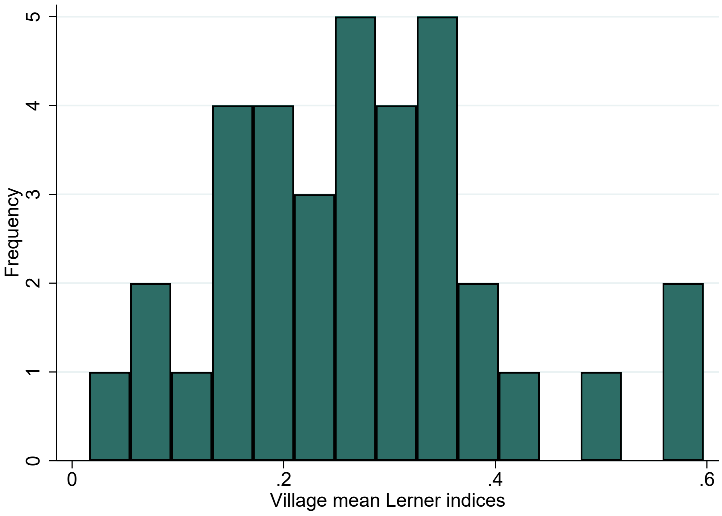
To get an overall sense of the magnitude of trader oligopsony power in Jambi we derived an overall estimated Lerner index for the province by taking the quantity-weighted average of the 40 village Lerner indexes:

$$\overline{L}_w = \sum_i (Q_i/Q)\overline{L}_{w,i} = 0.27, \tag{9}$$

where $Q = \sum_i Q_i$ is total raw rubber production in the surveyed villages.

In section 4 we derive rubber producers' supply function from estimation of a generalized Leontief cost function for rubber production. Point estimates of ε_f range from 1.00 to 1.34 depending on model specification, with $\varepsilon_f = 1.196$ representing the point estimate from the preferred specification. Applying this estimate to the mean value Lerner index from (9), we obtain $\overline{\theta}_w = \varepsilon_f \overline{L}_w = 0.323$, i.e., oligopsony power at the village level in Jambi is on average roughly equivalent to that exercised by three homogeneous traders under a noncooperative Cournot oligopsony.

Figure 1: **Lerner indices on village level**



Source: Own production, based on Kopp and Brümmer (2017). Each set of markers represents one of the sampled villages.

3.2 Trader-processor interactions

Rubber processors in Jambi province are a heterogeneous lot, both in respect to location and capacity of processing plants. Six companies presently operate ten crumb rubber factories. Five factories are located in Jambi city, with the rest located in outlying areas. As there is no shipment of raw rubber into Jambi, Jambi production represents the sole source of supply for the plants, and, given that the raw rubber is not perishable and transports quite readily, it is reasonable to assume that the geographic market encompassing the trader-processor interactions is the entire Jambi province.

At first glance this structure seems like a rather loose oligopsony (see table 1). Based on plant output data for 2013, the four-firm concentration ratio (CR_4) is 0.88, and the Hirshman-Hirfindahl (HHI) index is 2372.[9] Other characteristics of the industry, however, point to a greater potential for processor market power in acquiring rubber from traders than would be suggested purely based on market concentration (Arifin, 2005; Kopp et al., 2017).[10] In particular the processors have a powerful

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[9] HHI is the sum of squared percentage market shares for all firms operating in an industry, and is the statistic often used by antitrust authorities to measure market concentration. For example, the U.S. Justice Department regards industries with $HHI \epsilon [1,500 - 2,500]$ as moderately concentrated and industries with $HHI > 2,500$ as highly concentrated.

[10] Arifin (2005) provides some early empirical evidence of processor buyer power in the form of farm-wholesale price spreads, which widened considerably over 2001-04, a period of steadily rising output prices.

trade association, Gapkindo, and operate largely without interference of antitrust laws (Peramune and Budiman, 2007). Factories report their daily offer prices to Gapkindo and can, in turn, monitor prices offered by their rivals through the association.[11] Gapkindo may also play a role in limiting entry of new factories. Such entry requires government approval, and Gapkindo is consulted on whether approval should be granted (Kopp et al., 2017).

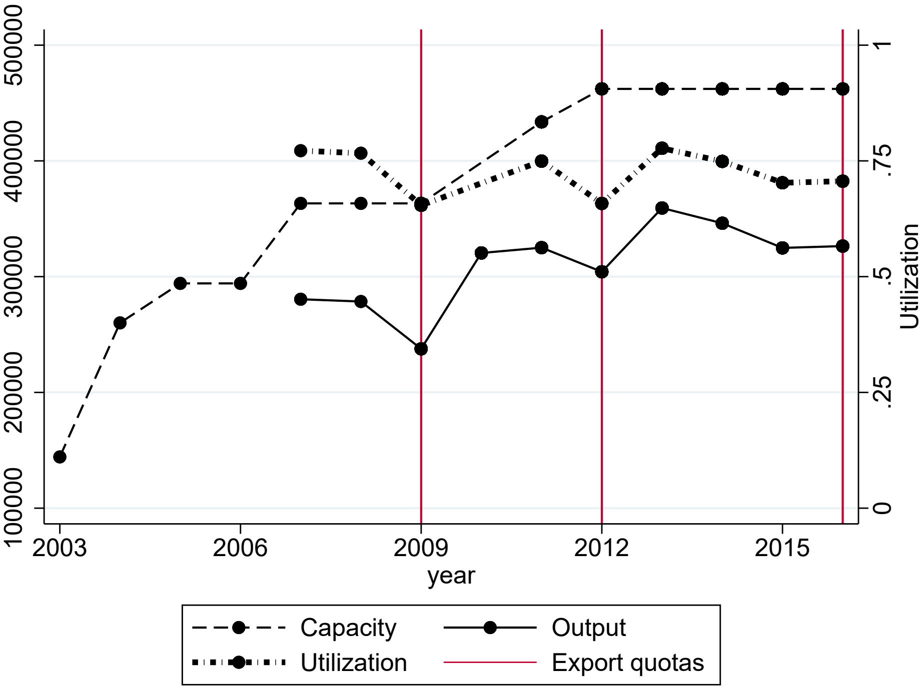
Table 1: **Market shares in processing in Jambi Province**

Processor ID	Output per processor	Market share
1	142,776	36.3%
2	92,760	23.6%
3	69,636	17.7%
4	40,980	10.4%
5	25,920	6.6%
6	20,772	5.3%

Source: Own calculations based upon data on processors' total sales in 2013 from Amalia et al. (2013, table 2). Output is denoted in tons per year.

Figure 2 shows that Jambi rubber factories have had a stable capacity utilization rate of about 75% (dotted line) most years, even during periods of capacity expansion (dashed line).

Figure 2: **Processing capacity and utilization**



Sources: Data on capacities from Jambi in Figures 2012 and 2018 (Statistics of Jambi Province, 2013; Statistics of Jambi Province, 2018), output quantities from Gapkindo, utilization based on own calculations.

The periods of low capacity utilization in Figure 2 correspond to the introduction of export quotas (indicated by the vertical lines) by the Indonesian government as part of a supply-control scheme undertaken by the major natural rubber exporting nations of Indonesia, Malaysia, and Thailand (Anwar, 2017; Verico, 2013). Capacity utilization decreased to 65.8%, on average during the

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[11] Sharing of price information among rivals has long been recognized as a device to enhance collusion. A key agricultural example is mandatory reporting and publication of processor prices paid for live cattle in the U.S. Whereas this requirement was intended to enhance transparency and competition in cattle procurement, a number of authors pointed out that it could facilitate packer collusion, with some empirical evidence supporting that it did (e.g., Cai et al., 2011).

quota years. However, given the fixed proportions relationship between raw and processed rubber, these supply quotas would have reinforced processor buyer power by effectively reducing raw rubber's marginal value product to zero at the quota levels and eliminating any incentive for processors to bid to acquire raw rubber beyond the quota volumes.

In section 4.2 we describe a simple procedure to estimate Jambi processors' market power in acquiring rubber from traders based on evidence regarding transmission of exogenous changes in the world price for processed rubber upstream to traders.

3.3 Market equilibrium under alternative competitive scenarios

Without loss of generality, we choose units of measurement of quantities at each stage of the supply chain so that one unit of raw rubber at the farm and trader levels equals one unit of processed rubber at the processor level. We start with the inverse supply function for a farmer in village i. To obtain analytical solutions, we specify farm supply in linear form, which follows directly from the generalized Leontief cost function for rubber farmers discussed in section 4:

$$p_f = \alpha + \beta q. \tag{10}$$

Since farmers are assumed to be identical, based on (7) we can depict a trader's PMC function for acquiring rubber from the representative farmer in village i:

$$PMC_{w,i} = \alpha + c_{w,i} + (1 + \theta_{w,i})\beta q, \tag{11}$$

where $\theta_{w,i}$ is the magnitude of trader buyer power in village i. The raw rubber purchased from a representative farmer in village i is determined by the condition of equality between a trader's PMC and his or her MVP based on downstream selling price and marginal handling costs:

$$\alpha + (1 + \theta_{w,i})\beta q_i = p_w - c_w.^{12} \tag{12}$$

Solving equation (12) for q_i yields:

$$q_i = \frac{p_w - c_w - \alpha}{(1 + \theta_{w,i})\beta}. \tag{13}$$

Village output is $Q_i = n_i q_i$. Let there be m villages. Then total output, Q, is:

$$Q = \sum_{i=1}^{m} Q_i = \sum_{i=1}^{m} \frac{p_w - c_w - \alpha}{\beta} \frac{n_i}{(1 + \theta_{w,i})} = \left(\frac{p_w - c_w - \alpha}{\beta}\right) \sum_{i=1}^{m} \frac{n_i}{(1 + \theta_{w,i})}, \tag{14}$$

Let $\Theta = \sum_{i=1}^{m} \frac{n_i}{(1+\theta_{w,i})}$. Under perfect competition in procurement, $\theta_{w,i} = 0$ for all i. Then $\Theta = N$, where $N = \sum_{i=1}^{m} n_i$ is the total number of rubber farmers, and (14) represents the competitive aggregate supply of rubber to processors. Otherwise $\Theta < N$, and the raw rubber supply function facing processors reflects marginalization due to traders' market power. Solving (14) in its inverse form yields:

$$p_w(Q) = c_w + \alpha + \frac{\beta}{\Theta} Q. \tag{15}$$

Since we assume a province-wide market for trader sales of rubber to processors, the processors collectively face equation (15) as the traders' aggregate inverse supply function to provide raw rubber to the processors' factories. Analogous to how farmer-trader interactions were handled, we proceed by constructing a PMC function for processors to acquire raw rubber from traders. Perfectly competitive (superscript *) processors take the traders' raw rubber supply, i.e., $p_w(Q)$, as given and add their marginal processing costs, c_p, to obtain $MC_p^* = p_w(Q) + c_p$, whereas a processing sector that acts as a joint monopsony (superscript m) derives a marginal cost curve as $MC_p^m = \frac{\partial (p_w(Q) \cdot Q)}{\partial Q} + c_p$. Combining the two expressions yields:

$$PMC_p = \theta_p MC_p^m + (1 - \theta_p) MC_p^*, \tag{16}$$

where $\theta_p \in [0, 1]$ represents processors' oligopsony power in procuring raw rubber from traders.

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[12] For notational and expositional convenience we drop the j subscript on trader price and marginal handling costs and assume symmetry among traders in these dimensions.

Computing MC_p^m based on (15) and inserting into (16) yields the parameterized version of processors' PMC function:

$$PMC_p = c_w + c_p + \alpha + (1+\theta_p)\left(\frac{\beta}{\Theta}Q\right) \tag{17}$$

Equilibrium rubber output under successive buyer power (i.e., double marginalization) is found by setting $PMC_p = p_p$ and solving, where p_p is the exogenous world price for processed rubber. Let this quantity be Q^{oo}:

$$Q^{oo} = \frac{\Theta}{\beta}\frac{p_p - c_w - c_p - \alpha}{1+\theta_p}. \tag{18}$$

We substitute this quantity into equation (15) to obtain the wholesale price, p_w^{oo}, under double marginalization:

$$\begin{aligned} p_w^{oo} &= c_w + \alpha + \frac{\beta}{\Theta}\left(\frac{\Theta}{\beta}\frac{p_p - c_w - c_p - \alpha}{1+\theta_p}\right) \\ &= c_w + \alpha + \frac{p_p - c_w - c_p - \alpha}{1+\theta_p} \\ &= \frac{\theta_p(c_w+\alpha) + p_p - c_p}{1+\theta_p} \\ &= \frac{\theta_p(c_w+\alpha) - c_p}{1+\theta_p} + \frac{p_p}{1+\theta_p}. \end{aligned} \tag{19}$$

Next substitute p_w^{oo} into equation (13) to get farmer output in each village under double marginalization, given symmetric trader marginal costs across villages:

$$\begin{aligned} q_i^{oo} &= \frac{p_w^{oo} - c_w - \alpha}{(1+\theta_{w,i})\beta} \\ &= \frac{-(c_w+\alpha)}{(1+\theta_{w,i})\beta} + \frac{p_w^{oo}}{(1+\theta_{w,i})\beta} \\ &= \frac{-(c_w+\alpha)}{(1+\theta_{w,i})\beta} + \frac{\theta_p(c_w+\alpha)}{(1+\theta_p)(1+\theta_{w,i})\beta} + \frac{p_p - c_p}{(1+\theta_p)(1+\theta_{w,i})\beta} \\ &= \frac{p_p - (c_w + c_p + \alpha)}{(1+\theta_p)(1+\theta_{w,i})\beta}. \end{aligned} \tag{20}$$

Total output in village i is $Q_i^{oo} = n_i q_i^{oo}$. Finally, we can substitute q_i^{oo} into equation (10) to get farm price in each village as a function of trader market power in the village and at the processor stage, processor marginal cost, trader marginal cost, and parameters defining the raw rubber supply function:

$$p_{f,i}^{oo} = \alpha + \frac{p_p - (c_w + \alpha + c_p)}{(1+\theta_p)(1+\theta_{w,i})}. \tag{21}$$

Both farm output and farm price are declining in trader and processor oligopsony power, as well as trader and processor marginal costs, and are increasing in the final product value of rubber. However, as equation (21) makes clear, transmission of changes in the exogenous processed rubber price upstream to farmers is muted by the exercise of processor and trader oligopsony power, a condition we exploit in section 4 to estimate processors' market power in acquiring raw rubber.

We can find other equilibria by setting the appropriate market-power parameters to zero. The benchmark of perfect competition is achieved by setting $\theta_{w,i} = \theta_p = 0$, for all i, while a setting of single marginalization with only processor buyer power is attained by allowing $\theta_p > 0$, while setting $\theta_{w,i} = 0$, for all i.[13] Figure 3 summarizes the alternative equilibria for a representative village i. The perfectly

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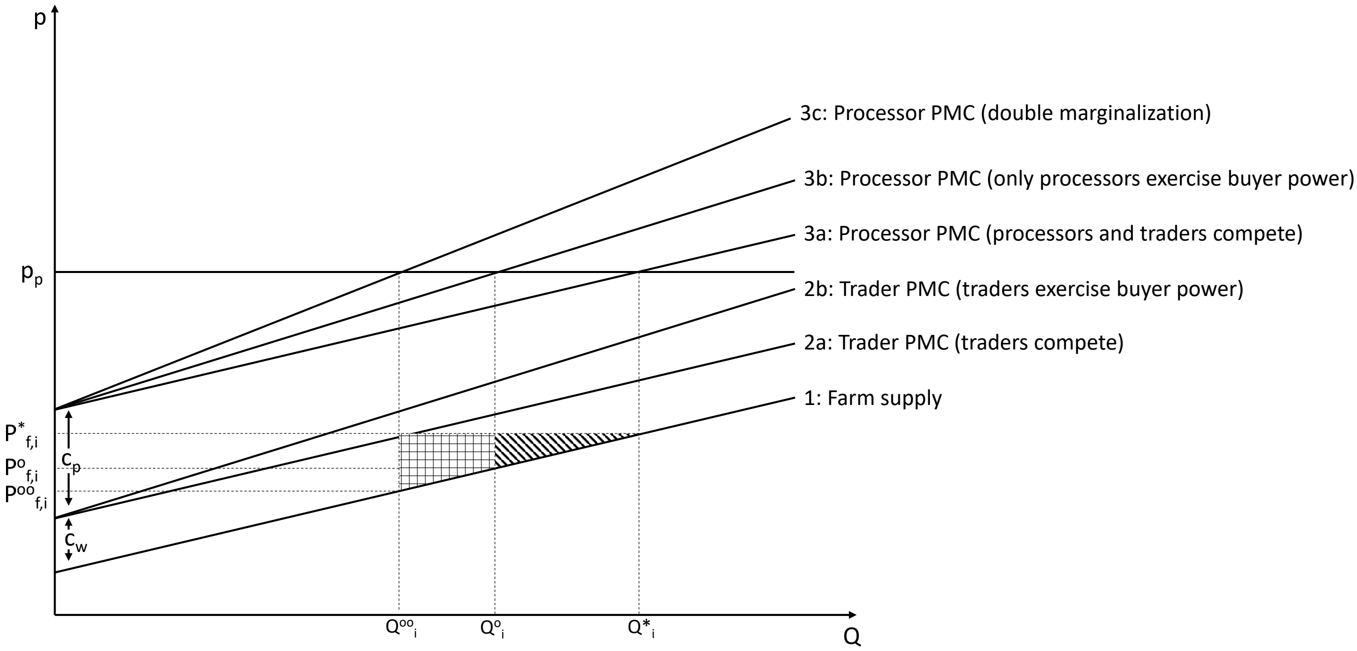
[13] The case of only trader power is found by allowing $\theta_{w,i} > 0$ and setting $\theta_p = 0$, but we consider this case of less interest because, whereas trader power could be reduced or eliminated through vertical coordination at the trader-processor stage, processor buyer power, to at least some extent, reflects structural considerations including barriers to entry and economies of scale.

competitive equilibrium is found where where inverse supply at the processor level, curve 3a in figure 3, intersects the world price, p_p, yielding output Q^* and farm price, $p^*_{f,i}$.

Figure 3: **Alternative equilibria in a representative village**



Source: Own design. The striped area represents the welfare loss from only processor oligopsony, while the checked area represents the additional welfare loss from double marginalization.

While perfect competition throughout the Jambi rubber value chain is unlikely to be achieved given barriers to entry and likely economies of size in rubber processing, the failure of the processor-trader stage to vertically coordinate is the "low-hanging fruit" for improved market performance. Elimination of traders' market power induces expanded production as figure 3 shows, with rubber procurement and output rising from Q^{oo} to Q^o, and farm price rising from $p^{oo}_{f,i}$ to $p^o_{f,i}$. Deadweight loss from exercise of market power is reduced by the cross-hatched trapezoid in figure 3, i.e.,

$$\triangle\, DWL^{oo\to o} = (Q^o - Q^{oo})\left(p^*_{f,i} - \frac{p^o_{f,i} + p^{oo}_{f,i}}{2}\right) > 0. \tag{22}$$

This reduction in DWL can be expressed on a percentage basis by the ratio of the cross-hatched trapezoid to the triangle DWL^{oo} consisting of the cross-hatched and striped areas in figure 3, which represents the DWL under double marginalization: $\%\triangle DWL^{oo\to o} = 100\frac{\triangle DWL^{oo\to o}}{DWL^{oo}}$, where $DWL^{oo} = (Q^* - Q^{oo})(p^*_{f,i} - p^{oo}_{f,i})/2$. Farmers in village i benefit from a higher price ($\triangle p^{oo\to o}_{f,i} = p^o_{f,i} - p^{oo}_{f,i}$), and by expanded sales from elimination of the double marginalization. Processors also benefit through lower procurement costs from eliminating the traders' margin and expanded procurement and sales. Processor profits from rubber procured in village i under the two alternative equilibria are $\pi^{oo}_i = (p_p - p^{oo}_{w,i} - c_p)Q^{oo}_i$, and $\pi^o_i = (p_p - c_{w,i} - c_p - p^o_{f,i})Q^o_i$. The possible profit increase from vertically coordinating village traders is calculated as

$$\triangle\, \pi^{oo\to o} = \sum_i (\pi^o_i - \pi^{oo}_i) > 0. \tag{23}$$

The increase in processor profits from eliminating trader power through vertical coordination is especially important because it demonstrates that processors have incentive to undertake this coordination if institutions are in place to support it, such as enforcement of contractual obligations.

4 Empirical models

The empirical analysis involves estimation of rubber farmers' supply function, rubber traders' and processors' marginal cost functions, and processors' degree of oligopsony power.

4.1 Farm supply

We estimate a generalized Leontief (GL) cost function which maps the farmers' variable costs C as a function of input prices, quantities of fixed inputs, and the output quantity (DIEWERT and WALES, 1987; RYAN and WALES, 2000). In addition to its flexibility as a second-order Taylor series expansion, the GL, unlike its commonly used counterpart, the translog function, readily accommodates observations with zero values for some inputs, a common occurrence for rubber production in the Jambi region (CLOUGH et al., 2016), and small scale agriculture more generally (BATTESE, 1997). Let C denote total variable costs, p_i and p_j denote farm input prices, q denote farm output, and I_i and I_j denote fixed input quantities. The GL cost function is then:

$$\begin{aligned} C = &\sum_{i=1}^{N}\sum_{j=1}^{N}\sigma_{ij}p_i^{0.5}p_j^{0.5}q + \sum_{i=1}^{N}\sum_{j=1}^{M}\eta_{ij}p_i^{0.5}I_j^{0.5}q + \sum_{i=1}^{M}\sum_{j=1}^{M}\theta_{ij}I_i^{0.5}I_j^{0.5}q \\ &+\sum_{i=1}^{N}\sigma_i p_i + \sum_{i=1}^{M}\eta_i I_i \\ &+\sigma_{qq}\left(\sum_{i=1}^{N}\kappa_i p_i\right)q^2 + \eta_{qq}\left(\sum_{i=1}^{M}\mu_i I_i\right)q^2 + u, \end{aligned} \tag{24}$$

where u is a mean-zero error term. As we have enough degrees of freedom, we can set $\sigma_{qq} = \eta_{qq} = 1$ and estimate the κ_i and μ_i directly.

Variable inputs include pesticides, fertilizer, and hired labor. Fixed inputs are family labor and the farm size in ha.[14] Descriptive information on the variables entering the estimation is provided in section 4.3.

Jambi rubber farmers use a variety of pesticides and fertilizers, so we scale these prices by their implied effectiveness, which is generated for each type by the inverse of mean quantity applied per ha in our sample. As noted, there are also farmers in the sample who do not use some of the variable inputs at all. The literature on inclusion of zero-input usages in estimating cost functions is limited. JAMALI JAGHDANI (2011, chapter 2) suggests proxying the price of the non-used input by the price paid by the closest neighbor. Since we lack information on the precise location of the farms, we rely instead on village averages. Following JAMALI JAGHDANI (2011, chapter 2), we also include dummy variables to indicate non-zero input use and interact these dummies with the respective input prices.

Supply elasticity: Given the model assumptions, the price elasticity of farm supply of raw rubber is identical across villages, so we drop the i subscript and denote the estimated elasticity as $\hat{\varepsilon}$. We estimate $\hat{\varepsilon}$ by (i) deriving the marginal cost (MC) function from the estimated generalized Leontief cost function, (ii) setting $MC = p_f$ as the optimizing condition for competitive farmers, (iii) solving this expression for its direct form, and (iv) computing the elasticity in the usual manner.

$$\hat{\varepsilon} = \frac{\Phi}{2\Upsilon q} + 1, \tag{25}$$

where $\Phi = \sum_{i=1}^{N}\sum_{j=1}^{N}\sigma_{ij}p_i^{0.5}p_j^{0.5} + \sum_{i=1}^{N}\sum_{j=1}^{N}\eta_{ij}p_i^{0.5}I_j^{0.5} + \sum_{i=1}^{N}\sum_{j=1}^{N}\theta_{ij}I_i^{0.5}I_j^{0.5}$ and $\Upsilon = \sum_{i=1}^{N}\kappa_i p_i + \sum_{i=1}^{N}\mu_i I_i$.

Parameterization of supply function: Given that the generalized Leontief function is quadratic in output, the marginal cost and, hence, farm supply functions are linear. The estimated slope

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[14] Non-farm employment opportunities are limited in Jambi (BOU DIB et al., 2018), making it reasonable to treat family labor as a fixed input.

of the farm level inverse supply function, β, from equation (10) can be expressed in terms of the estimated price elasticity evaluated at the sample means, $\overline{p_f}$ and $\overline{q}$, for farm price and output as follows: $\varepsilon = \frac{\partial q}{\partial p_f}\frac{\overline{p_f}}{\overline{q}} = \frac{1}{\beta}\frac{\overline{p_f}}{\overline{q}}$. Substituting $\hat{\varepsilon}$ into this expression and solving for β yields

$$\hat{\beta} = \frac{\overline{p_f}}{\hat{\varepsilon}\overline{q}}. \tag{26}$$

The estimated supply-curve intercept $\hat{\alpha}$ is generated by evaluating the supply function at the sample mean and solving:

$$\hat{\alpha} = \overline{p_f} - \hat{\beta}\overline{q}. \tag{27}$$

4.2 Processors' market power

To estimate θ_p, we employ time-series data on wholesale prices paid to traders by processors and the world rubber price received by processors for processed rubber. Equation (19) expresses the wholesale (trader) price as a function of the exogenous world processed rubber price, p_p, and processors' market power, θ_p. We re-express (19) as a regression equation as follows:

$$p_{w,t} = a + bp_{p,t} + \nu_t \tag{28}$$

where $b = \frac{1}{1+\theta_p}$, the intercept term a captures other variables in (19), including c_w and c_p, that are assumed to be constant over the one-year time horizon used in estimating (28), and ν_t is an error term with mean zero. We derive an estimate of processors' market power from the estimated coefficient for b as follows:

$$\hat{\theta_p} = \frac{1-\hat{b}}{\hat{b}}. \tag{29}$$

The price series used in estimating (28) were found to be non-stationary based on the augmented Dickey-Fuller test (Dickey and Fuller, 1979). Based on Johansen (1998), we estimated the relationship by a vector error correction model (VECM) with two lags.[15] The VECM produces more efficient point estimates and standard errors compared to the two-step Engle-Granger method (Engle and Granger, 1987; Johansen, 1998). Specifically, we utilized the following specification of the VECM based on Ihle et al. (2012):

$$\Delta p_{w,t} = m(\Delta p_{w,t-1} - b\Delta p_{p,t-1} - a) + \sum_{i=1}^{2}(\rho_i \Delta p_{w,t-i} + \upsilon_i \Delta p_{p,t-i}) + u_t, \tag{30}$$

where m is the short-term adjustment coefficient, b is the coefficient of the co-integrating relationship and ρ_i and υ_i are coefficients of short-run dynamics. Primary interest is in the coefficient of the long-run equilibrium, b, that is then utilized to infer processors' oligopsony power, θ_p, through equation (29).

4.3 Data

The farm cost function, equation (24), was estimated with data from a farmer survey conducted in 2012 (Euler et al., 2012). Forty villages in Jambi were selected through a stratified random sampling procedure. Among these villages, 26 yielded suitable data for this analysis.[16] Summary data on the variables entering the estimation are provided in table 2. The mean annual farm output based on the survey was $\overline{q} = 4,955$ kg, and the mean farm gate price paid based on a trader survey conducted during the same time period was $\overline{p_f} = 9,359$ Indonesian Rupiah (IDR). These values were used in specifying the farm supply function as specified in equations (26) and (27).

The relatively large heterogeneity in input prices as shown in table 2 mainly reflects price differences between villages. The biggest variance exists for the wage rate, for which the lowest village mean

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[15] The number of lags was determined by Akaike's information criterion, Schwarz's Bayesian information criterion, and the Hannan and Quinn information criterion, each of which supported the choice of two lags.

[16] Villages were excluded if they had no rubber trade or if there was insufficient information on the number of village households engaged in rubber production.

of wages is about 4,000 IDR/hr and the highest village mean is about 14,000 IDR/hr. Fertilizer prices exhibit similar, though less pronounced price variation, with the lowest value being about 3,500 IDR/kg and the highest one 5,500 IDR/kg. The herbicide prices are more similar across villages, with a minimum of 48,000 IDR/kg and a maximum of 59,000 IDR/kg. The heterogeneity in input costs among villages is primarily caused by differences in their accessibility due to road conditions and distance to the provincial capital through which most trade in inputs is channeled. Particularly in hinterland areas, the roads to small villages are poor, especially in the rainy season during which some villages are exclusively accessible via four-wheel-drive vehicles.

The traders' variable costs were calculated from a trader survey conducted in 2012 in the same 40 villages in Jambi as the farmer survey. Traders in each village were identified through a snowball-like search procedure. Across the 40 villages about 70% of all traders were interviewed. Based on the survey, traders' mean unit costs during the study period for acquiring rubber from farmers, handling it, and transporting it to processors were $\overline{c_w}$ =2,232 IDR/kg. Whereas traders' unit costs were important in the estimates of traders' oligopsony power conducted by Kopp and Brümmer (2017) and that were adapted for this study, their direct role in this study is limited to constructing the derived supply function for providing raw rubber to processors as depicted in figure 3.

We lacked direct observations of processors' variable costs. Our approach to estimating processors' oligopsony power described in section 4.2 assumes processors have constant unit costs over the estimation period (one year) but does not rely upon having estimates of those costs. Thus, processors' unit costs play a limited role in our analysis in terms of indicating the shift up in the rubber supply and PMC schedules from the wholesale (trader) stage of the supply chain to the processor stage, as indicated in figure 3. For this purpose we solved equation (21) for c_p for each of the 40 villages in the sample and then averaged those values across villages to obtain an estimate of $\overline{c_p} = 1,852$ IDR/kg.This estimate is consistent with information obtained through interviews with representatives of three processors conducted by the authors that indicated per-unit processing costs in the range of 1,500 - 2,500 IDR/kg of rubber output.[17]

Table 2: **Summary statistics of variables entering the farm cost function estimation**

Variable		Unit	Mean	Std. Dev.	Min.	Max.	N
C	*variable costs*	IDR	2,170,000	3,530,000	20,000	25,000,000	150
q	*rubber output*	kg/year	4,220	3,645	328	21,120	150
p_W	*wage rate*	IDR/hour	7,461	2,885	3,061	14,286	150
p_F	*fertilizer price*	IDR/kg	4,302	793	2,197	7,848	150
p_H	*herbicide price*	IDR/kg	52,447	7,111	33,159	82,676	150
I_L	*family labor*	hrs/year	703	551	96	3,063	150
I_P	*plot size*	ha	2.36	1.93	0.5	12	150

Source: See data description in Section 4.3.

Finally, the data used in the the VECM estimation of processor oligopsony power come from two sources: Wholesale prices, $p_{w,t}$, paid to traders were provided by the processors' association. Gapkindo collects the daily indication prices of the rubber processors located in Jambi City. These prices in practice are adjusted downward according to quality of the delivery. The actual prices received by traders in 2012 were known from the trader survey. We adjusted the price series provided by Gapkindo downward to reflect the prices actually paid. The processors' selling prices, $p_{p,t}$, were provided by PT Kharisma, a Jakarta based marketing company. For consistency with other data utilized in the analysis, we estimated the VECM model with 2012 data (193 observations). Table 3 provides summary statistics of the data entering the VECM for the base year 2012 and also for 2010. The 2010 data were used to estimate the VECM as a robustness check of the 2012 analysis.

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[17] Interviews with processors were conducted between 09.10.2017 and 19.10.2017.

Table 3: **Summary statistics of variables entering the VECM estimation**

Variables	Mean	Std. Dev.	Min.	Max.	N
$p_p 2012$	18,192	2,152	13,964	21,509	193
$p_w 2012$	14,283	1,650	11,374	16,843	193
$p_p 2010$	18,939	2,751	15,639	26,981	160
$p_w 2010$	14,707	2,039	12,271	20,036	160

Sources: See data description in Section 4.3. All units in IDR.

5 Results

5.1 Supply function and elasticities

Estimation results for the generalized Leontief cost function are presented in table 4. In addition to the full model, three variants of the general model were also estimated by restricting various coefficients in the generalized Leontief to zero, and those results are reported in the right columns of table 4. Model 2 omits dummies for non use of specific inputs, model 3 omits the interactions of the dummy variables indicating non use of a specific input with the input price, and model 4 omits the interaction terms that include fixed input quantities.

The base model explains about 80% of the variation in farm production costs. The restricted models also fit the data well, suggesting that accounting for farmers' use or non use of specific variable inputs is not an important aspect of the estimation.

The various models reveal some sensitivity of the coefficients to model specification. This is characteristic of second-order Taylor-series approximation models because of the large number of coefficients estimated and generally high multicollinearity among cross-product terms. The key coefficients for purposes of this paper are the terms involving squared output because of their role in determining the price elasticity of farm supply. These terms are generally of the same sign and consistent magnitude across models. The price elasticity of farm supply evaluated at the sample means was generated via equation (25) and is reported at the bottom of table 4 for all models. All estimates range in the interval $\hat{\varepsilon} \in [1.0, 1.340]$, with the estimate of $\hat{\varepsilon} = 1.196$ for the base model lying near the midpoint of this range.

The inverse farm supply function for the base model, computed through equations (26) and (27), is

$$p_f(q) = 2,138 + 1.46q. \tag{31}$$

Table 4: **Estimation results of generalized Leontief cost function**

	Unrestricted model	Restricted models		
Exogenous variables		Model 2	Model 3	Model 4
$p_W^{0.5} p_W^{0.5} q$	0.26*	0.21	0.22	0.21
	(0.0925)	(0.149)	(0.135)	(0.183)
$p_W^{0.5} p_F^{0.5} q$	-0.058	-0.079	-0.028	0.19
	(0.796)	(0.714)	(0.897)	(0.331)
$p_w^{0.5} p_H^{0.5} q$	-0.10*	-0.073	-0.089*	-0.13***
	(0.0635)	(0.148)	(0.0769)	(0.00679)
$p_F^{0.5} p_F^{0.5} q$	-0.25	-0.15	-0.26	-0.34
	(0.558)	(0.711)	(0.526)	(0.439)
$p_F^{0.5} p_H^{0.5} q$	0.09	0.07	0.07	0.02
	(0.361)	(0.480)	(0.438)	(0.761)
$p_H^{0.5} p_H^{0.5} q$	0.03	0.02	0.03	0.04
	(0.528)	(0.600)	(0.496)	(0.185)
$p_W^{0.5} I_L^{0.5} q$	0.35	0.37	0.34	
	(0.193)	(0.164)	(0.200)	
$p_W^{0.5} I_P^{0.5} q$	0.62	-2.01	-0.67	
	(0.921)	(0.743)	(0.911)	
$p_F^{0.5} I_L^{0.5} q$	-1.13*	-1.10*	-1.08*	
	(0.0609)	(0.0659)	(0.0668)	
$p_F^{0.5} I_P^{0.5} q$	3.83	6.49	4.36	
	(0.780)	(0.629)	(0.742)	
$p_H^{0.5} I_L^{0.5} q$	0.05	0.05	0.04	
	(0.820)	(0.826)	(0.838)	
$p_H^{0.5} I_P^{0.5} q$	-3.57	-3.43	-3.24	
	(0.390)	(0.405)	(0.427)	
$I_L^{0.5} I_L^{0.5} q$	0.08	0.25	0.25	
	(0.906)	(0.706)	(0.693)	
$I_L^{0.5} I_P^{0.5} q$	14.15**	12.19**	12.36**	
	(0.0250)	(0.0478)	(0.0395)	
$I_P^{0.5} I_P^{0.5} q$	-67.56	-55.15	-61.64	
	(0.638)	(0.701)	(0.663)	
p_W	3.910	27.51	21.39	31.98
	(0.981)	(0.862)	(0.892)	(0.851)
p_F	493.4	510.8	591.6	207.7
	(0.344)	(0.300)	(0.222)	(0.666)
p_L	-37.80	-6.64	-25.19	-15.44
	(0.479)	(0.857)	(0.492)	(0.768)
I_L	-364.8	-659.7	-565.5	534.1
	(0.680)	(0.451)	(0.509)	(0.146)
I_P	225,475	304,003	276,023	195,863
	(0.502)	(0.364)	(0.402)	(0.114)
$p_W q^2$	-5.71e-06	-3.85e-06	-4.63e-06	-2.46e-06
	(0.284)	(0.463)	(0.372)	(0.593)
$p_F q^2$	2.67e-05	2.23e-05	2.62e-05	5.94e-07
	(0.173)	(0.240)	(0.162)	(0.965)
$p_H q^2$	3.43e-07	2.32e-07	9.40e-08	7.26e-07
	(0.859)	(0.902)	(0.959)	(0.518)
$I_L q^2$	-3.93e-05	-4.75e-05	-4.70e-05	-1.73e-05***
	(0.246)	(0.159)	(0.152)	(0.00287)
$I_P q^2$	-0.003	6.98e-05	-0.0001	0.007**
	(0.803)	(0.996)	(0.994)	(0.0136)
$p_W D_W$	19.81	-60.45		64.06
	(0.866)	(0.122)		(0.609)
$p_F D_F$	21.44	-21.40***		25.81
	(0.571)	(3.66e-06)		(0.516)
$p_H D_H$	388.2	-74.98		-65.67
	(0.309)	(0.236)		(0.865)
D_W	-763,179		-572,367*	-1.011e+06
	(0.400)		(0.0578)	(0.294)
D_F	-2.286e+06		-1.186e+06***	-2.746e+06
	(0.250)		(8.75e-07)	(0.187)
D_H	-2.02e+06		-397,347	-253,408
	(0.214)		(0.133)	(0.879)
Constant	3.06e+06	919,590	1.6e+06	575,088
	(0.259)	(0.674)	(0.459)	(0.814)
Derived ε	1.196	1.340	1.083	1.000
Observations	130	130	130	130
R^2	0.802	0.792	0.798	0.731

p-values in parentheses.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

5.2 Processor market power

The results from estimation of the VECM model, equation (30), are displayed in table 5.

Table 5: **Results of the VECM estimation**

Exogenous variables	2012	2010
	Cointegrating relationship	
$p_{p,t-1}$	0.77***	0.76***
	(0.001)	(0.001)
a	252.37	215.67
	Error correction parameter	
m	-0.15***	-0.12**
	(0.001)	(0.016)
	Short-run dynamics	
$\Delta p_{w,t-1}$	0.09	0.11
	(0.173)	(0.235)
$\Delta p_{w,t-2}$	0.22***	-0.45
	(0.001)	(0.605)
$\Delta p_{p,t-1}$	0.04	0.13**
	(0.185)	(0.018)
$\Delta p_{p,t-2}$	0.06**	0.06
	(0.025)	(0.241)
Observations	190	157

p-values in parentheses.

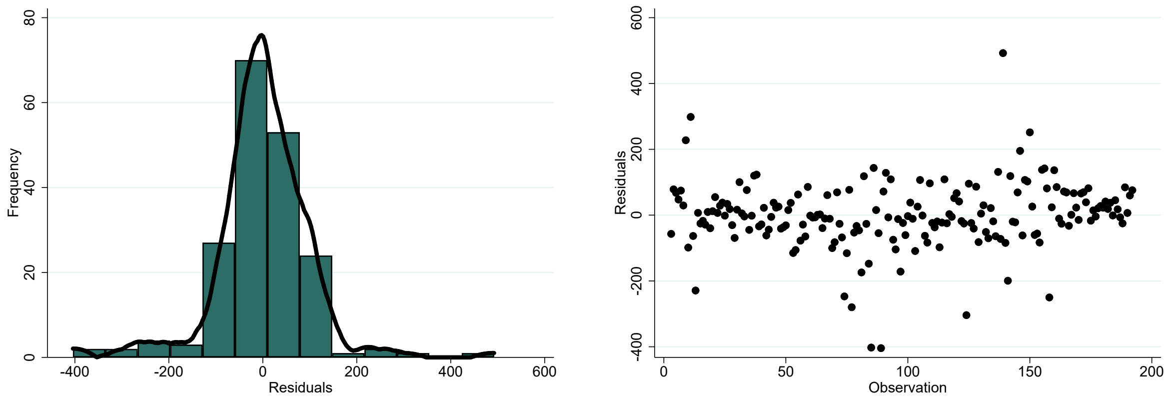
*** p<0.01, ** p<0.05, * p<0.1.

The estimated cointegrating relationship is as follows:

$$p_{w,t} = 252 + 0.77 p_{p,t} + \varepsilon_t. \tag{32}$$

Substituting the estimated $\hat{b} = 0.77$ into equation (29) yields $\hat{\theta}_p = 0.30$, the buyer power roughly equivalent to a three-firm symmetric Cournot oligopsony. As a robustness check the same estimation was carried out for a second year, 2010, for which full data were available. The results for 2010 are very similar, with $\hat{b} = 0.76$. The structural stability of the VECM estimation was checked through visual inspection of the residuals as depicted in figure 4. The residuals are approximately normally distributed (sub figure 4a) and stable over time (sub figure 4b).

Figure 4: **Residuals of the VECM estimation**



(a) **Error distribution**

(b) **Errors over time**

Subfigure (a): The black line is a kernel density plot indicating that the errors are roughly normal-distributed.
Subfigure (b): Presents a display of errors over time, indicating structural stability of the VECM estimation.

5.3 Implications of double marginalization for farm prices, rubber output, and welfare

If traders' oligopsony power is eliminated through vertical coordination of the trader-processor stage in the supply chain, i.e., if a level of marginalization is eliminated, village-level farm prices will rise in a magnitude dependent upon the level of trader buyer power at the village level. We denote this change in farm price as $\triangle p_{f,i}^{oo \to o}$, and equation (33) depicts the formula for estimating $\triangle p_{f,i}^{oo \to o}$:

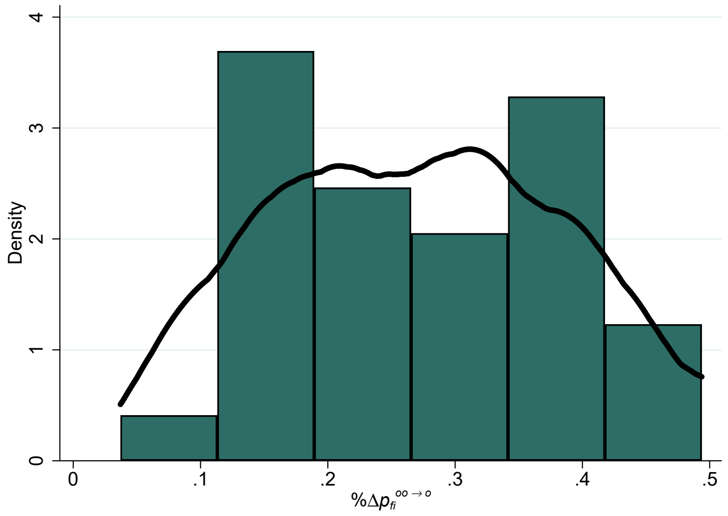
$$\triangle p_{f,i}^{oo \to o} = p_{f,i}^{o} - p_{f,i}^{oo} = \frac{p_p - (c_w + \alpha + c_p)}{(1+\theta_p)} - \frac{p_p - (c_w + \alpha + c_p)}{(1+\theta_p)(1+\theta_{w,i})}. \tag{33}$$

Estimates of (33) for each of the survey villages were obtained by substituting estimation results for α (from equation (27)), processor unit cost, c_p, trader unit costs, c_w, processor price, p_p,[18] trader buyer power in village i, $\theta_{w,i}$, and processor buyer power, θ_p, into the equation.

Figure 5 depicts the variation of estimated percentage price increases across the survey villages, and table 6 contains the estimated percentage farm price impacts, along with estimates of percent raw rubber output increase and percent deadweight loss reduction, given the estimated level of trader buyer power in each village. We obtained a Jambi-wide average farm price increase of 29.1%, output increase of 37.3%, given the estimated price elasticity of supply, and reduction in DWL of 69.3% from eliminating double marginalization. A notable caveat is that these estimates are based on the output expansion farmers would be prepared to undertake in response to the estimated price increase from removing the second layer of marginalization, holding land area in rubber trees constant. Our analysis of the processing sector indicates, however, that an expansion of this magnitude may be unattainable in the short run due to processor capacity constraints as discussed in section 3.2. Thus, the full price and output effects should be considered as a longer-run response attained only after incumbent processors expanded capacity or there was de novo entry into the processing sector.

Realistically trader market power will not be eliminated through any single action. Rather improved vertical coordination can be achieved over time through the policies discussed in the paper, so, although we model the response in a static equilibrium framework, we would expect a gradual expansion of capacity in the processing sector as coordination was improved and higher prices were transmitted to farmers. The estimates in table 6 represent the culmination of that process, holding rubber land area constant.

Figure 5: **Estimated farm price increases from vertical coordination of trader-proessor sector**



Percentage increase from $p_{f,i}^{oo}$ to $p_{f,i}^{o}$ by village.
Source: Own production.

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[18] For processor price we took the simple average of prices received by processors for 2012.

Table 6: **Impacts of eliminating traders' oligopsony power**

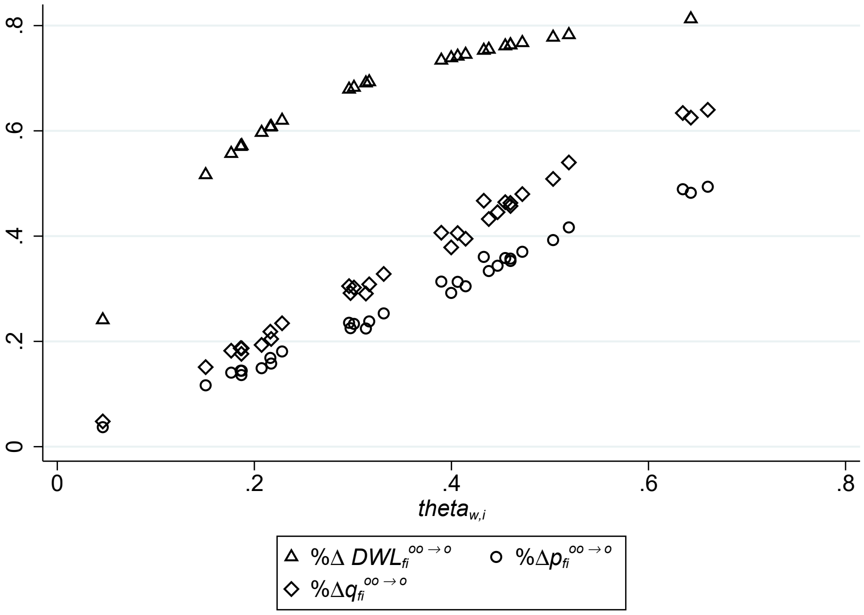
Village ID	$\theta_{w,i}$	$\% \triangle p_{f,i}^{oo \to o}$	$\% \triangle q_{f,i}^{oo \to o}$	$\% \triangle DWL^{oo \to o}$
01	0.46	0.35	0.46	0.76
02	0.15	0.12	0.15	0.52
03	0.19	0.14	0.19	0.57
04	0.22	0.17	0.22	0.61
05	0.05	0.04	0.05	0.24
06	0.32	0.23	0.31	0.69
07	0.22	0.16	0.20	0.61
08	0.52	0.42	0.54	0.78
09	0.41	0.31	0.41	0.74
10	0.64	0.48	0.63	0.81
11	0.40	0.29	0.38	0.74
12	0.21	0.15	0.19	0.60
13	0.19	0.14	0.19	0.57
14	0.41	0.31	0.40	0.75
15	0.18	0.14	0.18	0.56
16	0.43	0.36	0.47	0.75
17	0.30	0.23	0.30	0.68
18	0.30	0.24	0.31	0.68
19	0.31	0.23	0.29	0.69
20	0.44	0.33	0.43	0.75
21	0.47	0.37	0.48	0.77
22	0.45	0.36	0.47	0.76
23	0.23	0.18	0.23	0.62
24	0.39	0.31	0.41	0.73
25	0.46	0.36	0.46	0.76
26	0.50	0.39	0.51	0.78
Mean	0.36	0.29	0.37	0.69

Source: Own production.

Estimated price under vertical coordination of traders and processors is calculated with equation (21) and quantities with the parameterized farm supply function. DWL calculated from equation (22).

Figure 6 further illustrates the impacts of vertical coordination by plotting the percentage change in DWL and farm price and output as a function of the village level $\theta_{w,i}$. The figure depicts the monotone relationship between $\theta_{w,i}$ and the percentage increases in $p_{f,i}$ and q_i and the percentage decrease in DWL_i if, through vertical coordination, we eliminate double marginalization. It is very notable based on the geometry of DWL that even relatively modest market power at the trader level creates substantial DWL because it is incremental to the market power and DWL already in place due to processor buyer power and the fact that DWL increases at an increasing rate in the reduction in output from the competitive level.

Figure 6: **Relation between traders' buyer power and market outcomes in the sample villages**



Source: Own production, based on table 6.

Given the results for estimated prices and quantities under single marginalization, $p^o_{f,i}$ and Q^o_i, we can also calculate the additional potential processors' profits from removing trader market power through vertical coordination via equation (23). Additional annual profits to processors are $\triangle\pi^{oo\rightarrow o} = 8.39\text{e}{+}11$ IDR = 76.6 million USD, demonstrating the incentive for processors to vertically coordinate across their interactions with traders if institutions can support such coordination.

Table (7) displays the sensitivity of the overall results to variations in our two key estimated parameters: the elasticity of farm supply, ε_f, based on the GL cost function estimation results reported in table 4, and the vector error correction model on which our estimate of processors' market power, θ_p, relies. The alternative values of farm supply elasticity in Table 7 are the lower and upper bounds from the alternative specifications of the GL estimations. The alternative values for b represent the lower and the higher bounds of the 95% confidence interval of the VECM estimation.

The estimated percentage price changes are independent of ε_f and θ_p due to the linearity of the model. The percent output increase is, of course, increasing in the estimated value for ε_f, given the constant percent change in the $p_{f,i}$. The estimated percent reductions in the DWL_i also change as a function of ε_f and θ_p. Given the precision with which θ_p was estimated and the simulated range of values for ε_f, the range of values for $\% \triangle DWL$ is rather small, from 64% to 74%.

6 Conclusion

Supply chains in emerging economies tend to be more complex than for the same product in western economies. A product passing through multiple stages with arm's-length transactions creates the

Table 7: **Sensitivity analysis**

Scenario	Changed variables			Outcome variables		
	ε_f	b	θ_p	$\% \triangle p_{f,i}^{oo\to o}$	$\% \triangle q_{f,i}^{oo\to o}$	$\% \triangle DWL^{oo\to o}$
Benchmark	1.296	0.77	0.30	0.29	0.37	0.69
VECM Estimation						
b: 95% percentile: upper bound	1.296	0.8	0.25	0.29	0.37	0.74
b: 95% percentile: lower bound	1.296	0.74	0.35	0.29	0.37	0.65
Raw rubber supply elasticity						
Lowest value from estimations	1.00	0.77	0.30	0.29	0.29	0.64
Highest value from estimations	1.34	0.77	0.30	0.29	0.39	0.70

Note: The table depicts the effects of different results from the estimations on key outcome variables.

possibility that market power is exercised at multiple stages, and double marginalization becomes an issue. Despite this widely observed stylized fact of developing country markets, this paper is the first to fully develop the theory of price formation with buyer market power at multiple stages and estimate the magnitude of price, output, and welfare effects of double marginalization in an actual market setting.

Our analysis of the rubber value chain in the Jambi province of Indonesia finds moderate buyer power exercised by village traders over farmers and by rubber processors over traders. Specifically we found an average market power in each stage roughly equivalent to Cournot oligopsony among three homogeneous buyers. Evidence suggests that the market power that would emanate from the loose oligopsony structures at the trader and processor stages is reinforced by horizontal coordination among traders and processors and an absence of antitrust laws to proscribe such behavior. Our conceptual model demonstrated that a second level of market power is particularly damaging to efficiency in terms of the deadweight loss created, precisely because it represents efficiency loss that is added on to an efficiency loss from market power at another stage.

Whereas standard models of industrial organization predict that double marginalization can be eliminated by market participants' incentives to vertically coordinate, many impediments to achieving this coordination often exist in emerging economies. Contract enforcement is low, as well as trust levels among trading partners. Farmers are reliant upon traders for informal credit, and it is unlikely that processors could play that role effectively due to moral hazard problems that the independent traders are able to surmount through their familiarity with local villages. Policy responses that improve the functioning of institutions to improve contract enforcement and trust levels would enhance opportunities for vertical coordination. Improved infrastructure could reduce transaction costs of sourcing raw rubber and expand competiteness of procurement markets by broadening their geographic scope. Improved access to formal credit would reduce farmers' reliance on informal credit through traders would reduce buyer-seller lock in and also facilitate vertical coordination by reducing the importance of independent traders' information advantages.

Thus, although our results highlight the benefits to farmers and processors from removing a layer of marginalization from the supply chain and, accordingly, the incentives to accomplish it, the goal of improved coordination may be largely unrealized until effective policies are in place to reduce or eliminate the aforementioned barriers to coordination. Implementing such policies could be considered an important public priority because improved coordination would increase incomes of thousands of small farmers operating within a key export sector of the Jambi province and also help address an important environmental concern in terms of pressure rubber farmers are experiencing to convert land from rubber cultivation to oil palm (Kubitza et al., 2018).[19] Increased farm gate prices from the reduction or eventual elimination of traders' oligopsony power would diminish incentives to convert land to oil palm production.

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[19] The environmental concerns regarding expansion of palm oil production are discussed by Fitzherbert et al. (2008), Adnan and Atkinson (2011), Obidzinski et al. (2012), Guillaume et al. (2016), and Merten et al. (2016).

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