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Economic and ecological trade-offs of agricultural specialization at different spatial scales

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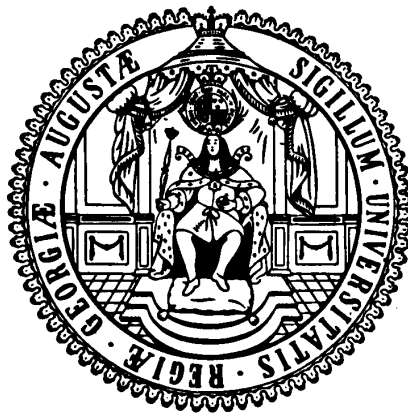
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Courant Research Centre

‘Poverty, Equity and Growth in Developing and Transition Countries: Statistical Methods and Empirical Analysis’

Georg-August-Universität Göttingen
(founded in 1737)



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1 **Economic and ecological trade-offs of agricultural specialization at different**
2 **spatial scales**

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37 Abstract

38 Specialization in agricultural systems leads to trade-offs between economic gains and ecosystem
39 functions. Economic gains can be maximized when production activities are specialized at
40 increasingly broader scales (from the household to the village, region or above), particularly when
41 markets for outputs and inputs function well and allow specialization as well as high levels of food
42 security. Conversely, a tendency toward specialization likely reduces biodiversity and significantly
43 limits ecosystem functions at the local scale. When agricultural specialization increases and moves to
44 broader scales as a result of improved infrastructure and markets, ecosystem functions can also be
45 endangered at broader spatial scales. Policies to improve agricultural incomes through
46 improvements in infrastructure and the functioning of markets thus affects the severity of the trade-
47 offs. This paper takes Jambi province in Indonesia, a current hotspot of rubber and oil palm
48 monoculture, as a case study to illustrate these issues. In doing so, it empirically investigates the
49 trade-offs between economic gains and ecosystem functions for three spatial levels of scale (i.e.
50 household, village, and region) and discusses ways to resolve these trade-offs.

51

52 Keywords

53 Ecosystem services, economies of scale, Indonesia, monoculture, oil palm, rubber

54 **1. Introduction**

55 For poor smallholder households that depend largely on the use of natural resources for their
56 livelihood, increasing agricultural incomes is critical to escape poverty (Klasen et al., 2013; Lipton,
57 2005; World Bank, 2007). In an environment of well-functioning markets and infrastructure, often a
58 first-best economic option is to specialize in the most profitable crop for given soil, climate, and
59 weather conditions (Lambin and Meyfroidt, 2011; Ruiz-Perez et al., 2004). At the same time, there
60 are some costs and constraints to complete specialization which partly relate to the availability,
61 access, and functioning of markets for inputs, outputs, labor, and credit. For example, complete
62 specialization often requires highly seasonal labor demand which often cannot be procured locally;
63 similarly, concentration on one crop exposes farmers to high risk against which they can only
64 imperfectly insure themselves; third, jointness in production can also lead to advantages of
65 diversified production (Allen and Lueck, 1998; Ballivian and Sickles, 1994; Klasen and Waibel, 2012;
66 Kurosaki, 2003). However, the better labor, capital, insurance, input, and output markets function,
67 the lower are these constraints to complete specialization. If, for example, seasonal labor demand
68 can be met with labor migrants, farmers have access to insurance, and improved infrastructure
69 promotes intra-regional and international trade in competitive input and output markets, these
70 constraints to specialization at increasingly broader scales are much less serious (Kurosaki, 2003). In
71 the extreme, this could lead to monocultures not only at the level of the individual household, but at
72 the level of the village, or even region. Hence, the degree of specialization may change along spatio-
73 organizational scales depending on market functioning (Fig. 1).

74 At the same time, there can be substantial ecological and also socio-cultural costs in terms of
75 reduced ecosystem services if such monoculture agricultural systems emerge at the level of a village
76 or an entire region. There might be losses in plant and animal biodiversity (Foster et al., 2011), but
77 also reduction of pollination services (Priess et al., 2007) or biological pest control (Stamps and Linit,
78 1997) as well as hydrological functions (Comte et al., 2012; Nedkov and Burkhard, 2012; Ojea et al.,
79 2012). Decomposition services and carbon sequestration may possibly be impaired, too.
80 Furthermore, cultural or information functions may be lost (Gasparatos et al., 2011; Millennium

81 Ecosystem Assessment, 2005). These losses crucially depend on the level of scale at which
 82 specialization on monoculture crops occurs, with specialization at broader scales generating more
 83 problems. There can also be a mismatch on a temporal scale: In the short term, the progressive loss
 84 of ecosystem functions and associated services may only have a small impact on the profitability of
 85 specialized monocultures, in the longer-term, the sharp reduction or entire disappearance of
 86 important functions might undermine the profitability of monocultures at broader spatial scales.

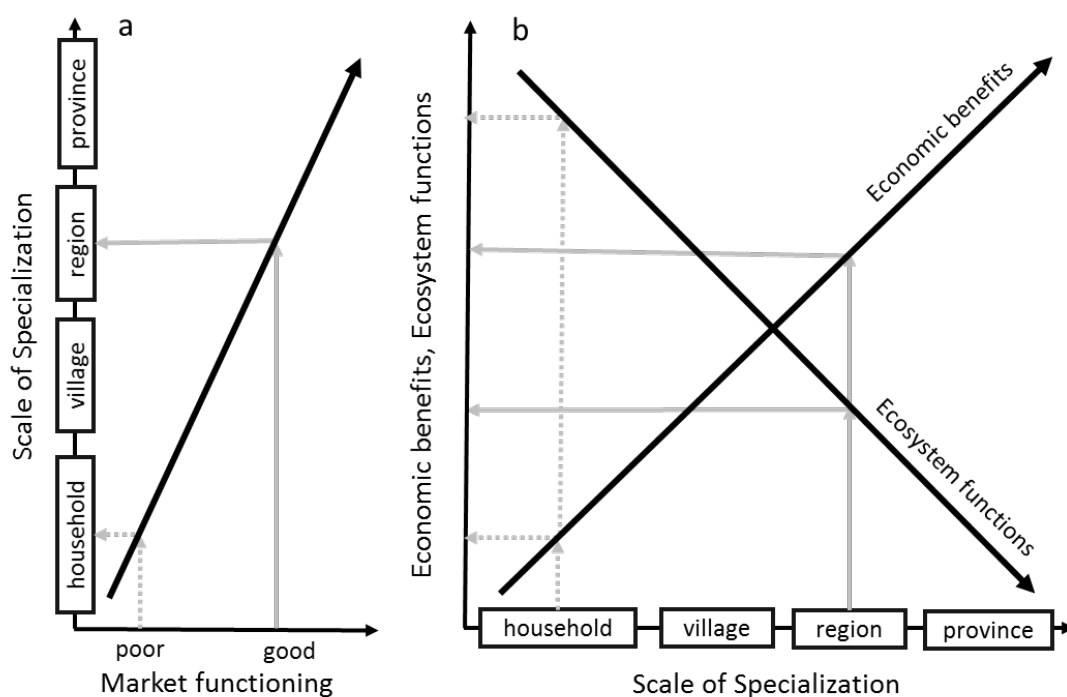


Fig. 1: Market functioning drives the level of scale at which specialization occurs (a), which in turn drives economic benefits and ecosystem functions (b; black arrows). Two scenarios are illustrated (grey arrows): In the poor market functioning scenario (dotted grey arrows), specialization is only possible at the household level (see a) which leads to low economic benefits and high ecosystem functionality (see b). In the scenario with good market functioning (grey line arrows), specialization is possible at broader scales such as the region (see a). This leads to loss of ecosystem functions and high economic benefits compared to the poor market functioning scenario (see b). Note that in this illustration the location of the crossing of the arrows is arbitrary. The general message is that there is a scale-dependent trade-off between specialization and ecosystem functions driven by market functioning.

88 The economic benefits and socio-ecological and cultural consequences depend therefore, to
89 a large extent, on the spatial scale at which specialization occurs. For example, specialization within
90 a village at the level of an individual farm might already generate many benefits of specialization with
91 relatively few ecological costs if the diversity of crops remains high within a village. Figure 1
92 illustrates this point by showing two scenarios: one where poorly functioning markets allow only
93 specialization at the household level; economic benefits of specialization are low but ecosystem
94 functions are high. In scenario two, well-developed markets allow specialization at the regional level
95 generating higher benefits but specialization at this broader scale reduces ecosystem services (see
96 also Timmer, 1997). This development of markets and specialization can also be driven by policies.
97 For example, policies can actively promote monocultures through supporting and subsidizing the
98 development of cash crops in particular regions; in the case of Indonesia, the promotion of the palm
99 oil sector was supported by various policies of the government, including migration policies, land
100 policies, infrastructure, etc. (McCarthy and Cramb, 2009). In addition, policies aimed primarily at
101 promoting growth and poverty reduction can also affect this trade-off between economic benefits
102 and socio-ecological and cultural consequences of specialization. For example, policies to improve
103 access and functioning of markets (e.g. through improved infrastructure, information systems) are
104 likely to be beneficial from an economic point of view as they increase the scope for specialization for
105 poor producers, but such policies might cause harm from an ecological point of view as they push
106 specialization to a broader spatial scale.

107 Some of these issues have been studied individually in both the economics (e.g. Belcher et
108 al., 2004; Hazell and Wood, 2008; Kurosaki, 2003; Ruiz-Perez et al., 2004; Timmer, 1997) and
109 ecological (e.g. Lambin and Meyfroidt, 2011; Smith et al., 2008) literature. Many studies have also
110 commented on the general trade-offs between intensive agricultural production and the loss of
111 ecosystem services (e.g. Evans, 2009; Hazell and Wood, 2008; Lambin and Meyfroidt, 2011;
112 Millennium Ecosystem Assessment, 2005). However, the interplay of specialization and ecosystem
113 functions and services at different spatial scales, and how they are influenced by policy has not been
114 studied at any level of detail so far. The purpose of this conceptual paper is to lay out these issues

115 and trade-offs and illustrate them with examples from the literature and with on-going research on
116 oil palm plantations in the province of Jambi in Indonesia which provides a real-time case study.

117

118 **2. Optimal Specialization from an Economic Perspective**

119 Economic benefits of specialization are very closely linked with the presence of economies of scale in
120 production. Economies of scale are defined as the advantage of large-scale production that results in
121 lower costs per unit of output (Kislev and Peterson, 1996). Hence, the total production costs are
122 spread over more units of output. Economists tend to distinguish between internal economies of
123 scale and external economies of scale (Hallam, 1991; Marshall, 1920). Internal economies of scale
124 refer to cost advantages that are due to conditions inside the production unit (e.g. the farm or the
125 firm), while external economies of scale relate the cost advantages that arise from greater
126 production of a sector or region (or even an entire economy, Caballero and Lyons, 1990). In the case
127 of agriculture, both internal as well as external economies of scale can be present.

128 For the case of cash crop agriculture, we identify four most relevant *internal* economies of
129 scale. Firstly, we refer to the specialization of labor. Larger production units can employ workers with
130 more specialized knowledge, for example in the application of chemical inputs (even though this
131 seems not to be the case in our example in Jambi, see section 4). Second, a finer division of labor is
132 possible which might increase the efficiencies of performing tasks and facilitate the monitoring of
133 labor in completing these tasks. Third, internal economies of scale can result through the indivisibility
134 of machines since the use of a more powerful machine, e.g. a tractor, is only profitable for larger
135 plantations. Lastly, the increasing dimension of production can reduce average costs, for example in
136 purchasing chemical inputs or in reducing transportation and processing costs - especially, if distance
137 to input and output markets is high.

138 Given these potentially large internal economies of scale, the question of optimal farm size
139 arises. If these economies of scale are so substantial, why does cash crop production not take place
140 exclusively on large plantations? And why do smallholders survive in the face of the cost advantages
141 of large plantations? This is because large production units in agriculture also have to contend with

142 substantial diseconomies of scale (e.g. Allen and Lueck, 1998; Binswanger et al., 1995; Lipton, 2005).
143 They are due to the need for large farms to rely on hired labor where principal-agent problems
144 (Levinthal, 1988), information and incentive problems might lead to high costs of monitoring labor
145 and/or low labor effort and productivity. As a result, the family farm has remained a competitive
146 production unit where these information and incentive problems are much less prevalent. As argued
147 by Binswanger et al. (1995), large plantations will prevail if the economies of scale in processing are
148 substantial (as is the case, for example, with bananas and tea) and/or when smallholders cannot
149 easily be linked to larger processing facilities, as is possible in our case study (see section 4). A key
150 message emerging from this discussion is that internal economies of scale generate substantial
151 benefits for farms to specialize on one output, even if it is not optimal for production to take place
152 exclusively on large plantations.

153 A key driver for *external* economies of scale in cash crop agriculture is the total growth of the
154 respective crop industry in a particular region. This facilitates the development of local processing
155 industries and the development of transportation facilities; both reduce transport costs and promote
156 trade. Growth of the industry in a local area can also help develop and improve the functioning of
157 input, output, and factor markets by ensuring more volume of transactions in these markets which
158 will increase the number of participating actors, thus promoting competition and lowering
159 transaction costs. Lowered transaction costs further promote trade and allow an increasing
160 separation between production and consumption of agricultural households (Timmer, 1997):
161 production is specialized on the most profitable crop given soil and climatic conditions, while
162 consumption of food and other needs is procured through trade.

163 Despite these substantial scale advantages in production, there are barriers and limits to
164 specialization on one output. One limit can be product-specific. For example, joint production of
165 several outputs can be technically optimal (e.g. in the case of inter-cropping or crop rotation to
166 optimally use existing soil resources or preserve/improve soil fertility, e.g. Ballivian and Sickles,
167 1994). It may also be the case that local heterogeneity of soil, water, and weather conditions
168 recommend a more diversified portfolio of optimally adapted outputs. Second, there may be an

169 intrinsic value attached to maintaining a diversified portfolio of output, particularly also if these
170 portfolios ensure adequate provisioning of households with the most important necessities and/or
171 the diversified portfolio has itself ethnic or cultural significance. Socio-cultural ecosystem services
172 have been recognized in many studies (de Groot et al., 2002; Millennium Ecosystem Assessment,
173 2005). Nevertheless, cultural aspects too often have been neglected in the ecosystem services
174 assessment (Chan et al., 2012; Schaich et al., 2010) and therefore the analysis of land-use and
175 landscape development may produce misleading results. Altogether, non-material benefits and
176 intrinsic values such as culture and ethnicity as well as the social embedding or sentimental
177 attachment to places usually constitute limits to specialization.

178 Apart from these technical and socio-cultural limits to specialization, the main other basic
179 constraint to complete specialization relates to the functioning of markets and the associated
180 transaction costs of engaging heavily with input, output, and factor markets. If transport costs are
181 high and labor markets absent, farmers will be forced to maintain a diversified portfolio of outputs at
182 a local scale that includes all major food necessities (Timmer, 1997). Production decisions will then
183 also be made depending on the availability of family labor; and a diversified portfolio will be
184 beneficial if labor demands can then be spread over the year. Moreover, concentration on one crop
185 can be risky as there are high output and price risks; in the absence of functioning markets for credit
186 and insurance, such risks can devastate farmers if production fails or prices fall (Klasen and Waibel,
187 2012; Morduch, 1995; Ray, 1999). Since poor farmers live close to subsistence, the absence of well-
188 functioning credit and capital markets will force them to rely on a diversified production portfolio to
189 reduce these risks (Morduch, 1995).

190 Conversely, this implies that improvements in the functioning of these markets will reduce
191 those constraints to specialization and will enable also smallholder farmers, including poor ones, to
192 specialize much more. They can then increasingly rely on credit and insurance markets to deal with
193 production and price risks, they can rely on labor markets to deal with seasonal labor demand
194 problems, and they can ensure reliable access to food and other needs through trade. Of course,
195 these markets will never function perfectly but the point to emphasize here is that as the functioning

196 of these markets improves, specialization becomes economically more attractive. Moreover,
197 specialization can then move to a broader spatial scale. In particular, if input, output, and labor
198 markets improve substantially, complete specialization on one cash crop can move from the
199 household and the village level to the regional or even national level.

200 A second point of note is that policies that improve the functioning of input, output, labor,
201 capital, and insurance markets are likely to promote this specialization at an increasingly broader
202 scale. Thus, while these policies are beneficial to smallholder producers as they promote higher and
203 more stable incomes, they will come at a cost of increasing specialization and monocultures at
204 broader spatial scales with important consequences for ecosystem functions and services.

205

206 **3. Ecological consequences of specialization at increasingly broader scales**

207 Specialization leads to monocultures, and monocultures are usually less beneficial for ecosystem
208 services and associated biodiversity than polycultures. In addition, specialization often leads to
209 intensification which is typically accompanied by higher inputs and the removal of remnant
210 vegetation. A range of ecosystem services can potentially be affected. Most importantly, provisioning
211 services such as crop production may suffer significant losses due to reduced crop diversity (Di Falco
212 et al., 2007; Smith et al., 2008). On the long run, high fertilizer inputs may lead to eutrophication
213 (Tilman et al., 2001) and altered soil physical characteristics and microbial communities. This may in
214 turn reduce production services. Thus, high crop diversity can be critical for achieving food security
215 (Palmer and Di Falco, 2012), at least for subsistence farmers and at local scales. Regulating ecosystem
216 services such as biological pest control may also be more efficient in polycultures or when remnant
217 vegetation is present. For instance, most insect herbivore species have lower densities in
218 polycultures than in monocultures (review on 287 species in 209 studies by Andow, 1991). Complex
219 agronomic multicropping systems have lower pest insect populations than simpler systems (Stamps
220 and Linit, 1997). Temperate forests that consist of multiple tree species have fewer pest outbreaks
221 than single-species stands (Stamps and Linit, 1997). However, supporting services such as soil fertility
222 and regulating services such as nitrogen-use efficiency have been shown to depend more on

223 management than on crop diversity (Snapp et al., 2010). A reduction of coffee yields due to declining
224 pollination services under deforestation may be counteracted by preserving patches of forest (Priess
225 et al., 2007).

226 Associated biodiversity is often, but not always enhanced in polycultures as compared to
227 monocultures. For instance, polycultures of different annual crops harbored greater weed species
228 richness than monocultures of these crops (Palmer and Maurer, 1997). However, in Malaysia, bird
229 species richness was found to be higher in monoculture oil palm plantations than in polycultures
230 (Azhar et al., 2014), probably due to higher human disturbance during weeding and harvesting in
231 polycultures.

232 With increasingly broader spatial scales at which specialization occurs, the spatial extent of
233 the resulting monocultures and their ecological effects will also be scaled up. This means that not
234 only crop diversity may be lost over larger areas, but also that landscape configuration might be
235 affected. For instance, technological and environmental factors (e.g. road access, topography) may
236 cause the few crop types to be clustered in space. This heterogeneity may augment the loss of
237 diversity because species that depend on a certain uncommon crop type are less likely to find the
238 remnants of this crop type. Moreover, landscape fragmentation has non-linear effects on species
239 survival, with extinction setting in long before the last remnants of this crop type have vanished
240 (Bascompte and Sole, 1996).

241

242 **4. Illustrating specialization trade-offs in Jambi, Indonesia**

243 **4.1 The case study of Jambi**

244 Indonesia is the country with the largest increase in forest cover loss from 2000 to 2012 (Hansen et
245 al., 2013). At the same time, monoculture cash crops expand rapidly. Since 2007, Indonesia has been
246 the largest palm oil producer in the world (Coordinating Ministry of Economic Affairs, 2011), and it is
247 also the second largest producer of natural rubber. Seventy percent of the palm oil area in Indonesia
248 is located in Sumatra and approximately 42% of palm oil land is managed by smallholders
249 (Coordinating Ministry of Economic Affairs, 2011: 53). Similarly, the majority of the rubber

250 production is produced by smallholders (Coordinating Ministry of Economic Affairs, 2011: 57). The
251 province of Jambi has a total land area of 5,300,000 ha (BPS Provinsi Jambi, 2011: 3) and is a
252 showcase of high dependency on the agricultural sector. The total area under oil palm and rubber
253 cultivation are approximately 936,500 ha and 1,284,000 ha, respectively (Pemda Jambi 2010). The
254 average per capita income in Jambi province is roughly 17.5 million RP/year (BPS Provinsi Jambi,
255 2011), which is substantially below the national average of 26.8 million RP/year (Kopp et al., 2014: 2).
256 Fifty-two percent of the workforce in Jambi is employed in the agricultural sector. Increase in the
257 number of large plantations has contributed to reducing the area of farmland accessible to
258 smallholders. This has led to forced agricultural intensification (Potter, 2001) and induced agricultural
259 transition (Rigg, 2005). More specifically, subsistence strategies of smallholders in the province
260 shifted from extensive swidden farming to cash crop production. Consequently, 99.6% of rubber in
261 Jambi province are cultivated by smallholders (Estate Crop Services of Jambi Province, 2012) and the
262 cash crops have the potential to increase the economic and social development in the rural areas of
263 Jambi considerably.

264 Transformation of the Jambi lowland forests started in the 19th century when the Dutch
265 colonial power exploited the natural resources in the region. In the early-1970s, the Indonesian state
266 sold almost the entire lowland rainforests of Jambi Province as logging concessions. While the earlier
267 concessions exploited already existing timber resources, the current ones serve cash crop
268 plantations, primarily oil palm and industrial timber. This change from a predominantly extracting
269 economy to a production economy resulted in the establishment of an agricultural frontier zone
270 where government-led transmigration programs were implemented from 1983 to 2002 to meet the
271 demand for labor force on oil palm plantations (Hauser-Schäublin and Steinebach, 2014: 3f).
272 Migration resulted either from state-organized transmigration projects or from 'informal rural
273 migrants' (Bock, 2012) and led to strong increases in population size. The population in Jambi grew
274 from 1.1 million people in 1971 (16 people/km²) to 2.4 million people in 2000 and reached 3.4 million
275 in 2014 (63 people/km²) (Drake, 1981: 473; BPS Provinsi Jambi, 2013: 136 - 137). Between 1967 and
276 2007 reportedly 96,401 families or 394,802 people were resettled to Jambi by transmigration

277 projects as a measure of poverty alleviation and regional economic development (Pemerintah
278 Provinsi Jambi, 2008). These households received parcels of land (about 2.5 ha each) and contracts
279 with agribusiness companies to cultivate oil palm within a smallholder-contract-system. In summary,
280 land-use transformation in Jambi province is closely linked to immigration because immigration is
281 essentially triggered by the rising agro-business and oil palm economy to which migrants either act as
282 a workforce for plantations or hope to be set up with land and begin production by themselves. In
283 2012 the share of residents with migratory background reached about 80% (Suara Pembaruan,
284 2012).

285 In the case of Jambi, specialization on oil palm or rubber plantations has been considered the
286 (economically) best land-use option because returns to land and labor are higher compared to
287 rubber agroforests (Feintrenie and Levang, 2009) and other non-commercial land-use systems (Zen
288 et al., 2005). While Belcher et al. (2004) found higher returns to land in oil palm plantations
289 compared to rubber agroforests and rubber plantations in East Kalimantan, Feintrenie et al. (2010)
290 observed the opposite in Jambi where returns to land are higher in rubber plantations than in palm
291 oil plantations and rubber agroforests. All authors found higher returns to labor in oil palm than in
292 rubber plantations. However, these plantations rarely provide any non-material benefits or other
293 cultural services, nor do they provide intrinsic values. Interestingly, this coincides with the fact that in
294 the native habitat of oil palms in Western Africa, socio-cultural importance is not related to
295 monocultures but to the palm individual, or parts of it (Atinmo and Bakre, 2003).

296 On the contrary, non-financial considerations such as ethnic (and thus also migratory)
297 background can play an important role (Belcher et al., 2004): ethnic-specific perceptions of the
298 environment apparently have a serious impact on land and resource management (Pfund et al.,
299 2011; Reenberg and Paarup-Laursen, 1997; Steinebach, 2013). Indigenous households often also
300 depended to a much greater extent on a diverse range of habitats and species than non-indigenous
301 households (Laird et al., 2011). Such livelihood dependency on prevailing land-use systems
302 constitutes an important factor determining land use and specialization.

303

304 **4.2 Specialization across scales in Jambi**

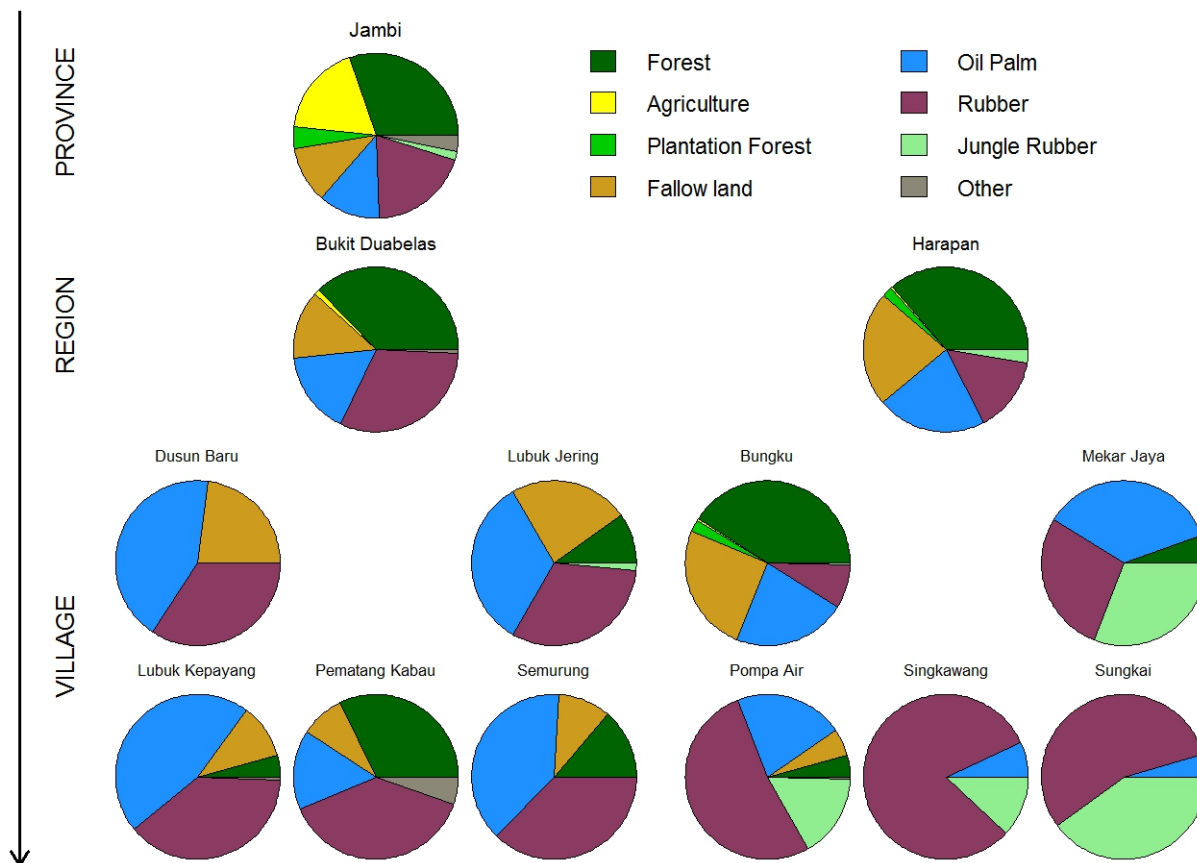


Fig. 2: Land-use types in the province of Jambi in Indonesia in 2011 show that specialization decreases from the fine to the broad scale, i.e. from the village level (five villages per region, bottom rows) to the region level (Bukit Duabelas and Harapan, second row) to Jambi province (top row). Data source: Landsat and RapidEye images analyzed according to Indonesian ministry guidelines (Ministry of Forestry, 2008).

305

306

307 As predicted by our conceptual framework, the level of specialization differs by the level of scale
 308 considered (Fig. 2). To assess scale dependence, we analyze land-use types based on the Land
 309 Use/Land Cover (LULC) maps derived by visual interpretation (GOFC-GOLD, 2013; Liu et al., 2005) of
 310 the most cloud-free mosaics of Landsat and RapidEye images with the guideline of land cover
 311 mapping produced by the Indonesian Ministry of Forestry (Ministry of Forestry, 2008, Fig. 2). This

312 analysis does not cover the household level, but the village, region, and province levels. We find that
 313 specialization on one or a few crops is strongest at the village level, whereas differentiation increases
 314 at the region level and is highest at the province level (Fig. 2). More detailed data are available for
 315 the household and village levels from a household survey (N=701 smallholder households in 45
 316 villages) and a village survey (N=98, containing the 45 villages of the household survey) conducted in
 317 2012 in the province of Jambi with structured interviews (Faust et al., 2013). For the present study,
 318 we analyze the main land-use types in the area, i.e. oil palm, rubber, paddy, fruits and vegetables. At
 319 the household level, we find very strong specialization (Fig. 3a). Most households specialize on a
 320 single crop and only very few grow two or three crops. Most cultivated land is owned by pure rubber
 321 farmers and by households that focus on rubber and oil palm plantations. Similarly, at the village
 322 level, there are more villages that specialize on one or two crops than villages with more land uses
 323 (Fig. 3b). However, specialization is much weaker at the village level than at the household level.

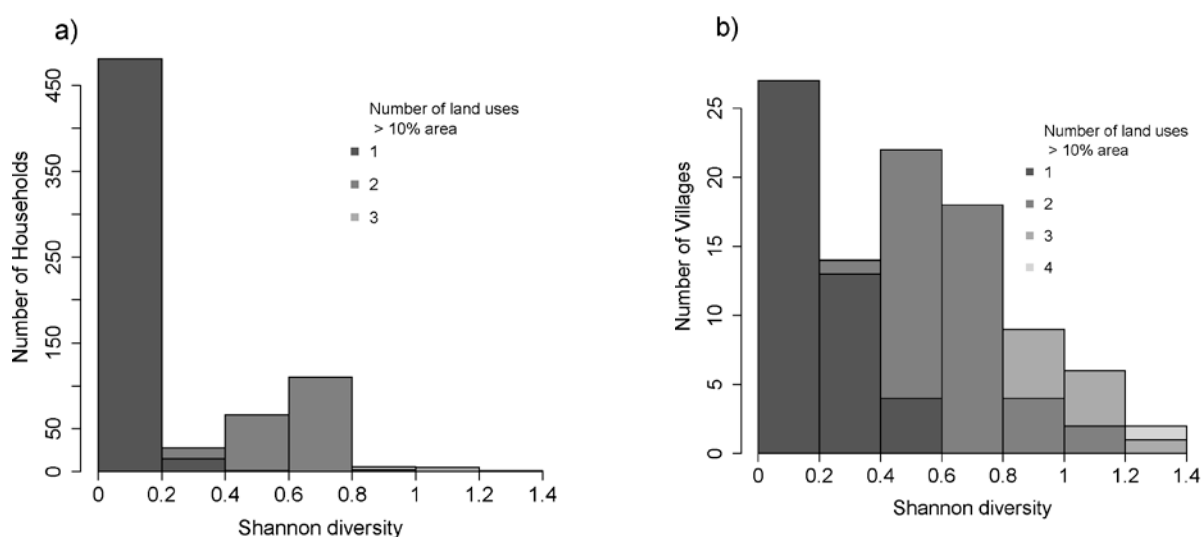


Fig. 3: Number of smallholder households (a) and villages (b) that fall into different categories of Shannon diversity (Magurran, 1988), an inverse measure of specialization. The number of land-use types with a minimum share of 10% of the total cultivated area per household or village, respectively, is indicated in grey shades. Overall, there are more specialized households and more specialized villages than households or villages that grow a diverse portfolio of crops. Specialization is much stronger at the household level (a) than at the village level (b). Data source: own calculation.

325 Hence, overall, specialization decreases from household via village to province level. In line with our
326 conceptual framework, this suggests that markets are not functioning well enough (yet) to allow a
327 greater specialization at broader spatial scales. At the same time, there is, as expected, already
328 considerable specialization at the household and village levels which appears to be the optimal
329 economic strategy for households (at least in the short term).

330 To assess to what extent economies of scale drive specialization in the Jambi case study, we
331 take the example of oil palm cultivation and analyze both the production output and the production
332 costs of oil palm farmers. Since output and factor costs differ across plantation age, we categorize
333 the age in accordance to the yield cycle of oil palms into four age groups. For each age group we
334 determine the median plot size and divide the plots into one group with smaller-than-median plot
335 sizes and one group with larger-than-median plot sizes. As has been found in many studies (see, e.g.
336 review by Binswanger et al., 1995; Ray, 1999), output per unit land is larger for small farms (Table 1).
337 This is partly due to more intensive input use (especially labor, but also other inputs) on small plots
338 (Table 1). It can also be due to more intensive and improved use of these inputs as the incentive
339 problems afflicting large farms with hired labor are less prevalent here (see discussion in section 2).

340 Production costs are investigated in the form of labor and input costs per hectare and year.
341 Labor comprise operations such as land clearing, pits taking, seedling transportation, planting and
342 replanting, manure and fertilizer application, chemical and manual weeding, harvesting, and pruning
343 and marketing. Inputs costs refer to costs for seedlings, plant and animal waste, soil amendments,
344 fertilizer, herbicides, machinery, and input and output transportation. Results for input and labor
345 costs suggest lower costs for larger-sized plots (Table 1). This is especially apparent for labor costs,
346 and there for immature and young plantations (age groups 1 and 2). However, profits per hectare do
347 not support the existence of economies of scale in our study region. Only for the third age group the
348 profit per hectare of larger plantations exceeds the profit of smaller plantations. Hence, our results
349 for the Jambi case study suggest only weak evidence for economies of scale.

350 Thus, as discussed in our conceptual framework, we can confirm the finding from many other
351 countries that there are gains from specialization at the farm level but that this specialization does

352 not inevitably lead to a consolidation of smallholder farms to ever-larger units; instead specialization
 353 is taking place among smallholders at the household and, as we have shown above, at broader scales
 354 as well.

355

356 **Table 1:** Yearly values on mean yield, mean factor costs (costs for labor and inputs) and mean profits
 357 of oil palm plots per plot size category for plantations in different age groups. The first age group
 358 contains plantation ages 0 to 3 years, because most trees start to produce harvestable fruits in the
 359 third year. Further age groups are group 2 (4-9 years), 3 (10-17 years), and 4 (18-23 years). Standard
 360 deviations are shown in parentheses. Data source: own calculation.

Plantation age group	Small plantations i.e. \leq 50% percentile				Large plantations i.e. $>$ 50% percentile			
	Mean yield [MT/ha]	Mean factor costs/ha		Profit [US\$/ha]	Mean yield [MT/ha]	Mean factor costs/ha		Profit [US\$/ha]
		Mean labor costs [US\$/ha]	Mean input costs [US\$/ha]			Mean labor costs [US\$/ha]	Mean input costs [US\$/ha]	
1	0.23 (1.07)	184.00 (271.56)	114.85 (121.17)	-98.24 (930.20)	0.34 (1.87)	70.28 (91.07)	103.70 (98.09)	138.75 (1631.33)
2	12.33 (9.66)	409.56 (302.89)	157.13 (131.65)	9680.01 (8095.78)	9.88 (7.65)	208.49 (239.56)	132.70 (111.86)	7997.01 (6519.13)
3	16.96 (10.42)	425.90 (403.14)	181.18 (142.43)	13809.95 (8705.82)	17.30 (8.54)	292.64 (401.01)	203.81 (164.47)	14597.71 (7166.60)
4	20.43 (7.50)	377.65 (363.66)	269.59 (271.02)	16720.72 (6311.65)	14.56 (6.08)	181.01 (80.25)	94.88 (69.56)	12100.11 (5216.16)

361

362

363 4.3 Policy influence on agricultural specialization in the Jambi case study

364 Two main policies affected the agricultural specialization process in Jambi fundamentally, the
 365 transmigration programs and the current master plan of the Indonesian government. The Indonesian

366 government's transmigration program played a key role for the start and spread of oil palm
367 cultivation in Jambi and the significant involvement of smallholder farmers (Gatto et al., 2014). The
368 oil palm cultivation was organized in so-called nucleus-estate and smallholder (PIR-NES) schemes.
369 The government support in terms of technical and financial assistance and land titles provided to the
370 oil palm NES schemes was instrumental for increasing the specialization of transmigrant smallholders
371 on oil palm.

372 The master plan for Indonesian Economic Development designated Jambi as part of the
373 Sumatra Economic Corridor as a 'Center for Production and Processing of Natural Resources and as
374 Nation's Energy Reserves' (Coordinating Ministry of Economic Affairs, 2011: 46). The economic
375 development strategy for the corridor focuses on three main economic activities: palm oil
376 plantations, rubber plantations, and coal. To support the development of the main economic
377 activities within the corridors the government will contribute around 10 percent the development
378 cost. The remaining costs will be provided by state-owned enterprises, private sector, and through
379 public private partnership (PPP) (Coordinating Ministry of Economic Affairs, 2011: 55). Furthermore,
380 regulatory requirements, infrastructure improvements, technology development and research
381 activities will be supported which will altogether lead to further specialization on palm oil and rubber
382 plantations from the household to the province levels of scale.

383 Thus, policy has strongly supported specialization directly through the economic
384 development strategy in Jambi and indirectly through the provision of infrastructure and
385 improvements in the functioning of markets. This has surely contributed to raising incomes in the
386 region, but the associated specialization at increasingly broader scale is generating precisely the
387 trade-off that we have discussed above.

388

389 **5. Conclusions: How can the trade-offs caused by specialization be addressed?**

390 Specialization causes trade-offs between economic benefit and ecosystem functions that increase
391 with the spatial scale of specialization which is in turn determined by market functioning. Since
392 economic benefit and ecosystem functions and services are both legitimate concerns, a solution that

393 satisfies all stakeholders is not straightforward. Such a solution must address the spatial distribution
394 of agricultural production in the landscape, be promoted by policies, and is also affected by the issue
395 of long-term consequences that are not necessarily considered in specialization debates.

396 Regarding the spatial distribution of ecological and economic functions in the landscape,
397 there are two basic approaches, land sharing and land sparing (Lambin and Meyfroidt, 2011). Under
398 land sharing, some land is set aside for conservation while other land is used intensively for
399 production. Under land sparing, less intensive production techniques are used to maintain some
400 ecological functions (and especially biodiversity) throughout agricultural land (Fischer et al., 2014;
401 Green et al., 2005). The concept of mosaic landscapes with intensive plantations intermingled with
402 both agroforestry zones and high conservation value areas proposed by Koh et al. (2009) constitutes
403 a combination of land sharing (agroforestry zones) and land sparing (intensive oil palm plantations,
404 high conservation value areas). Mosaic landscapes would be especially promising in areas where
405 both large companies and smallholders are present, as is the case in Jambi. Companies with their
406 efficient work schemes would benefit from economies of scale, could engage in intensive plantations
407 and set some land aside for conservation (Koh et al., 2009; Tschardt et al., 2012). Smallholders
408 may prefer the less specialized agroforestry systems, especially if supported by policy incentives.

409 Policies should not directly promote specialization, but rather aim at improving incomes,
410 lowering poverty, and safeguarding ecosystem services. This might or might not lead to increased
411 specialization at different spatial scales. Certification programs such as the Roundtable on
412 Sustainable Palm Oil may help to reconcile economic benefits with ecological functions by supporting
413 sustainable production modes. These might include diversification to a certain degree and at some
414 levels of scale. Payment for Ecosystem Service Schemes can more directly support the maintenance
415 of ecosystem services. Taking the example of oil palm, lowland plantation owners could be asked to
416 compensate upland farmers beyond 600 m elevation where oil palm cannot grow for water-related
417 ecosystem services such as provisioning of drinking water and electrical power generation.
418 Moreover, there is no economic justification for promoting inter-regional trade by artificially
419 lowering transport costs. In Indonesia, there are substantial fuel subsidies (Stern 2011) that are

420 not only costly to the government but increase CO₂ emissions from the transport sector (Jakob et al.,
421 2014). They also artificially promote specialization and trade beyond what is economically optimal as
422 the external costs of subsidized transport costs are not considered by actors. For example, for many
423 areas in our case study province Jambi it will be cheaper to source food from elsewhere in Indonesia
424 than produce it locally, allowing even more specialization in palm oil and rubber production.
425 Removing these subsidies and taxing energy so that it reflects the external costs of its use would
426 move specialization to its economically optimal level. It would also then help conserve biodiversity.
427 Thus, removing energy subsidies and taxing fossil fuels would have the quadruple benefit of relieving
428 the state budget, allow for pro-poor expenditure reforms, reduce CO₂ emission, and help conserve
429 biodiversity. Such policies might be able to turn the specialization-driven ecological-economic trade-
430 off into win-win situations at least for some spatial scales and over longer temporal scales.

431 Temporal scales and especially long-term consequences of specialization were not in the
432 focus of this paper, but could provide a worthwhile perspective for future attempts on the topic.
433 Specialization may have long-term costs as it may destroy vital ecosystem services required for the
434 long-term viability of crop production. Furthermore, diversification incentives may lead to a greater
435 sustainability also in economic terms, e.g. via improved biological pest control or pollination services,
436 when considering sufficiently long time horizons. To the extent this is the case, there is a case for
437 government intervention to slow down specialization through zoning and other land-use regulations.
438 This would then also be in the long-term interest of smallholder producers, so that the mostly small-
439 scale specialization-driven trade-offs between economic benefit and ecosystem functions can be
440 converted into win-win situations.

441

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445

446

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