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## Working Paper

# Drivers of households' land-use decisions - A critical review of micro-level studies in tropical regions

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## Drivers of households' land-use decisions

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A critical review of micro-level studies in tropical regions

Elisabeth Hettig, Jann Lay and Kacana Sipangule

EFForTS discussion paper series

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**Abstract:** This paper reviews 70 recent empirical and theoretical studies that analyse land-use change at the farm-household level. The review builds on a conceptual framework of land-use change drivers and conducts a meta-analysis. It turns out that the most frequently analysed scenario is the conversion of non-used forests or forested areas into land used for agricultural purposes – about a third of all considered scenarios. The second largest share is accounted for by studies that look into the conversion of non-used forests or forested areas into ranching. Most studies analyse land-use change using household and/or village data and, in doing so, often rely on relatively small samples of 100–200 observations. There is a clear regional concentration of studies on Central and South America and some studies on African countries, with only few studies on Asian countries. This is surprising, since evidence hints at high deforestation rates in South-East Asia due to logging activities and plantation agriculture. We find that a number of studies face problems of internal validity because of endogeneity (simultaneity and reverse causality) and omitted variable bias that are not adequately addressed. Despite these weaknesses, the literature points at micro-level economic growth, for example in income and capital endowments, as a strong catalyst of human induced land-use change. The rich reviewed empirical literature illustrates the complexity of micro-level land-use change processes, in particular the inter-relationships between household-level characteristics, factor market conditions, and land-use change. These are conditioned by institutions and policies. In particular, the market-oriented reforms adopted by many developing countries in the 1980s and 1990s seem to have had an important role in altering land use, while impacts of more recent policies, like PES or REDD+, still need to be better explored. However, the empirical designs of many reviewed studies fail to properly account for this complexity. Finally, the review reveals a lack of interdisciplinary work that uses integrated data and models to analyse land-use change.

**Keywords:** land-use change, farm households, deforestation, meta-analysis, micro-level

**Drivers of households' land-use decisions:  
A critical review of micro-level studies in tropical regions**

**Elisabeth Hettig, Jann Lay and Kacana Sipangule**

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# Drivers of households' land-use decisions

## A critical review of micro-level studies in tropical regions

Elisabeth Hettig<sup>ab</sup>, Jann Lay<sup>ab</sup> and Kacana Sipangule<sup>c</sup>

### Abstract

This paper reviews 70 recent empirical and theoretical studies that analyse land-use change at the farm-household level. The review builds on a conceptual framework of land-use change drivers and conducts a meta-analysis. It turns out that the most frequently analysed scenario is the conversion of non-used forests or forested areas into land used for agricultural purposes – about a third of all considered scenarios. The second largest share is accounted for by studies that look into the conversion of non-used forests or forested areas into ranching. Most studies analyse land-use change using household and/or village data and, in doing so, often rely on relatively small samples of 100-200 observations. There is a clear regional concentration of studies on Central and South America and some studies on African countries, with only few studies on Asian countries. This is surprising, since evidence hints at high deforestation rates in South-East Asia due to logging activities and plantation agriculture. We find that a number of studies face problems of internal validity because of endogeneity (simultaneity and reverse causality) and omitted variable bias that are not adequately addressed. Despite these weaknesses, the literature points at micro-level economic growth, for example in income and capital endowments, as a strong catalyst of human induced land-use change. The rich reviewed empirical literature illustrates the complexity of micro-level land-use change processes, in particular the inter-relationships between household-level characteristics, factor market conditions, and land-use change. These are conditioned by institutions and policies. In particular, the market-oriented reforms adopted by many developing countries in the 1980s and 1990s seem to have had an important role in altering land use, while impacts of more recent policies, like PES or REDD+, still need to be better explored. However, the empirical designs of many reviewed studies fail to properly account for this complexity. Finally, the review reveals a lack of interdisciplinary work that uses integrated data and models to analyse land-use change.

**Keywords:** land-use change, farm households, deforestation, meta-analysis, micro-level

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# 1 Introduction

Global change is the aggregate result of billions of individual decisions and understanding the determinants of these decisions is crucial for the analysis of global change. This is particularly true in the case of land-use change as an important component of global change. Land-use change has impacts on biodiversity, food security as well as on the levels of atmospheric carbon dioxide. Governments, policies as well as global and domestic markets set the conditions, under which micro-agents, i.e. households, firms, and farms, eventually take and implement decisions on land use.

Studying the patterns, causes, and consequences of land-use change requires the integration of social, geographical information and natural sciences (Rindfuss et al., 2004). Geographers and natural scientists utilize spatially explicit models at highly disaggregate scales while social scientists mostly rely on models that include human behavioral components to understand the determinants of land-use change (Irwin and Geoghegan, 2001). Based on these approaches, land-change science has evolved from a science that solely addressed the patterns and causes of deforestation to a science that is now capable of analyzing more subtle land-cover changes through the use of intricate models that conceptualize the causal and feedback relationships within coupled human and environmental dynamics (Lambin et al., 2003; Turner et al., 2007). The data fed into these models has also become more sophisticated in recent years and now includes high-resolution satellite imagery, geographic information systems as well as socio-economic and geophysical data to model the human-environment interactions that drive land-use change (Vance and Geoghegan, 2002).

Since the emergence of land change science, a number of literature reviews and meta-analyses on the causes of land-use change have been published, in particular Angelsen and Kaimowitz (1999) and Lambin and Geist (2001). These reviews are based on the first wave of land-use change studies that analyzed the causes of deforestation in tropical regions in the early 1990's. Earlier literature reviews called for more micro-level case studies that enable a better understanding of the causes and the mechanisms of land-use change (Geist and Lambin, 2001; Angelsen and Kaimowitz, 1999). Since then, a large empirical literature of micro studies has emerged and early meta-analyses of these studies include Keys and McConell (2005) and Rudel (2007).

Our paper aims to analyze and review the drivers that influence households' land-use change decisions. We systematically review 70 micro-level studies and conduct a meta-analysis to understand the importance of specific determinants of households' land-use decisions. These studies that consist of both empirical and theoretical multidisciplinary works were conducted in tropical regions and published between the years 2000 and 2012. Similar to Keys and McConell (2005), our focus is on tropical regions as they have experienced dramatic land-use change in the last decades. The studies reviewed have all been conducted at spatially disaggregated levels i.e. at the parcel, plot or village levels.

The remainder of this paper is structured as follows: We first introduce the conceptual framework adapted from Angelsen and Kaimowitz' (1999) model. This is followed by meta-analysis of the reviewed micro-level studies. We then provide a detailed literature review and close with a summary, conclusions, and some reflections on future research.

## 2 Conceptual framework of land-use change

To conceptualize the multiform and complex dynamics of land-use change, we build on a concept on the causes of deforestation proposed by Angelsen and Kaimowitz (1999). These authors' simple framework has become standard in the deforestation and land-use change literature. It includes a three-stage-process of underlying causes (macroeconomic variables), immediate causes (decision parameters) and sources of deforestation (agents' actions). While we find that this model is a good starting point for a more detailed analysis of land-use change, we see two major limitations. The framework does not explicitly consider feedback mechanisms between the different stages, for example between the actions of agents and macroeconomic variables, and between specific causes within one of the stages, for example between different decision parameters such as the interlink between technology options and accessibility of infrastructure. In addition, it neglects the role of household endowments and characteristics as drivers of land-use change.

We draw on this standardised deforestation model but modify it to suit our purposes in the following ways; first, we take deforestation as just one facet of land-use change. Thus, we expand the definition of land-use change to also include phenomena such as reforestation or the transformation of non-forest land, for example the conversion of wetlands to agriculture. Second, rather than analysing all scales of land-use change, we only focus on the land use decision parameters of farm-households and small-scale farms. Third, we expand the range of micro-level drivers (institutions, infrastructure, markets and technology) proposed by Angelsen and Kaimowitz (1999) and include household characteristics/endowments (for example ethnicity, physical capital, family workforce) and key policies, (for example forest conservation policies; institutional reforms of land rights; or market policies for agricultural products). Lastly, we present more precise elaborations of the feedback mechanisms between (and within) the micro-level drivers, the underlying causes and the final land-use change outcome. Our concept thus integrates the land-use change determinants and outcomes both vertically, i.e. between underlying causes, micro-level drivers, and outcomes, and horizontally, in particular between specific micro-level drivers.

Figure 1 shows our framework. It illustrates how the underlying causes of land-use change (macro-economic variables) are linked to the micro-level drivers and to the final land-use change outcomes which we defined as forestry, logging, fallow, agroforestry, agriculture, ranching, or wetland cultivation. Underlying causes include policies, population growth, and global markets.

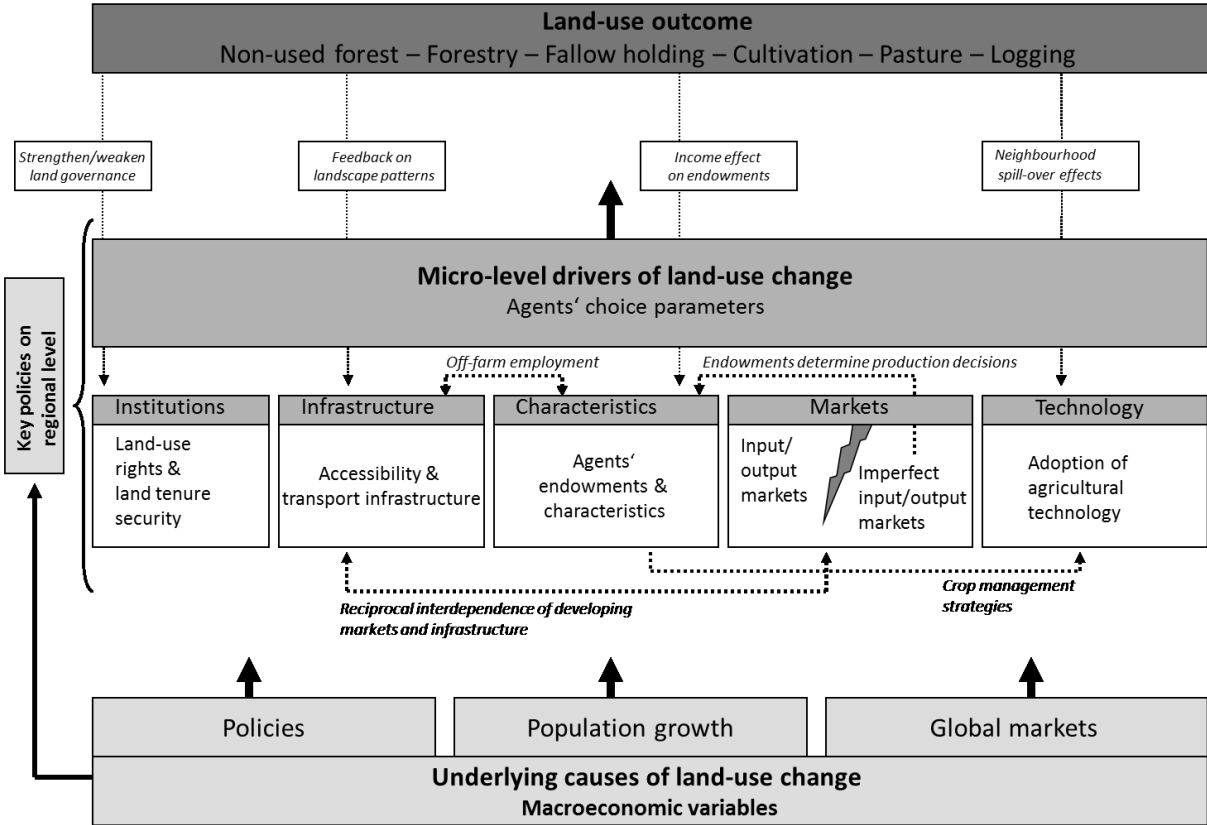
To keep a transparent concept allowing for generality, we focus on the central causalities between macro- and micro-level variables. The impact of underlying policies on land-decision making centres on two relevant aspects: first, on the institutional framework of land use rights and the (non-)existence of land tenure security and second, on key policies for land use. Individual land-use decisions depend highly on the respective land governance and how land-use rights could be transmitted and guaranteed. Likewise, land-specific key policies, such as settlement programs, public schemes for highway expansion, or land extension services, influence and alter all other land-use decision parameters of agents. To illustrate how population growth impacts agents' land-use decision, our concept focalizes primarily on local population pressure via immigration. Immigration is either triggered by key policies and/or by price signals of developing markets. Finally, we discuss the impact of global markets and

bring out especially global cash crop markets, which create incentives for agents to switch their land use towards cash crop cultivation for higher income.

The micro-level drivers consist of the relevant choice parameters of households, which are institutions, infrastructure, agents' characteristics, markets and technology. Introducing institutions, we highlight that land-use change is driven by local land-use rights, such as formal property rights or customary rights. Taking these contrary systems as an example, agents may react differently regarding their decision on land extension or cash crop cultivation. The degree of tenure security, implemented through legal titling or local agreements, determines the reliability of these land rights. The second decision parameter, the accessibility to public services/markets centres and transport infrastructure, influences agents' land use decision, for example, in enabling rural households to improve their access to agricultural inputs and/or to sell their products. Thirdly, the agent's characteristics include for example the culture/ethnicity of households and their endowments (for example physical capital, labour or social capital). These are key parameters for agent's land-use decision making. To illustrate, a higher level of wealth enables households to invest in a more capital intensive land use, for example pasture. These individual effects are reinforced if access to capital (or other factor) markets is limited. This is because with universal and perfect access to capital markets, the wealth of a household should – theoretically – not matter for investment and hence land use decisions. Thus, the differences between household in this regard would not matter and the micro studies would not yield an effect of wealth on households' land use decision. Hence, the quality of input and output markets plays a fundamental role for agents' land-use change. Households' land-use differs, if markets for labour and agricultural inputs are limited or even non-existent. For example, cash crop adaption and/or agricultural expansion - and thus systematic forest conversion - is more restricted for households in areas with fragmented markets. Finally, land-use decisions are determined by the respective agricultural technology available for and adopted by households.

Further, our framework on land-use change identifies four relationships between the micro-level drivers, depicted by the dotted lines. First, there is a reciprocal link between the accessibility to infrastructure and developing markets. On the one hand, public improvements in transportation networks reduce transportation costs and facilitate economic activity and thus the emergence of input and output markets in remote areas. On the other hand, evolving markets trigger infrastructure development. Both dynamics are interdependent and mutually reinforcing. Second, household characteristics and endowments affect the adoption of technologies and agents' crop management strategies. For example, the adoption of a more labour-intensive technology depends either on household's capital available to hire labour or on family workforce. Third, access to infrastructure and public services influences agents' options of off-farm employment and vice versa. And lastly, market conditions determine the production decisions of households. If input and/or output markets are limited or non-existent, households have to fall back on family workforce and capital endowments. Thus, the decision on land-use change depends on the own shadow price for family labour, leisure and assets and is not determined by external factor market prices.

**Figure 1: Concept of the micro-level drivers of land-use change**



Source: Authors' concept based on Angelson and Kaimowitz (1999).

Feedback loops also operate from final land-use outcomes back to the micro-level drivers through four mechanisms depicted by small text boxes. Certain land-use changes could strengthen or weaken land rights. This is especially the case if land is weakly governed and/or there are additional informal rules of land rights. For example, the conversion of un-used forests in tropical regions often goes along with the introduction of property rights. Thus, longer fallow periods could tempt other agents to convert foreign land for own purposes. In addition, different land-uses and the corresponding landscape changes may require different infrastructure, such as those necessary for plantation cultivation. At the household-level, land-use choices may have income effects, for example cash constraints could be relieved, allowing the household to accumulate physical capital for new investments. This in turn determines production decisions, especially so under imperfect factor markets. Finally, land-use outcomes induce neighbourhood spill-over effects, for example via copying or knowledge transfer in informal networks.

### 3 Meta-analysis

The studies reviewed in this paper were collected during the period from March 2011 to August, 2012. They were sourced from academic databases and search engines such as Google Scholar, Scirus, Repec, Mendeley, AgEcon Search as well as from cross references of cited papers. Key words and search items included “ land-use, “household”, “village”, “household survey” and/or “land-use change”, restricted to studies published between 2000

and 2012. Our initial search resulted in a total number of 158 studies. These studies were carefully read by two of three authors and only included in the sample of studies if they met three key restrictions. First, the data analysed in the studies must have been collected at a spatially disaggregated level i.e. at the household, community, village, parcel, or plot level. Second, the papers had to be published in peer reviewed journals between the years 2000 and 2012.<sup>1</sup> We took 2000 as the base year because the last comprehensive meta-analyses and empirical reviews were published in the early 2000s. Third, we restricted our sample to studies that were conducted in tropical and sub tropical regions. These restrictions resulted in a subset of 70 studies that were included in the review.

After the 70 papers were selected, the authors underwent a rigorous reading and coding process based on a self-constructed questionnaire. The questionnaire was designed to collect information including the academic backgrounds and present affiliations of the authors of the reviewed studies, the year of publication, and applied methods. The main results of the papers, i.e. the type of land-use change and the considered explanatory variables as well as the region and country of study were also systematically collected.<sup>2</sup> Each paper was read and coded by two of the three authors and a third team member to allow for a stringent cross-verification of all entries.

Our classification of the drivers of land-use change is based on the conceptual framework introduced in the preceding section. In addition to the five main drivers identified by Angelsen and Kaimowitz (1999) we include two new drivers of land-use change, that is, household characteristics/endowments and key policies. 281 proxy variables for specific drivers are reported in the 70 surveyed studies as having a significant impact on land-use change in the studies.

### **3.1 Land use (and cover) change**

The reviewed studies are not using a uniform definition of land-use change. In fact, the literature on micro-level land-use changes defines the term *land-use change* often rather implicitly or vaguely. Additionally, some studies do not make a clear distinction between *land use* and *land cover*. However, to synthesize the results of the 70 studies, a precise separation between land use and land cover is required, as suggested similarly by Lambin and Geist (2006) and Fisher and Unwin (2005).

A widely shared definition, defines land cover as the observable (bio-) physical qualities of the Earth's land surface (Di Gregorio and Jansen, 1998). In contrast, classifying land use always demands a socio-economic perspective on land (Fisher et al., 2005). Consistent with this approach, Lambin and Geist (2006) refer to land use as the “purposes for which humans exploit the land cover, involving the manner in which biophysical attributes of the land are manipulated and the intent underlying that manipulation”. Hence, land use is always characterized by the activities and inputs “people undertake in a certain land cover type to produce, change or maintain it” (Di Gregorio and Jansen, 1998). Following these definitions,

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<sup>1</sup> Selection of articles published in peer reviewed journals and the omission of grey literature may result in a publication bias; however, we assume that acceptance for publication in a peer reviewed journal is indicative of the quality of the paper.

<sup>2</sup> The questionnaire has been included in the appendix. The complete list of variables coded from the reviewed studies is available from the authors upon request.

a change in land use does not lead necessarily to a change in land cover, for example in the case of intensification. Moreover, the terms land cover and land use follow a many-to-many relation (Fisher and Unwin, 2005). For example, land covered by *forest* could be land used for forestry or conservation forest. In turn, agriculture can occur on land cover classified as grassland, woodland or wetland. Inconsistencies in the use of these terms render the systematic comparison of study results difficult, especially if evidence is based on remote sensing data, which need the interpretation of aerial information (Fisher and Unwin, 2005).

In our systematic analysis of land-use change across the reviewed case-studies we are, first, able to capture more subtle land-use change scenarios which have been not yet systematized in literature reviews. Second, we illustrate that it is indeed useful and instructive to distinguish clearly between land cover (change) and land use (change). We identify the initial land uses (LU) and land covers (LC) and also the final LU and LC for each study in our sample using a one-to-many relationship between LC and LU categories (see Table 1). Considering the variety of research objectives and applied methodologies, we include only the land uses and land covers, which are central for each study. For those cases that do not provide direct information about the initial and final land covers/ land uses, we derive the categories from study site descriptions and central statements or conclusions provided by the respective study. Since most studies analyse several land-use change scenarios, we allow for more than one land-use change scenario per study. We finally identify 140 land-use change scenarios that fall into 26 different categories of land-use and cover change (the sum of all non-zero entries in Table 1).

Due to the variety in land cover information across studies and disciplines (and sometimes the lack of precise information) our cover categorization follows a broader definition than other, more detailed categorizations, for example the Land Cover Classification System (LCCS) by Di Gregorio and Jansen (1998). Thus, we classify land cover into *forest*, *cultivated land*, *grassland*, *shrubland* and *wetland*. As *forest* we subsume land cover referred in studies, for example, as natural forest, primary forest, old-growth forest, mature forest, secondary forest, residual forest or woodland. *Cultivated land* we define as land referred to areas used for agricultural purposes (including orchards and plantations). The land cover categories *grassland* and *shrublands* denote land cover described as pasture land, arable land, savanna, bushland, or non-forest vegetation. The last land cover, *wetland*, indicates land covered, for example, by swamps.

Under these LC categories we further classify 12 different land uses. We ascribe five forest uses: *Non-used forest* capturing natural forests; *forestry*, which refers to resource extraction, for example firewood collection and hunting; *protected forest*, for example forest reservation; *logging*, which denotes logged forests for commercial reasons; and *fallow*, which is land left for regeneration for example reforestation. Cultivated land could be used for *agriculture* or *agroforestry*, whereby agriculture is understood as mono and mixed-cultivation and agroforestry combines woody perennials and agricultural crops (Nair, 1993). Grasslands and shrublands are mainly used for *ranching*, for example livestock farming, cattle ranching or agro-pastoralism. To capture the use of natural grasslands and shrublands, we include the negative definition using the term *non-used grassland/non-used shrublands*. Similar to this, we subsume for the cover category wetland both the use *non-used wetland*, capturing natural wetlands, and *wetland cultivation*, for example rice fields.

As illustrated in Table 1, 83 percent of all scenarios analysed in the reviewed concern land covered initially by forests. Within this subsample, the conversion of non-used or even protected forest receives most attention. Looking at final land-uses, land is predominantly changed towards agricultural usage (51 percent) followed by ranching (29 percent) and some minor categories, like fallow (9 percent), forestry (6 percent) and agroforestry (2 percent). Hence, as expected, the mostly analysed scenario is the conversion of non-used forests or forestry for agricultural purposes, making up together 50 cases (36 percent) of all land-use changes. The second largest share is accounted for by studies that look into the conversion of non-used forests or forestry towards ranching with 31 cases (22 percent). Hence, deforestation - in our sample represented by the change of forests into cultivated land or grassland/shrubland - is still the main focus of studies analysing land-use change on the micro level.

Nevertheless, Table 1 also reveals other important land-use change scenarios, for example the change of land used for agriculture or ranching towards fallow holding (together 12 cases in the scenario sample).<sup>3</sup> There are also an important number of cases (9) that analyse the transformation of protected forest to forestry.

None of the studies in our sample looks into the reverse process, i.e. land-use change scenarios towards protected forest (or other protected zones). While these transformations may indeed be less frequent, a complete lack of such studies at the micro-level – at least when our inclusion criteria are applied – is surprising. Further, the quite small number of cases focusing on the conversion of wetlands for agricultural purposes reveals the lack of research on, for example, the transformation of mangrove forests, which have been declining at a faster or equal rate than adjacent inland tropical forests (Duke et al., 2007). Additionally, only two cases consider land-use transitions from non-used forests/forestry towards logging. The lack of studies examining logged forests maybe explained by the fact that logging is predominantly carried out in large-scale concessions held by larger firms (Sodhi et. al, 2004). However, we could not find studies that analyse these agents who, in principle, would have conformed to our definition of micro actors. Second, if logging is done by households, it is typically illegal and therefore difficult to be captured by household surveys (Sodhi et al. 2010).

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<sup>3</sup> In contrast, we identify only 5 cases of converted fallow holdings for agricultural purposes and none for ranching.

**Table 1: Land use (and cover) change of reviewed micro-level case-studies**

| <i>Final LC and LU</i>     |                                     | <i>Forest</i>          |                 |                         |                |               | <i>Cultivated land</i> |                    | <i>Grassland/shrubland</i> |                                     | <i>Wetland</i>             |                         | <i>Total</i>   |
|----------------------------|-------------------------------------|------------------------|-----------------|-------------------------|----------------|---------------|------------------------|--------------------|----------------------------|-------------------------------------|----------------------------|-------------------------|----------------|
|                            |                                     | <i>Non-used forest</i> | <i>Forestry</i> | <i>Protected forest</i> | <i>Logging</i> | <i>Fallow</i> | <i>Agroforestry</i>    | <i>Agriculture</i> | <i>Ranching</i>            | <i>Non-used grassland/shrubland</i> | <i>Wetland cultivation</i> | <i>Non-used wetland</i> |                |
| <i>Initial LC and LU</i>   | <i>Non-used forest</i>              |                        | 5               |                         | 1              | 1             | 2                      | 28                 | 14                         |                                     |                            |                         | <b>51</b>      |
|                            | <i>Forestry</i>                     |                        |                 |                         | 1              |               |                        | 22                 | 17                         |                                     |                            |                         | <b>40</b>      |
|                            | <i>Protected forest</i>             |                        | 3               |                         |                |               |                        | 7                  | 4                          |                                     |                            |                         | <b>14</b>      |
|                            | <i>Logging</i>                      |                        |                 |                         |                |               |                        | 3                  | 2                          |                                     |                            |                         | <b>5</b>       |
|                            | <i>Fallow</i>                       |                        |                 |                         |                | 1             |                        | 5                  |                            |                                     |                            |                         | <b>6</b>       |
| <i>Cultivated land</i>     | <i>Agroforestry</i>                 |                        |                 |                         | 1              |               |                        | 2                  | 1                          |                                     |                            |                         | <b>4</b>       |
|                            | <i>Agriculture</i>                  |                        |                 |                         | 10             |               |                        | 1                  | 1                          |                                     |                            |                         | <b>12</b>      |
| <i>Grassland/shrubland</i> | <i>Ranching</i>                     |                        |                 |                         | 2              |               |                        |                    |                            |                                     |                            |                         | <b>2</b>       |
|                            | <i>Non-used grassland/Shrubland</i> |                        |                 |                         |                |               |                        | 3                  | 1                          |                                     |                            |                         | <b>4</b>       |
| <i>Wetland</i>             | <i>Wetland cultivation</i>          |                        |                 |                         |                |               |                        |                    |                            |                                     |                            |                         |                |
|                            | <i>Non-used wetland</i>             |                        |                 |                         |                |               |                        |                    |                            | 2                                   |                            |                         | <b>2</b>       |
| <b>Total</b>               |                                     |                        | <b>8</b>        |                         | <b>2</b>       | <b>14</b>     | <b>3</b>               | <b>71</b>          | <b>40</b>                  |                                     | <b>2</b>                   |                         | <b>N = 140</b> |

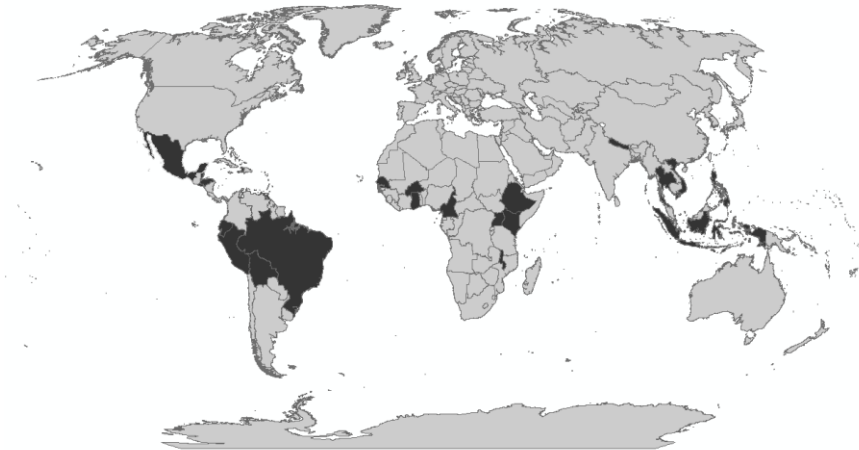
Source: Authors' own compilation



### 3.2 Geographical coverage

The studies in our sample were carried out in 22 tropical and subtropical countries. The map in Figure 2 shows the geographical coverage of these studies.

**Figure 2: Geographical coverage of micro-level case studies on land-use change in tropical regions in the period 2000-2012**



Source: Authors’ own compilation.

South America accounts for the largest share of studies in our sample (44 percent) and together with Central America, it contributes to 70 percent of all the reviewed studies (see Table 2). This share is in line with the earlier review by Lambin and Geist (2001) who find that countries in Latin America account for 78 percent of case studies reported. This large share can be attributed to the high deforestation rates in Central and South America which hold the major share of earth’s primary forest cover and stocks in forest biomass (FAO 2010; Laurance et al., 2001). The high number of studies in Central and South America could also be a result of regional preferences by research groups and the general availability of land-use data.

**Table 2: Regional coverage of reviewed micro-level case-studies**

| <i>Region</i>              | <i>Central America</i> | <i>South America</i> | <i>Africa</i> | <i>Asia</i> | <i>Total</i> |
|----------------------------|------------------------|----------------------|---------------|-------------|--------------|
| <i>No. of case studies</i> | 18                     | 31                   | 13            | 8           | 70           |
| <i>Percent</i>             | 26                     | 44                   | 19            | 11          | 100          |

Source: Authors’ own compilation.

19 percent of the studies in our study comprise African countries, while only 11 percent analyse land-use change in Asian countries. The limited number of Asian case studies is surprising, since evidence hints at high deforestation rates in South-East Asia due to logging activities and plantation agriculture (Sodhi et. al, 2004; Miettinen et al., 2011). As noted

above with regard to the lack of studies on logging, firms that operate such logging or large-scale agricultural activities appear to remain beyond the scope of micro-level studies of land-use change determinants.

### 3.3 (Inter)disciplinarity

Land-change science ideally integrates natural, social and geographical sciences to understand patterns of land-use change (Rindfuss et al., 2004). We have examined which disciplines are most actively involved in land-use change research and to which extent these disciplines collaborate. This is done by running background checks of the authors' educational qualifications and their current research interests. Table 3 provides a summary of the disciplines that are involved in land-use change research according to the studies reviewed.

**Table 3: Scientific disciplines in micro-level land-use change case studies reviewed**

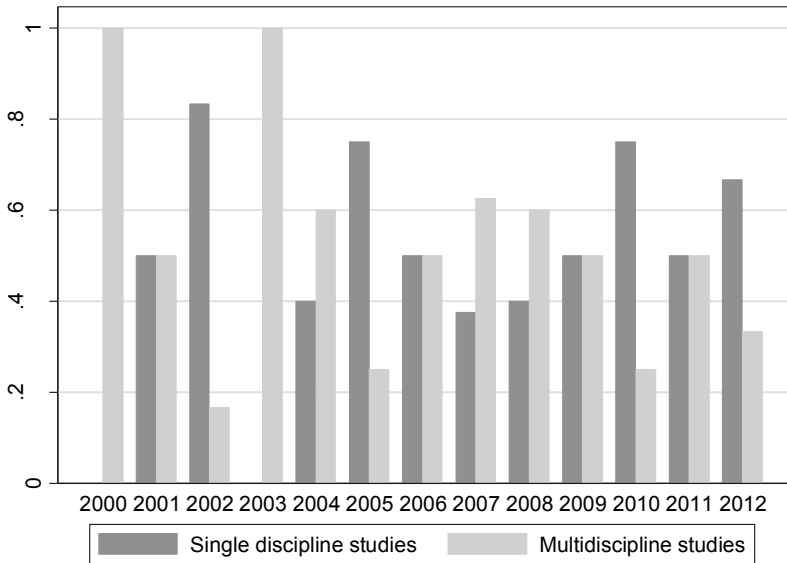
| <i>Discipline</i>          | <i>Sub-disciplines</i>  | <i>Contribution to literature (percent)</i> |
|----------------------------|---|---|
| <i>Economics</i>           | Agricultural Economics, Forest Economics, Environmental Economics, and Resource Economics   | 36  |
| <i>Geography</i>           | Spatial Analysis and Spatial Planners   | 26  |
| <i>Ecology</i>             | Environmental Sciences, Ecology, Biology, Botanic, Forestry, Biogeochemistry, Agricultural Science, Oceanography, Biostatistics, Entomology, and Soil Science | 16  |
| <i>Anthropology</i>        | Anthropology  | 9   |
| <i>Social Science</i>      | Sociology, Political Science, Development studies, Public policy  | 9   |
| <i>Demographic Science</i> | Demography, Population Science  | 3   |

Source: Authors' own compilation.

Note: The academic qualifications of the all authors were aggregated into the six main disciplines listed in the first column. An author was recorded as having more than one discipline if the academic qualifications were from different disciplines.

We now look at interdisciplinary collaborations in land change science and classify the reviewed studies either as single disciplinary or multidisciplinary studies (this serves as proxy for interdisciplinary work). Multidisciplinary studies are defined as studies that are written by a group of authors with more than one differing disciplines. On average, about half of the studies are multidisciplinary and this share remains relatively constant over the period (Figure 3).

**Figure 3: Multidisciplinary work in micro-level land-use change case studies**



Source: Authors' own compilation.

**3.4 Methods and data**

We aggregate the methods used in the reviewed studies into five categories that comprise regression analysis (including choice models), multivariate analysis, descriptive statistical analysis, theoretical models, and (data-based) simulation techniques. Some studies use multiple methods, which gives 81 methods applied in 70 studies. Table 4 shows that regression analyses account for 70 percent of the methods used. 10 percent of all applied methods are simulation techniques and out of these half of the studies use agent-based modelling systems. We did not find that methods are determined by the disciplinary background of the authors.

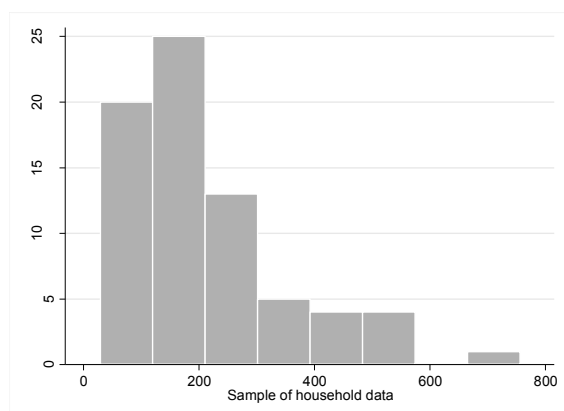
In regression analyses, typical left-hand-side, explained or dependent variables are represented by discrete choices, for example pixels related to specific land-use types. When analysing continuous changes, the models often explain total area deforested by households, total cropped area of households, or fallow length of plots. The regression models are chosen accordingly, with binary or multinomial choice models, OLS, or system estimations being most common. In addition, few studies (N=7) rely on multivariate analysis (for example ANOVA, Hazard models) or just simple descriptive techniques, for example correlation analysis.

**Table 4: Methodological approach in micro-level land-use change studies**

| <i>Method</i>                | <i>Percent</i> | <i>N</i>  |
|------------------------------|----------------|-----------|
| <b>Regression analysis</b>   | 70             | 57        |
| <b>Multivariate analysis</b> | 10             | 8         |
| <b>Theoretical model</b>     | 3              | 2         |
| <b>Descriptive analysis</b>  | 7              | 6         |
| <b>Simulation techniques</b> | 10             | <b>8</b>  |
|                              | <b>100</b>     | <b>81</b> |

Source: Authors' own compilation.

Most studies analyse land-use change using household and/or village data. Household-level studies often rely on relatively small samples of 100-200 observations (see Figure 4). 40 percent of all studies (N=28) integrate socio-economic data and information from satellite images. Only few studies (explicitly) include qualitative data, such as results from focus group discussion or expert interviews (N=2). Though most studies explore between-household variation, i.e. household-level data, 10 percent (N=7) of all studies are based on village-level data.

**Figure 4: Sample size of household data in reviewed case studies**

Source: Authors' own compilation.

In terms of temporal dimension, most studies are based on cross-sectional data, while only 16 studies use panel data with typically two rounds of observation (see Table 5). Beyond that, some studies rely on retrospective data (N=8) despite its obvious limitations, for example recall biases, especially for longer time periods (Bernard et al. 1984).

**Table 5: Variance of micro-level studies over spatial and time dimension (N=67)**

| <i>Spatial level</i>   | <i>Cross-section Analysis</i> | <i>Panel analysis (t = 2)</i> | <i>Panel analysis (t &gt; 2)</i> |
|------------------------|-------------------------------|-------------------------------|----------------------------------|
| <b>Household level</b> | 31                            | 16                            | 8                                |
| <b>Village level</b>   | 5                             | 0                             | 2                                |
| <b>Regional level</b>  | 3                             | 1                             | 2                                |
| <i>N</i>               | <b>39</b>                     | <b>17</b>                     | <b>12</b>                        |

Source: Authors' own compilation.

### 3.5 Internal and external validity

Before we provide some meta-analytical insights on the results of the studies, we want to briefly discuss some methodological challenges in the analysis of the micro-level drivers of land-use change and how the reviewed studies deal with them. One of the key empirical challenges is to reveal truly causal relationships between a specific driver and the dependent variable. While some studies do their best to address the challenges of causal inference, other studies face problems of internal validity because of endogeneity (simultaneity and reverse causality) and omitted variable bias. If these possible sources of bias are not accounted for a correlation between land-use change and changes in a specific driver (or rather a proxy of it) is mistaken as a causal effect of the latter on the former.

In a number of studies, these empirical (econometric) problems are not adequately addressed. When estimating, for example, the causal effects of *household-level variables* (agents' endowments, off-farm employment) on land use, the results may often be biased because of reverse causality and simultaneity, i.e. not only is the driver influencing land-use change, but also vice versa. If household wealth (or income) and a particular land use, notably cash cropping and ranching, are found to be correlated, this does not necessarily imply that wealthy households are more likely to be engaged in these land uses. Such a correlation is also likely to reflect that engaging in these activities has turned households wealthy in the first place. A similar argument can be made for off-farm employment, a variable that is often used as an explanatory variable in land-use change regressions. Here, reverse causality stems from the fact that the proceeds of cash crop farming enable otherwise liquidity-constrained households to invest in off-farm activities. More generally, both theory and evidence suggest that rural households that are constrained on important factor markets – most notably labour and credit markets – decide simultaneously on agricultural and non-agricultural production as well as consumption.<sup>4</sup>

At the household level, another factor – often ignored in empirical land-use change studies – is the so-called “unobserved heterogeneity”. In particular, regression analyses of *technology adoption* or *market participation*, i.e. cash crop adoption and land-use change, suffer from this type of omitted-variable bias. Households may have unobserved characteristics, such as, their intrinsic motivation or entrepreneurship skills, in rent-seeking behaviour, or risk-attitude that directly explain their patterns of land-use change. Such unobserved characteristics tend to be correlated with some of the typical household or farmer characteristics included in regression analyses, for example education, income, and wealth. If unobserved characteristics are now omitted from the estimation equation, the effects of these variables are hence biased and mistakenly considered causal.

Omitted variable bias is not only a problem at the household-level. A particular challenge of empirical studies at the micro level regards disentangling the effects of policies that tend to affect all studied households and individual (household-level) effects. Large-scale land-use change is often the results of deliberate planning policies, in particular agricultural and settlement policies. These policies establish infrastructure and create markets and households react to them and these incentives by moving at the agricultural frontier, engaging in cash

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<sup>4</sup> This simultaneity is formalized in so-called “agricultural household models”. See Taylor and Adelman (2003) for an accessible overview.

crop farming (sometimes through contract farming). This implies that empirical studies in such contexts need to account for the fact that there is a policy that simultaneously causes roads to be built, migrants to move into a certain area and for these migrants to engage in a specific land use; and it is obvious, that the correlation between roads and deforestation that will be observed in such a context cannot be taken as causal.

Finally, another very severe problem of reverse causality often arises, when the effect of *institutions* on land-use change is analysed. Property rights at the agricultural frontier are often obtained directly by deforestation. This implies that a correlation between insecure property rights (acquired by deforestation) and land-use change cannot be taken as a sign of a causal relationship from weak institutions to deforestation. All these challenges pose serious threats to the internal validity of micro-level land-use change studies, i.e. to correctly attributing causality to specific drivers of land-use change. These challenges are addressed in only 17 of the 57 regression analyses for example by using IV techniques or fixed effects estimations. The application of these techniques is taken as a proxy that the study has made an explicit effort to systematically reflect upon issues of endogeneity. We acknowledge that this is not to say that these issues have been addressed convincingly by the respective study.<sup>5</sup>

Studies dealing with land-use change on the micro-level face difficulties in presenting the external validity of their results. Since micro-level studies have per definition a small geographical coverage, they have to be clear in their contextualization referring also to the representativeness of their results. However, some studies fail to differentiate between the mechanisms explicit to the study area and the generalization of reported drivers of land-use change. For example, insights in the impact of a particular set of communal rights on land could be very restricted to a certain study site. Similar challenges arise, if the effects of settlement programs or subsidies are evaluated for a specific region. However, some studies take up the challenge and compare results to other studies analysing similar set-ups of settlement policies or institutional change. Further, some studies fail to be transparent in referring to contextual factors, which can shape their results on the determinants of land-use change, for example the impact of global markets (for example fluctuations in commodity prices) or institutional changes on the national level.

### 3.6 Drivers analyzed

In this section, we extract some first generalisations on the drivers of households' land-use decisions analyzed by the many case studies over space and time.<sup>6</sup> This indicative analysis is based on the frequency of a reported driver that is found to have a significant effect on land-use change.

We classify the 281 variables that were reported as significant land-use change determinants in the case studies into the seven main categories of drivers<sup>7</sup> (property rights and institutions,

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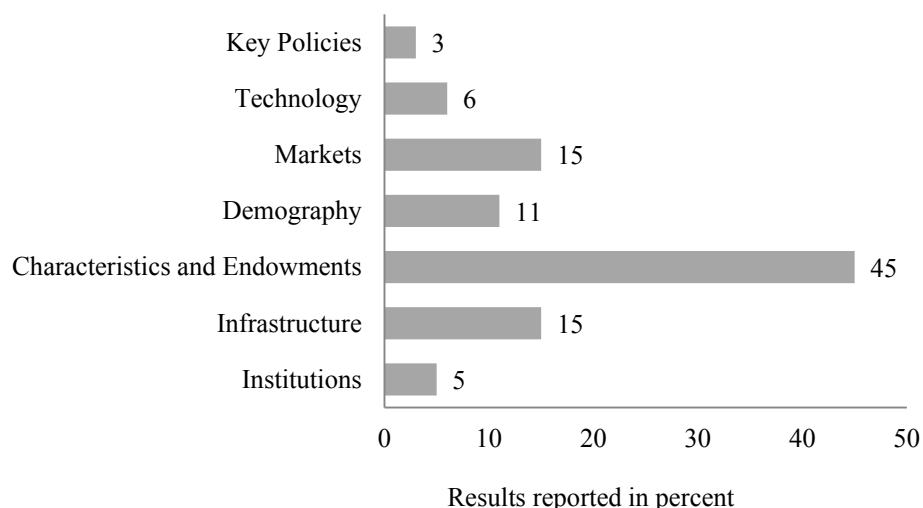
<sup>5</sup> The above empirical problems do, in principle, not apply to simulation and theoretical models (with the exception of regression-based simulations). Here, assumptions, functional forms, rules, and parameters have to be put under scrutiny. Very few studies, however, rely on very stylized optimization models (N=2).

<sup>6</sup> Meta-analysis are common place in the natural and medical sciences; however, they are becoming more common in land-use change and deforestation studies (Geist and Lambin, 2001; Rudel; 2007).

<sup>7</sup> This was done by first listing all 281 drivers and then categorizing them in order of frequency using content analysis. For example, if a regression model reported that land property rights or land tenure significantly

market accessibility and infrastructure, characteristics and endowments, population and migration, input and output markets, adoption of agricultural technology, key policies).

**Figure 5: Micro-level driver of land-use change across reviewed case-studies (N=281)**



Source: Authors' own compilation.

Our findings reveal that household endowments and characteristics, account for 45 percent of all identified drivers (see Figure 5). This is followed by market dynamics and infrastructure that both represent 15 percent of the drivers reported in the studies; there is also a minor role for demographics, technology, key polices, and institutions.

Since household endowments and characteristics emerge as the most prominent driver, we further examine these endowments and characteristics and disaggregate them into physical-, human- and social capital and labour (see Table 6). Among the household characteristics, physical capital is found most often to be significantly associated with land-use change. In addition, labour and human capital also receive considerable attention and often turn out as significant drivers.

**Table 6: Decomposition of the micro-level driver household endowment and characteristics**

| Household endowment and characteristics | <i>Physical capital</i> | <i>Labour</i> | <i>Human capital</i> | <i>Social capital</i> |
|---|-------------------------|---------------|----------------------|-----------------------|
| %                                       | 46                      | 30            | 18                   | 7                     |

Source: Authors' own compilation.

These meta-analytical findings need to be interpreted with caution. They cannot be directly taken as evidence that, for example, household characteristics and endowments are the most important driver of land-use change. For their interpretation, it is important to understand that they of course reflect the level of variation that most of the studies under review are based on, namely the variation between households. In micro-level studies households tend to be

affected land use change, institutions were recorded as the driver. Similarly agricultural prices or access credit were significant in a regression, we code these results as “markets”.

exposed to the same socio-economic and ecological environment; be it with regard to prices, other market conditions or institutions. Detecting land-use change in response to changes in the households' environment typically requires variation and data over time; and we have seen above that well less than half of the studies have such data.

That scale matters for the results, becomes apparent when we disaggregate the studies into different scales distinguishing between data collected on the household, village or regional level. It turns out, that demography is the most important driver of land-use change on the village level. This finding points at the importance of migration for land-use change since demographic variation between villages is mainly driven by migration, not by natural demographic forces.

Once these caveats to the above aggregation exercise of drivers are understood, the meta-analytical findings first tell us that there is indeed substantial household heterogeneity, not only in terms of household-level characteristics, but also of observed land-use choices. Second, the household heterogeneity, in particular in terms of income and endowments, is significantly associated with land-use change. It is important to note that this is not necessarily the case, as one may expect household-level land-use change to be driven mainly by external forces with all households reacting more or less the same. In contrast, the detailed review of selected studies below will illustrate how household-level factors condition households' reaction to these external forces. Third, in addition to this general insight regarding the heterogeneity in household characteristics and reactions, the results of Table 5 and 6 can be taken as a first indication that economic growth is an important aggregate force that drives land-use change, as the micro-level determinants of economic growth, in particular physical capital, often turn out to be associated with households' land-use decisions.

However, there is not a simple relationship between land-use change and these growth-associated micro-level drivers. As the subsequent literature review will show, there are complex interactions between these micro-level determinants, for example the use of capital and labour and the applied technologies, and context-conditions, in particular institutions, policies and the conditions on factor markets.

## **4 Literature review**

We organized the review below accordings to the grouping of seven drivers suggested above. In addition to the factors that have been considered in earlier reviews, we hence carefully review household endowments/characteristics as well as key policies addressing land-use change. The many examples and case studies illustrate the complex interrelationships between land-use change and its supposed drivers. Many different transmission channels with different weights in different contexts are at work, often simultaneously. Empirical ambiguities do not only arise form different context conditions, but also because of the existence of non-linearities in the relationship between a specific driver and land-use change.

### **4.1 Property rights and institutions**

In a setting where households draw their sustenance from agricultural activities, the rules and institutions that govern the ownership and utilisation of land play a key role in determining households' behaviour and decisions. A significant number of the households analysed in the



studies reviewed are faced with weakly defined and insecure property rights (Dolisca et al., 2007; Mena et al., 2006; Muriuki et al., 2011; Murphy, 2001; Otsuka et al., 2001; Pan et al., 2004).

In the absence of well-defined property rights and tenure security households often gain de facto land rights through deforestation and land clearing (Damnyag et al., 2012; Dolisca et al., 2007; Otsuka et al., 2001, Cattaneo, 2001). Cattaneo's (2001) simulation-model-based analysis of deforestation in the Brazilian Amazon assumes that deforestation enables the acquisition of property rights to "unclaimed" land. He further argues that this adds a speculative value of informal tenure rights to the potential returns from agriculture. These relationships imply an ambiguous effect of tenure security on deforestation or other forms of land-use change. In general, households or farmers in environments with relatively insecure rights may tend to use land conversion or possession of "unclaimed" land as a way of establishing informal land use rights. In line with this argument, Dolisca et al. (2007) find that illegal occupants are more likely to convert forest into cultivable land than farmers with titled land in Haiti. Such behaviour is reinforced by regulations that foresee titling through adverse possession; that is, farmers acquire titles after physically living on a piece of land for a 20 year period. Yet, Dolisca et al. (2007) also point at evidence for the same country that shows that titling programs have equally caused more deforestation, as more land is then cleared because of an increased value of the property rights established by clearing – very much in line with Cattaneo's (2001) argument above. Generally, households will deforest or clear land up to the point where the marginal benefits of clearing (including both the value of potential agricultural production and of tenure rights) exceed or match the marginal costs of doing so (including the direct costs of clearing, for example labour costs, and of violating laws).

Beyond these "direct" effects of establishing property rights through land conversion, the presence of insecure tenure has important effects on agricultural management practices, profits to be earned from agricultural activities, and, hence, investment decisions. It is well established that insecure property rights have an inverse relation with household's planning horizons (Goldstein and Udry, 2008; Besley and Ghatak, 2010). With shorter planning horizons, farmers are more likely to apply less sustainable agricultural management practices; in particular they may invest less in soil conservation measures and leave too little land fallow. In line with this argument, Damnyag et al. (2012), for example, show that farm households in Ghana are more likely to invest in shade grown cocoa and other perennial crops when they have a secure land title. It should not go unnoticed that these decisions may still be optimal for the individual household under the constraints faced. Less sustainable agricultural practices may eventually lead to land degradation and to possibly higher rates of conversion of non-cultivated to cultivated land again.

In household surveys, the common practice in collecting information on land tenure and property rights is to include questions that either specify the characteristics of land tenure arrangement (customary or freehold, titled, rented or leasehold, share cropped) or that ask about the land acquisition process (inheritance, leasehold, purchase or illegal use) (Dolisca et al., 2007; Damnyag et al., 2012). In cases where land titles are absent (or no information is available), property rights may be proxied through the duration of residence (Dolisca et al., 2007). These measures and proxies are typically used as explanatory variables in an equation that explains land-use change. This procedure is not without problems, as it neglects the possibility that causality may be reverse of the assumed relationship: for instance, it assumes

that land-use decisions are determined by property rights (and not vice versa). However, the act of clearing forest may just be observed because this decision gives rise to some kind of property right.

The feedback between land rights and land-use change is nicely illustrated in a study by Otsuka et al. (2001) who use data from Sumatra, Indonesia. They show that customary land rights respond to changing context conditions, in particular higher population pressure, by giving higher tenure security to households that invest more, specifically through planting trees, into land acquired by clearing communal forests.

## 4.2 Market accessibility and infrastructure

Households' land-use choices depend highly on the access to infrastructure and markets. Infrastructure networks and market integration determine households' production decision and thus the spatial arrangement of land uses. This is because they influence the economic structures beyond agriculture, i.e. income-generation opportunities in non-agricultural sectors with possible repercussion on land-use change. Hence on a gradient of market integration, the production costs of agricultural commodities, the distribution networks, and the opportunity costs of engaging in agriculture differ and so will thus households' land uses. The interrelation between developing markets and infrastructure extension is twofold: First, infrastructure can be triggered by developing markets, cash crop adoption and economic growth – possibly reinforced by spontaneous in-migration. Secondly, infrastructure extension can be a component of rural development and settlement policies and exogenously drive market integration. In reality, this process will often be iterative and both channels will reinforce each other.

Similar to earlier reviews (Angelsen and Kaimowitz, 1999; Geist and Lambin, 2001), recent empirical findings confirm a strong impact of changing market integration on households' land-use decision (Caviglia-Harris, 2004; Kaminski and Thomas, 2011; Vadez et al., 2008). Better access to markets is found to be positively correlated with the extension of agricultural areas, especially for cash crop cultivation (Ellis et al, 2010; Vance and Geoghegan 2002; Klepeis and Vance, 2003). Accordingly, a number of studies find a negative relation between distance to market centres and deforestation (Caviglia-Harris and Harris, 2011; Geoghegan et al., 2004; de Souza Soler and Verburg, 2010; Sunderlin and Pokam, 2002; Wyman and Stein, 2010; Pan, et al. 2007).

Most studies capture the effect of accessibility to markets on land-use change by controlling for infrastructure variables, such as *distance to markets* (Müller and Zeller 2002) or *distance to all-year roads* (Maertens et al., 2006). As outlined above, it is not without problems to interpret the correlations between these variables and land-use change decisions as truly causal. This is because neither the establishment of infrastructure nor the development of markets (the latter even much less) can always be considered exogenous to the household's decision. Instead, both land-use change decisions as well as the establishment of rural infrastructure may be driven by the same – unobserved or non-considered – factor, for example a rural development policy aimed at cash crop expansion. Further, capturing market accessibility via distance variables is prone to ignore underlying variables, for example failing output and input markets.

Some studies provide very instructive insights on the relationship between infrastructure/markets and land-use change. Cattaneo (2000), for example, uses a dynamic computable general equilibrium model to analyse the impact of infrastructure extension on deforestation in the Amazon. He explicitly considers the response of commodity markets and finds that a 20 percent reduction in transportation costs for all agricultural products leads to an increase in deforested land between 21-39 percent.

Other studies, however, suggest a more complex relationship between market access and land-use change. Using cross-sectional village-level data combined with GIS-data from Central Sulawesi, Indonesia, Maertens et al. (2006) analyse how improved technologies in the lowlands affect agricultural expansion and deforestation in the uplands. In doing this, the authors do also control for market access of households. Their findings suggest an inverse U-shaped relation between market access and agricultural expansion and argue that improved market access and declining transaction costs lead households to expand their land for agricultural production. However, in a second stage, households start to invest in off-farm activities, which in turn reduce the pressure on the forest. Müller and Zeller (2002) combine satellite imagery and survey data from Vietnam to analyse econometrically the land use dynamics in the central highland of Vietnam. They find that a period of land-intensive agricultural expansion (at the expense of forest) was followed by a second period of labour- and capital intensive agricultural growth. This pattern of agricultural growth without further land expansion was driven mainly by increased market integration that eased constraints on agricultural input and output markets.

### **4.3 Household characteristics, income and wealth**

Household characteristics and endowments are crucial determinants of households' behavior and are often included as 'controls' in regressions even when they are not the main motivation behind the study. Education levels, income, wealth/assets, and age of the household head are commonly controlled for in regression analyses of land-use change. Furthermore, households' endowments with land, physical capital, and (family) labour are important determinants of land-use change decisions, but these will be discussed in the subsequent section.

The framework above clearly shows the rationale for including education and income as explanatory variables into land-use change regressions. Yet, most studies could be more explicit about the reduced-form character of this type of exercise. In addition, endogeneity issues remain largely unaddressed in most studies. Education and age, for example, affect the productivity and opportunity costs of most economic activities (in off-farm activities often more than in farming). At the same time, they affect values and attitudes of all kinds, for example the valuation of work as a farmer or consumption aspirations. The effect observed in a regression of land-use change on education (or age) will hence always reflect a combined (reduced-form) effect of these different transmission channels. Instead of acknowledging this, most studies tend to present a fairly eclectic interpretation of the relationship between a specific household characteristic and land-use change. Codjoe and Bilsborrow (2011) and Dolisca et al. (2007), for example, point at a possible effect of education through increased consumption aspirations, Busch and Geoghegan (2010) stress the importance of education for the profitability of off-farm and/or non-agricultural opportunities at higher levels of education. While the hypothesized effects are likely to be at work in the respective cases,

there may be other relevant transmission channels of education to land-use change. In addition, most studies fail to note that formal education is typically correlated with unobserved abilities (of different kinds, for example logical reasoning), which again tends to bias the measured effects.

The relationship between income and land-use change is the most important and interesting, but also empirically most challenging, one. It is common for empirical micro-level land-use change studies to find a positive correlation between income and bringing land under cultivation (Schmook and Vance, 2008; Godoy et al., 2009). We have above already pointed at the obvious problem of reverse causality in this relationship, i.e. income determines the household's current land-use and, at the same time, this land-use also influences income levels. Yet, very few studies make an attempt to address this problem. One exception is Caviglia-Harris and Harris (2008) who use lagged variables of income – instead of current income – in their analysis of cattle ranching expansion in the Brazilian Amazon. They find a positive correlation between income and pasture but not for cropland.

Off-farm income, as an important component of income of many rural households, is often explicitly considered in analyses of land-use change. It can reduce households' dependency on agriculture and, as an important alternative income generation strategy, determines the opportunity costs of engaging in agriculture (Kaminski and Thomas, 2011). At the same time, off-farm activities may provide the liquidity required to invest in certain agricultural activities that require some initial investment, for example livestock or certain cash crops. Most studies do not make an attempt to disentangle these effects, but they can confirm a net reduction in deforestation due to increased off-farm income. As the income portfolio and hence income, are simultaneously determined (by the same factors), the abovementioned empirical caveats in terms of a causal relationship between off-farm income and land-use change also apply to off-farm income. Setting these concerns aside, the Mexican case study from the southern Yucatán, Mexico, by Geoghegan et al. (2001), for example finds that households' income generated through off-farm employment is found to be negatively correlated with forest clearance. In one of the few panel data studies, Rodríguez-Meza et al. (2004) empirically analyse the determinants of households land use in El Salvador. Controlling for household fixed effects, they also find that the households engage in income diversification through non-farm activities reduces land clearance. Pender et al. (2004) examine the determinants of land management in Uganda using village-level data. The results suggest six different development pathways where one is related to increasing non-farm activities. The study points at another interesting effect of higher opportunity costs for labour. That pathway of increased off-farm opportunities seems to enhance soil degradation since less household labour is available for more sustainable practices.

While education, income, and wealth are certainly among the fundamental drivers of land-use change towards agricultural use, they are often reinforced (or mitigated) by social networks and other forms of social capital that are likely to play an important role particularly in the diffusion of certain crops or agricultural technologies. They facilitate learning by observation and provide farmers with local knowledge of soil quality, suitable agricultural technologies and crop marketing when extension services and other forms of formal institutions are absent. Busch and Vance (2011), for example, develop a theoretical model that focuses on the role of information spill-overs in spurring the diffusion of pasture in the southern Yucatan for groups of households originating from the same villages. They find that increases in village networks

increase cattle adoption at a decreasing rate. Similarly, Vanwambeke et al. (2007) find that belonging to a social network is positively correlated with a household's increased use of inputs (intensification) in irrigated areas in Northern Thailand. They also use village membership as a proxy for membership in a social network. Their analysis is limited to short term effects and they do not find evidence for the decreasing positive impact of social capital reported in Busch and Vance (2011).

#### **4.4 Input and output markets**

In developing countries, rural smallholders typically face considerable constraints on input and output markets. While constraints on output markets generally hamper agricultural expansion, imperfections on capital, labour and other input markets may have ambiguous effects. On the one hand, they may also simply constrain expansion; on the other, input factor and input market imperfections may lead to substitution of these factors for land and thus promote land-intensive agricultural strategies.

This mechanism is, for example, shown by Busch and Geoghegan (2010) who analyse land-use choices of rural households in the southern Yucatán region in Mexico. Using a cross-sectional survey, the authors show that labour scarcity drives households' expansion in cattle ranching, which is more intensive in land and capital than in labour. However, intensification of one sector can alter returns to factors and thus reduce pressure on land. Shively (2001) illustrates in his case study on Philippine farm households at rainforest margins the effect of agricultural intensification in a context of a dichotomous lowland-upland economy. He estimates a rural household model and finds that upland forest clearing and hillside farming are reduced by agricultural intensification in the lowlands (here the introduction of irrigation). Higher labour productivity in the lowlands increases demand for labour from the uplands and creates a small but significant reduction in the rate of forest clearing.

A typical finding of micro-level studies with regard to labour is the correlation between deforestation and agricultural extension and the use of hired labour (for example, Mena et al. 2006; Caviglia-Harris and Harris, 2008; Walker et al., 2000, Walker et al., 2002), particularly for commercial agriculture (Walker et al., 2002). Unfortunately, these studies often fail to take into account that hired labour is endogenous to land-use change: Labour use, be it family or hired labour or a combination, is always determined by the production technology and labour market conditions, i.e. wages and the availability of labour for hire – rather than vice versa.

Access to and availability of a considerable amount of capital is an essential requirement for many of the agricultural activities that are being investigated as land-use change drivers by the reviewed studies. Access to capital may not only be required to finance investment costs, for example setting-up a rubber or oil palm plantation, but also to finance fertilizer and other inputs. These are two important related, but yet separate transmission channels that would probably result in ambiguous dynamic effects of access to capital – facilitating agricultural expansions initially and saving land later. To date, however, the literature has little to say on these possible dynamic ambiguities, which are also difficult to assess empirically. This is, for example, because capital incorporated in established farming activity is often not easy to measure. This may explain why the reviewed studies typically hypothesize a positive correlation of the availability of physical capital with agricultural land-use. This conceptual weakness is reinforced by the fact that the problems of endogeneity and attribution of

causality, which are similar to those with regard to income, are often not addressed. While some studies directly use capital endowments to explain land-use change, others recur to access to capital. It should be noted that the estimates of the effects of the latter variable are also prone to suffer from endogeneity biases, as access to capital is typically determined by the same unobserved factors that determine land-use change, for example entrepreneurial or farming ability. Despite these shortcomings, the fact that capital (or access to it) is often found to be correlated with land-use change has some empirical content and points at the important role of capital. A number of studies suggest that capital is an important driver of deforestation for ranching and agriculture purposes (Busch and Geoghegan, 2010; Klepeis and Vance, 2003; Perz et al., 2006; Schmook and Vance, 2008; Vance and Geoghegan, 2002; Vance and Geoghegan, 2004; Vance and Iovanna, 2006; Wyman and Stein, 2010). The “effect” of capital can be very large. For example, using data on 132 households from Uruara county in eastern Brazil, Caldas et al., (2007), find that households with some capital (measured as durable goods available to the household upon arrival on the property) deforest between 20-30 hectares more of forest than poorer households without any capital (the mean farm size in the study is 23 hectares). In addition, access to capital is also found to be associated with the adoption of longer term and higher yielding activities such as the cultivation of perennial cash crops and adoption of pasture in a number of studies (Perz et al., 2007; Van Wey et al., 2011; Vanwambeke et al., 2007). Kaminski and Thomas (2011) investigate the impact of institutional reforms within the cotton sector on households’ land uses in Burkina Faso, Africa. The authors combine a structural framework with cross-sectional regression analyses to show that the increase in cotton cultivation can be linked to both the enhanced access to credits and improved credit conditions after institutional reforms.

In the same study, Kaminski and Thomas (2011) also theoretically analyse the role of price fluctuations and the role of marketing risk for household’s crop choices; hence looking at product markets. In their estimation strategy they account also for the importance of price fluctuations including the relative crop price variability of crop prices as proxy. They find that optimal land uses is also determined by the relative risk-profitability of households’ crop portfolios, which are a function of households’ technologies and input and output prices. This study illustrates the important role of output markets as a central driver of households’ production decision and land-use change, as does another study by Caviglia-Harris and Harris (2011) on the impact of settlement design in the Brazilian Amazon. Based on panel data of Brazilian households, which are predominantly small-scale farmers, the authors find a short- and a long-term impact of milk prices on deforestation: First, increasing milk prices translate directly in higher income and encourage agents to intensify agricultural production. Then, labour is drawn away from forest clearing. In the longer term, increasing milk prices however raise incentives to extend the production which leads to further forest clearance to support larger cattle herds.

Finally, recent analyses of input markets also reflect land as a factor input stressing the role of speculation. Takasaki (2007) for example uses a theoretical model for agricultural households considering forest clearance as well as providing land as input for households’ production and also as an investment for further production. The model suggests that if labour and land markets exist, increasing land prices promote forest clearance for speculative land holding. The empirical case study of Carrero and Fearnside (2011) also provides evidence for the role of speculation in land holding. The authors analyse the land-use strategies of households in

one of Brazil's deforestation hotspots along the Transamazon Highway. They find that pasture indeed pushes the forest frontier, although income reliance of households on beef sales is low. Their case study results suggest that at least 30 percent of surveyed farmers acquire land for speculative reasons.

#### **4.5 Adoption of agricultural technology**

The availability of and the capacity (and willingness) to adopt agricultural technologies is a key driver of land-use change. Once a technology is chosen, it will determine smallholders' factor use and the respective output level. Hence, the technology applied by households determines land uses and may induce land-use change depending on the specific characteristics of the technology. These technological characteristics for example the level of substitutability between input factors, interact with household endowments, for example the availability of family labour, and prevailing factor market conditions, for example the availability and price for hired labour. Once new agricultural technologies are adopted, they may lead to technological spill-over effects within villages and communities.

Most recent studies on the impact of technology on agriculture examine technology as a land-saving or land-consuming driver of land-use change. Empirically, these studies focus on the use chemical inputs (Caviglia-Harris and Sills, 2005; Rodríguez-Meza et al., 2004), irrigation systems (Shively and Pagiola, 2004), or mechanical tools (Codjoe and Bilsborow, 2011). The results are ambiguous: Some studies observe a negative link between the adoption of a new technology and deforestation or agricultural expansion. (Mertens et al., 2000; Pender et al, 2004; Vanwambeke et al, 2007). However, other studies find evidence for land extensification to be driven by technological improvements (Rodríguez-Meza et al., 2004; Sankhayan and Hofstad, 2001).

Although these studies show a correlation between land conversion and technology adoption, some of them fail to take into account the respective market conditions, particularly on input markets, as an underlying driving force. Especially in rural regions, area extension due to technical improvements may be induced through relaxed access to formerly constrained input markets. We have already pointed at Kaminski and Thomas' (2011) study on institutional reforms as the main driver of cotton expansion in Burkina Faso above. These reforms improved access to input markets and to technical advice. Underlying driving factors would need to be factored in not only conceptually, but also in the empirical analysis. The correlation between the use of a technology, for example chemical inputs or mechanical tools, and land conversion may often be traced back to underlying driving forces, such as access to capital or degraded soils.

Only few studies discuss the net effects of new technologies on land use once the technology's impacts on factor use (substitution) factor prices and possibly resulting spill-over effects between regions and sectors are taken into account. In South-East Asia, rural areas are often characterised by an upland-lowland dichotomy. Shively's (2001) study of such a context in the Philippines suggests that the adoption of a more labour-intensive technology (irrigation) in the lowlands promotes employment and reduces pressure on forests in both regions: With higher productivity the factor returns in the lowland increase and lowland wages rise. As a consequence, upland households, who are now employed in the lowlands, pursue an intensification strategy on their own land, which in turn leads to a decrease in forest

clearing and hillside farming. In the same country context, Shively and Pagiola (2004) confirm these results using panel data with a focus on the impact of intensification on deforestation. With irrigation development in the lowlands, wages and employment rise and the authors show a positive correlation between the shadow value of lowland labour and the days of hired labour in the uplands. This indicates that upland households employed in the lowlands replace family labour with hired labour on their own farms. The wage-induced increase in labour productivity in the uplands reduces forest clearing and leads to intensification.

Müller and Zeller (2002) use cross-sectional regression analysis to investigate the possible land-saving effects of intensification in the Central Highlands of Vietnam. They show that intensification indeed triggers land-saving effects; yet, only if technological change is accompanied by enhanced market integration and simultaneously enforced forest protection policies. These results are in contrast to those obtained by Maertens et al. (2006) who apply cross-sectional village-level data combined with GIS-data to analyse the land-use implications of the introduction of hand-tractors in the rice sector in Central Sulawesi, Indonesia. They show that the improved technology for rice cultivation induces a shift of labour into the forested uplands and thus increase agricultural extension and deforestation. The opposite effects found in these two studies illustrate the importance of context conditions, here in particular the labour market conditions, in shaping the effects of technological change.

With regard to the processes of technology adoption, a couple of recent studies have investigated the role of household interaction for the diffusion of technologies. Mena et al. (2011) uses an agent-based model fed with empirical data where the authors assume that households transfer information and knowledge through imitation of neighbours' cultivation strategies. Vanwambeke et al. (2007) analyse the emergence of cash crop markets and the industrialization of rural households in northern Thailand. Based on cross-sectional household data and remote sensing data the authors apply a choice model to examine the impact of social-networks on new land use strategies. The authors show that social networks defined by the numbers of other adopters in the village lead to intensified land use through information via sharing or observing.

#### **4.6 Population and migration**

There is a consensus in the literature that population pressure is an important driver of land-use change (Ellis et al., 2010; Garedew et al., 2012; Mena et al., 2006) and that it also triggers technological change in agriculture technologies (Maertens et al., 2006).<sup>8</sup> More precisely, population growth – often accelerated by migration – can either result in extensive (if uncultivated lands are available) or intensive land use (if uncultivated lands are not available). As many of the areas within the studies reviewed were previously forest land before they were converted to settlements or agricultural lands, the opening of these lands has been accompanied by migration into the previous forest lands.

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<sup>8</sup> Since population pressure can only be partially reflected at the household level, micro-level studies on land-use change often incorporate census data into their analysis (see for instance, Cattaneo, 2001; Ellis et al., 2010; Garedew et al., 2012; Geoghegan et al., 2004; Maertens et al., 2006; Mena et al., 2006 and Walsh et al., 2008).



In fact, migration has received considerable attention in the land-use change literature and migration status has in many micro-level studies been hypothesized to affect households' land-use decisions. First, migrants are expected to follow intensive and unsustainable agricultural practices that lead to the encroachment of the forest frontier because they have shorter planning horizons, which cause them to be more destructive than host populations (Codjoe and Bilsborrow, 2011). Second, migrants are assumed to use unsustainable agricultural practices due to their limited knowledge of the local agro-ecological conditions of their new region. Codjoe and Bilsborrow (2011) find weak empirical support for these hypotheses for migrant farmers in central Ghana, as they tend to have less fallow years than non-migrants.

In a study on colonist farm incomes in the Ecuadorian Amazon, Murphy (2001) finds that new migrants earn less because they have less experience about the regional conditions. While this supports the claims made above that new migrants are not familiar with the agro-ecological conditions of their new residence it does not provide any evidence on their land-use patterns. Other studies that show that duration of residence matters for land-use change include Dolisca et al. (2007) who find that the longer households have lived in the Forêt des Pins Reserve in Haiti the less likely they are to clear forests.

Using data from Southern Yucatán in Mexico, Schmook and Radel (2008) find that households with migrants that have migrated to the US have more pasture than non-migrant households. This is because the establishment of pasture is initially labour intensive but requires very low levels of labour inputs once established which makes it ideal for households with members that have migrated to the US. In addition, they find that migrant households cultivate more summer maize and chili and are less likely to cultivate traditional milpa when compared to non-migrants.

#### **4.7 Key policies**

To analyse the impacts of policies temporal data that captures the conditions before and after the policy or data on a counterfactual group that consists of households with the same characteristics that have not been exposed to the policy change is necessary (Schmook and Vance, 2009). However since policies are often experienced uniformly within a region, such data is usually not available for most of the studies reviewed in this paper and the analyses are sometimes made with retrospective data that questions households on their experiences before the policy change.

Market-oriented reforms adopted by many developing countries in the 1980s and 1990s played an important role in altering land use in many of the countries covered by the reviewed studies. One of the most extensively studied policies with respect to its land use change implications is *the Programa de Apoyo Directo al Campo* (PROCAMPO), a cash transfer program introduced in 1994 in Mexico to mitigate the possible adverse effects of the North American Free Trade Agreement (NAFTA) on rural populations (Kleipis and Vance, 2003; Schmook and Vance, 2008). Kleipis and Vance (2003) were the first to clearly establish a link between receipt of PROCAMPO cash transfers and the subsequent land-use decisions made by farm households. Using a panel data set with individual farm-level data that spans an eleven year period from the southern Yucatán peninsula in Mexico, the authors show that PROCAMPO payments are responsible for nearly 38 percent of deforestation that occurred in

the study region between 1994 and 1997. They relate this finding to the eligibility conditions of PROCAMPO that are at odds with fallow regeneration and cause households to clear more forests in order to maintain the cultivation of crops in rich soils.<sup>9</sup> A later study, by Schmook and Vance (2009) uses a seemingly unrelated regression to compare the effects of PROCAMPO and another agricultural support program - *Alianza Para el Campo* - on the households in the same region. PROCAMPO puts no restrictions on how the transfer should be spent, but attaches conditions on how land should be used. Instead, transfers from Alianza are tied to specific agricultural activities that have to be implemented by households (Schmook and Vance, 2009). In line with Kleipis and Vance (2003) they find that PROCAMPO is significantly correlated with a reduction in forest area and with increases in area under pasture and cultivation. In a similar vein, Alianza is found to significantly influence land-use, in particular in favour of pasture.

The finding that market-oriented reforms increased deforestation and expanded areas devoted to agriculture is not unique to south-eastern Mexico. Another example is the abovementioned case of the reform of the Burkinabé cotton sector analyzed by Kaminski and Thomas (2011) that included the privatisation of the parastatal firm SOFITEX (National Cotton Fibre Company). Going back to Mexico, Barsimantov and Antezana (2012) discuss how the adoption of the 1992 Forestry Law and the 1992 Reform of the Mexican Constitution that were part of a set of free market and reregulation policies increased deforestation and later led to an increase in the production of avocados. The authors show that forest cover was reduced considerably as a result of these policy changes, particularly in the non-forestry communities that had relatively less forest cover to begin with.

Other policies that have played a key role in driving the land-use decisions made by households in the reviewed studies include policies targeted at infrastructure development (Müller and Zeller, 2002; Pender et al., 2004) and settlement policies (Caviglia-Harris and Harris, 2011). Caviglia-Harris and Harris (2011) show that even when policy makers take extra precautions in designing alternative new settlement policies to ensure that they meet both environmental and social objectives, in the long term the design does not influence land cover choices and that land clearing is extensive in all agricultural lots. After a ten year period they find that very little forest remains in the radial lots that are introduced by the new alternative settlement policy.

While many of the policies discussed above appear to have affected land-use indirectly by reforming markets that matter for land-use choices, a number of policies have also been formulated with the principle aim of altering land use and cover. Prominent examples of these policies include the Payment for Environmental Services (PES) and Reducing Emissions from Deforestation and Degradation (REDD and REDD+).<sup>10</sup> These policies directly address households' decisions to deforest by altering the payoffs to different land uses. Yet, whether these policies are effective in actually influencing land-use change is still under-researched.

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<sup>9</sup> Other studies that analyse the impacts of PROCAMPO such as Vance and Geoghegan (2002), Busch and Geoghegan (2010), find similar results. Yet, Busch and Vance (2011) and Chowdhury (2007) find opposite effect on area under cultivation and fallow, respectively.

<sup>10</sup> PES is a policy that compensates land owners and resource managers for the provision of ecosystem services (Jack et al., 2007). Providing income to resource managers for ecosystem services encourages sustainable land-use practices. REDD is based on a similar monetary incentives mechanism, it compensates developing countries with income payments that are equivalent to the amount of carbon emissions reduced if their national deforestation levels decrease (Damnyag et al., 2012).

## 5 Conclusion

For this paper, we have reviewed 70 recent empirical and theoretical studies that analyse land-use change at the farm-household level. The review builds on a conceptual framework of land-use change drivers that extends previous work by Angelsen and Kaimowitz (1999). The framework considers feedback mechanisms between the different stages of the land-use change process, for example between the actions of agents and macroeconomic variables, and between specific causes within a stage, for example between different decision parameters such as the interlink between technology options and accessibility of infrastructure. Furthermore, our framework explicitly considers the role of household endowments and characteristics as drivers of land-use change.

We first conduct a meta-analysis of the 70 studies. It turns out that the most frequently analysed scenario is the conversion of non-used forests or forestry into land used for agricultural purposes – about a third of all scenarios. The second largest share is accounted for by studies that look into the conversion of non-used forests or forested areas into ranching. Most studies analyse land-use change using household and/or village data and, in doing so, often rely on relatively small samples of 100-200 observations. There is a clear regional concentration of studies on Central and South America and some studies on African countries, while only 11 percent analyse land-use change in Asian countries. The limited number of Asian case studies is surprising, since evidence hints at high deforestation rates in South-East Asia due to logging activities and plantation agriculture. In our view, this may be explained by the literature's focus on household farms. Yet, the omission of firms that operate logging and large-scale farming activities implies that a key (micro-level) actor's behaviour remains unexplored. We find that a number of studies face problems of internal validity because of endogeneity (simultaneity and reverse causality) and omitted variable bias that are not adequately addressed. Similarly, many empirical studies fail to acknowledge that their empirical findings tend to be “reduced-form” estimates.

When we aggregate the variables identified as drivers in the micro-level studies into stylized categories, we find that household-level heterogeneity and the resulting differences in land-use decisions can be considered a key driver of land-use change. This is less trivial than it may appear, as it is also conceivable that forces external to households, in particular policies and market signals, are strong enough to dwarf the effects of household-level differences. Among the household-level characteristics, the literature points at micro-level determinants of economic growth, in particular in physical capital, as a catalyst of human induced land-use change.

However, as our detailed literature review shows, the relationship between land-use change and these growth-associated micro-level drivers is complex, in particular because of the interactions between these drivers, for example the use of capital and labour and the applied technologies, and context-conditions, in particular institutions, policies and the conditions on factor markets. It is these complexities and interactions that cause the abovementioned important challenges in the empirical study of land-use change.

Land governance systems are a case in point. It is well established that the absence of well-defined property rights and tenure security often leads households to gain de facto land rights through deforestation and land clearing. In addition, insecure tenure shortens farmers' planning horizons, which, in turn, makes them more likely to apply less sustainable

agricultural management practices. When the impacts of tenure security on land use and management practices are empirically analysed reverse causality issues, i.e. the fact that tenure security is influenced by land use and management, receive too little attention in the literature.

Reverse causality is also an often unresolved issue in a fundamental relationship in micro-level land-use change studies, the relationship between income and land use: Income determines the household's current land-use and, at the same time, this land-use also influences income levels. Similarly, empirical problems often remain unaddressed in the analysis of the effects of infrastructure development and increasing market integration that some studies also deem to be an important driver of land-use change. More and better infrastructure can be the result of increasing demand caused by cash crop adoption and economic growth, but it can also exogenously drive market integration. The literature too often assumes a one-directional causal relationship and ignores that infrastructure development may well be driven by the same rural development policy, for example one aimed at cash crop expansion.

Complex causal relationships hence complicate the empirical analyses and so do non-linear relationships as well as interactions between different drivers that are also frequently observed. One example for an important non-linearity is the inverse U-shaped relationship between market access and agricultural expansion that has been shown in a number of studies: Improved market access first leads to agricultural expansion, but, in a second stage, households start to invest in off-farm activities and reduce the pressure on forests. Important interactions are at work between factor (land, labour and capital) markets and household characteristics. Factor markets in developing countries tend to be highly imperfect, which implies that households' initial factor endowments, for example initial wealth or household labour, may play an important role in explaining land-use and management choices. Factor market imperfection and/or limited household endowments may then simply constrain expansion. However, as the same market imperfections may lead to substitution effects, they may also promote land-intensive agricultural strategies. In the case of capital, these ambiguities are reinforced by the fact that capital does not only finance initial investment costs but also current costs for fertilizer and other inputs. This implies that access to capital may facilitate agricultural expansions initially and saving land later. These mechanisms are similar for technology adoption. New technologies, for example the introduction of a new crop, are often found to lead to agricultural expansion. Yet, they may also lead to land savings, conditional on the substitutability between input factors and possible interaction with household endowments and factor market conditions. In terms of household-level determinants of technology adoption, the literature has often stressed that migrant status tend to be associated with the application of intensive and unsustainable agricultural practices.

In sum, the reviewed rich empirical literature illustrates the complexity of micro-level land-use change processes, in particular the inter-relationships between household-level characteristics, factor market conditions, and land-use change. These are conditioned by institutions and policies. The review suggests that market-oriented reforms adopted by many developing countries in the 1980s and 1990s have had an important role in altering land use, while impacts of more recent policies, like PES or REDD+, still need to be better explored.

The empirical designs of many reviewed studies fail to properly account for this complexity. While these studies have explored some key facets of household-level drivers of land-use

change, future research would greatly benefit from more methodological rigor and some more care should be taken when results are interpreted as causal relationships. Yet, does it matter if an empirical analysis does not pay attention to the fact that income is also determined by land-use change and not only vice versa? Yes, it does since the conclusion to be drawn from either finding differ dramatically. If income growth causes deforestation, there are good reasons to worry since most rural households at forest frontiers are still way below income levels that they would consider desirable – and are probably likely to achieve at some point in the future. If incomes, however, have in past grown for reasons related to land-use change, for example because of growing a cash crop on converted forest, they might in the future grow for different reasons, for example because growing economies tend to become more diversified and people engage more in non-agricultural activities.

We want to close by reflecting briefly on some further implications of this review for the way forward. In addition to the methodological challenges, the review reveals a lack of interdisciplinary work that uses more integrated approaches to analyse land-use change. While the household-survey-based analysis that tends to dominate this field of study has yielded important insights, more integrated approaches are desirable. These approaches may include both statistical and model-based analyses that combine data from a variety of sources, of course still including survey-based information. This should also enable researchers to extend the sample sizes and increase the external validity of the findings. External validity could also be improved by paying due attention to case selection and some more reflection on whether results should be regarded as context-specific or generalizable.

Two important and related gaps in the literature struck us as gaps to be filled. While our review focused on household-level studies, we were surprised to find virtually no study that would have analyzed – at the micro-level – the decisions by firms that operate logging and large-scale farming activities. This implies that a key (micro-level) actor's behaviour remains unexplored and this omission also partly explains the lack of studies in Asian contexts, where these players are probably more important.

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## Appendix: Review questionnaire

### Drivers of households' land-use decisions

#### Constructed Questionnaire

This questionnaire was constructed to systematically record information from the 70 studies selected to be included in the review. The entries were recorded and cross verified by two of the three authors and a research assistant working with the authors. The data is available upon request from the authors. For more information on the data entry, please contact the corresponding author at the following email address: [hettig@giga-hamburg.de](mailto:hettig@giga-hamburg.de)

| Question Number | Question  | Comments   |
|-----------------|---|--|
| 1               | Who authored the paper?   | <i>List orders according to publication order</i>                    |
| 2               | What are the academic backgrounds of the authors?                 | <i>Here look at the authors academic qualifications and profiles</i> |
| 3               | In which (peer-reviewed) journal was the paper published?         |  |
| 4               | When was the paper published?                                     |  |
| 5               | In which region (tropical or subtropical) was the data collected? |  |
| 6               | What country was the data collected in?                           |  |
| 7               | What type of analysis is conducted in the study?                  |  |
| 8               | What type of methodology is used by the authors in the study?     |  |

|    |   |  |
|----|---|--|
| 9  | What type of spatial analysis is used in the study?   |  |
| 10 | What type of data is collected in the study?  |  |
| 11 | When was the household data used in the study collected?  |  |
| 12 | What variable to the authors use to identify land change?   |  |
| 13 | Which explanatory variables are found to have a significant impact on the land change variable identified in question 13? | <i>Here only record the variables that significantly affect LUC</i>  |
| 14 | What are the main socio-economic drivers of land-use change identified by the authors?                                    | <i>Here only include the main drivers that are cited by the authors and not all significant explanatory variables listed in question 13.</i> |
| 15 | How can the drivers identified in questions 14 be classified to match our coding scheme?                                  | <i>Here classify the drivers in question 14 into the 7 main categories</i>   |