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The cost effectiveness of payments for ecosystem services—Smallholders and agroforestry in Africa

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ABSTRACT

Certain smallholder farmers in parts of sub-Saharan Africa engage in conservation agriculture and participate in agroforestry ecosystem services schemes that generate additional on-farm revenues through payment for ecosystem services (PES). However, smallholder farmers that are inadequately compensated for the foregone income from agricultural production due to marginal ecosystem services provision have no incentive to participate. On the other hand, over-compensating participating farmers will also lead to PES schemes inefficiencies. Therefore, stakeholders are confronted with the challenge of evaluating farm-level interactions between agricultural production and ecosystem services' provision when making strategic decisions on the efficient level of compensation. We propose in this contribution to assess the efficiency of PES schemes by measuring the marginal cost of ecosystem services based on farm level bio-economic interactions. The quantitative assessment is based on a theoretical classification of the relationship between marketed agricultural output and ecosystem services into complementary, supplementary or competitive. We use a flexible transformation function and cross-sectional data on 120 surveyed smallholder farmers with agroforestry certification in rural Mount Kenya. The results suggest that the joint production (of agricultural output and ecosystem services) for a substantial number of smallholder farms in Kenya may not show a complementary relationship. The biophysical linkage between marketed outputs and ecosystem services strongly influences the marginal cost of ecosystem services. PES schemes could become more efficient if they would target smallholder farms based on the aforementioned classifications by offering a range of contracts to encourage competitive bidding.

1. Introduction

Trees and crops simultaneously cultivated on farmland (*henceforth agroforestry*) are an integral part of rural agriculture in parts of sub-Saharan Africa and have a long standing tradition in the agricultural production system. Ruhl (2000) and Sauer and Wossink (2013) argue that agroforestry provides ecosystem services that form a complex bundle of services. Agroforestry ecosystem services are classified into regulating, provisioning, cultural and supporting (Millennium Ecosystem Assessment, 2005; Smith and Scherr, 2003). Overall, these ecosystem services are beneficial to society and may improve smallholder farmer's livelihood. Participation in agroforestry and agroforestry ecosystem service schemes (*henceforth agroforestry PES schemes*) requires upfront investment of time, resources and secure land tenure (Unruh, 2008; Current et al., 1995). However, most rural areas in developing countries are subjected to highly constrained credit markets that result in people making decisions under strict cash constraints (Salami et al., 2010; Benjamin et al., 2016). This has not deterred smallholder farmers in parts of sub-Saharan Africa from engaging in agroforestry, due to its contribution to soil fertility replenishment and crop productivity (Sanchez et al., 1997).

Although the primary goal of agriculture is crop (food) production, there are a number of ecosystem services such as pest control and soil conservation that certain types of agricultural practices also provide. These agricultural ecosystem services may enhance the performance and resilience of agroforestry ecosystems services, and thus, are sources of inputs and outputs in the production system. Conversely, agriculture also requires several crucial inputs for its production, some of which can be derived from agroforestry ecosystem services (Barbier, 2007). For instance, agroforestry has been observed to reduce fertilizer drainage and provide shade to climate sensitive crops (Lin et al., 2008). Therefore, ecosystem services provided by agroforestry and agriculture are interrelated (Dale and Polasky, 2007). It is important to note that there are some ecosystem services provided at the farm-level which are inseparable (Sauer and Wossink, 2013). Some agricultural and agroforestry ecosystem services may have monetary value to farmers due to

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the existence of parallel markets, while others may be difficult to quantify in monetary terms.

National policies on eco-agricultural practices in Eastern African countries (e.g. Vision 2030 for Kenya, Vision 2025 for Tanzania and the Poverty Eradication Action Plan for Uganda) are designed to ensure economic growth, poverty reduction and environment protection (Thomas et al., 2008). The Kenyan Forest Act (2005) stipulates that the management of all indigenous forest and trees should provide environmental services which, among others, include carbon sequestration. In parts of Kenya, there are *agroforestry PES schemes* that assist smallholder farmers in adopting conservation agriculture and quantifying the carbon they sequestrate through agroforestry. These *agroforestry PES schemes* often promote the use of indigenous trees that are neither invasive nor harmful to the environment for carbon capture and storage. One of such schemes in Kenya is The International Small Group Tree Planting Program (*henceforth TIST*). The carbon captured and stored by trees planted by TIST smallholders on their farmland are quantified and traded on the emission market using various standards and mechanism (TIST, 2016). These mechanisms, which include the Clean Development Mechanism (CDM), Climate, Community & Biodiversity Alliance (CCBA), Verified Carbon Standard (VCS) etc. results in payment for ecosystem services – *PES* either at the farm- or community level. *Agroforestry PES schemes* have been observed to have numerous (co-)benefits to smallholder farmers in rural Kenya e.g. financial inclusion (Benjamin, 2015; Benjamin et al., 2016).

A simple marginal cost analysis of agroforestry ecosystem services that neglects its production relationship with other agricultural outputs in a joint farm-level structure may be biased and misleading to policy makers. Sauer and Wossink (2013) argue that such a relationship can influence farmer's opportunity cost, directly impacting the design of a cost-effective conservation program. Furthermore, transaction costs determine both the likelihood of participation in *agroforestry PES schemes* and the marginal costs of ecosystem services. Thus, neglecting these factors may have far-reaching consequences with respect to an efficient policy design for PES schemes in developing countries esp. sub-Saharan African. We therefore propose an interdisciplinary approach by expanding economic models that takes ecological effects into consideration. This study is a static analysis of *agroforestry PES schemes* which focuses on the relationship between agroforestry supporting and regulating ecosystem services (e.g. soil fertility, carbon sequestration etc.) and agricultural output. It follows a similar approach outlined by Sauer and Wossink (2013) and Benjamin and Sauer (2016) using a 3rd order flexible Generalized-Leontief (GL) transformation function, capable of estimating multi-input-output production relationships, to investigate the interconnection between ecosystem services provision and agricultural production. Our approach allows for the joint (agriculture and ecosystem services) output structure at the farm level to be categorized into a complementary, supplementary and competitive relationship. Based on the estimated relationship, individual farmers are classified with respect to their prevailing production relationship. This allows the respective opportunity costs, and the cost effectiveness of the PES scheme to be ascertained. Such a quantitative assessment of the cost effectiveness of *agroforestry PES schemes* at the farm-level according to Wade et al. (2008) and Wunder (2007) is relevant for the success of such schemes.

Only few studies have compared a joint and separate ecosystem services and agricultural production structure (Polasky and Segerson, 2009). The analysis of the Entry Level Stewardship (ELS) in England suggest that farmers use options that best serve their purpose when presented with multiple options within an agri-environmental PES scheme but opportunity costs of resources use should be considered (Hodge and Reader, 2010). Furthermore, the study by Nelson et al. (2009) which analyses the trade-off between commodity production value and quantified ecosystem service in the U.S state of Oregon found that payment for carbon sequestration largely mitigates this trade-off. To the best of our knowledge, this is the first empirical analysis of marginal- and opportunity cost of agroforestry PES schemes that takes the relationship between agricultural and ecosystem services outputs, at smallholder farm-level, into consideration in Africa. Majority of the available literature on the opportunity cost of ecosystem services – Thacher et al. (1996), Newburn et al. (2005), and Pagiola et al. (2005) focus on regions outside Africa despite its relevance to policy makers in the region. The study by Quillerou et al. (2011) treated ecosystem services strictly as a competing output when investigating farm-level compensation.

The remainder of the paper is organized as follows: Section 2 outlines the conceptual framework which serves as a basis for the empirical analysis developed in Section 3. This is followed by the description of the data in Section 4 and the model estimation (Section 5). Subsequently, the results of the empirical analysis are discussed in Section 6, whereas Section 7 concludes the study by highlighting implications of the analysis with respect to a more efficient PES policy design.

2. Material and methods

There is evidence (Palm, 1995) that crop yields increase when trees are present on farmlands due to the nutrients trees provide to the intercropped plants. However the provision of this nutrient is conditional on a number of factors ranging from water availability, soil organic matter, temperature just to mention a few. Gillespie (1989) argue that certain factors, among others, nutrient diffusion rate, mobility/soil interaction and root diameter and their interrelationships determine below-ground competition in agroforestry mixed cropping.

Some experts argue that trees with vertical roots distribution similar to that of maize (*Zea mays* L.) in mixed cropping system are more likely to compete for nutrient and water (Gillespie, 1989). In Eastern Africa, maize is one of staple crops cultivated by a substantial number of smallholder farmers at any point in time while some of these farmers are increasingly adopting agroforestry (Sanchez et al., 1997). This is because farmers, especially those with land rights, would choose trees species that improve the quality of their fields and livelihoods (Benjamin et al., 2017). Thus, agroforestry soil nutrient replenishment can be considered a non-marketed ecosystem service to agriculture because it is produced alongside agricultural output and contributes to agricultural productivity. The carbon sequestrated via agroforestry that results in PES is a marketed ecosystem service.

All joint production between agricultural and (non)marketed ecosystem services output described above can be placed in a compatible product-product relationship (Wossink and Swinton, 2007). However, the true value and level of ecosystem services may differ considerably and are unlikely to be adequately estimated given the ecological and structural complexity (Sauer and Wossink, 2013). This study, similar to Sauer and Wossink (2013), put forth a conceptual framework which captures the effects of the product-product interaction in a joint production context.

Agroforestry PES schemes usually prescribe certain conditions which farmers have to fulfill before they can be admitted into such programs. These conditions may include the minimum number of trees required to be cultivated on each farmland, using farming practices that limits greenhouse gas (GHG) emission e.g. mulching and/or mandatory meeting attendance. These conditions set by *agroforestry PES schemes* is denoted as Z_0 in Fig. 1 while the constraints to farmers due to limited availability of resources e.g. farmland is denoted as Z_1.

The product-product relationship in a production process with multiple outputs can be competitive, complementary, or supplementary (see Wossink and Swinton, 2007) as illustrated in Fig. 1. A competitive relationship leads to a situation where agricultural and ecosystem services compete with each other. This implies that one product has to be decreased for the other to increase and is depicted as a declining concave production possibility frontier (PPF) in Fig. 1I. Conversely, in a complementary relationship – see Fig. 1II, both agriculture and ecosystem services output contribute to each other's growth up until a