

Anelise Rahmeier Seyffarth\*, Department of Economics, University of Oldenburg,  
Phone +49 441 798 44 45, E-mail: anelise.rahmeier.seyffarth@uni-oldenburg.de  
Emmanuel Asane-Otoo, Department of Economics, University of Oldenburg,  
Phone +49 441 798 26 54, E-mail: asane.otoo@uni-oldenburg.de

## Overview

Rapid land cover changes in Brazil have been observed in recent decades with significant trade-offs in land resources between cropland, pasture and natural ecosystems (Lepers et al 2005). The trade-off between agricultural land and forest has been exacerbated by the increasing prominence of energy and export crops (e.g. sugarcane and soybean) triggered by growing domestic and global markets, amongst others. The consequent effect is the huge increase in land area under sugarcane and soybean production due to the favorable rents associated with the production of these commodities. As a result, Brazil has evolved as a major global player in the sugarcane-based ethanol, sugar and soybeans markets (Flaskerud 2003 and Hausman 2012).

While Ethanol production is centered in the Southeast, the production of sugarcane has historically been centered in the Northeastern coastal regions and the rich agricultural lands in the Southeast and the South which has also been the main hub for soybean production. The concentration of production of these two important commodities in these regions thus, explains the pronounced land competition between these crops (Nassar et al 2008) with its consequent implications on deforestation especially in the “Legal Amazon”<sup>1</sup>. Given the limited availability of agricultural land in the traditional growing regions, it has been argued that sugarcane expansion rides on the back of displacing soybean acreage. Consequently, the rising demand for soybean also provides incentives for farmers to produce soybeans elsewhere, for instance in less fertile regions like the north, center-west (‘cerrado’) and into the Amazon where not only land prices are relatively lower but facilities for sugarcane-based ethanol production such as refineries are also rare (Hausman 2012) - limiting sugarcane production. This phenomenon has been debated as a potential driver of the Amazon’s “arc of deforestation” which has long been the world’s most active land-use frontier in terms of forest loss (FAO 2006; Morton et al 2006).

This paper contributes to the discussion on sugarcane-soybean-deforestation nexus with an empirical investigation into the possible indirect impacts of sugarcane acreage expansions in the main sugarcane producing regions on deforestation in the “Legal Amazon”. This indirect impact is envisaged to materialize through the displacement of soybean acreage in these regions leading to the conversion of forest or the replacement of pasture for soybean production in the “Legal Amazon”. The relevance of this issue hinges on the trade-off between the goal of emission reduction through sugarcane-based ethanol production and the erosion of carbon sinks, valuable ecosystems and an increase in emissions through conversion of forest area in the Amazon biome which approximately account for 22% of total net CO<sub>2</sub> emissions in Brazil (Tollefson 2013).

## Methods and results

We constructed a panel dataset for our empirical assessment using secondary data ranging from 1990 to 2009 for all of Brazilian 27 federative states. This dataset includes state specific data on population, on ethanol production (given in 1000m<sup>3</sup>), on the value of agricultural production (provided in R\$ - deflated to constant prices of the year 2000), on harvested area (provided in hectares) for sugarcane, soybeans, corn and all other perennial and annual crops as well as data on pasture land. Further we included satellite measures data on deforestation per year for the nine states in the “Legal Amazon”.

We specify a time-state fixed effect OLS model to investigate the impact of the share of harvested sugarcane acreage on the share of harvested soybean acreage<sup>2</sup> in the five main sugarcane producing states, namely São Paulo, Minas Gerais, Paraná, Goiás and Mato Grosso do Sul. We also apply a Two Stage Least Squares (2SLS) instrumental variable technique to control for potential problems of reverse causality. However, we draw our conclusions based on the OLS models because endogeneity tests show that the share of harvested sugarcane acreage can actually be treated as exogenous.

The negative sign of the estimated coefficient of sugarcane acreage variable suggests that as the share of land allocated to sugarcane increases in the main sugarcane producing states, land allocation to soybean in these

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\*Corresponding Author

<sup>1</sup> The Brazilian „Legal Amazon“ corresponds to about 60% of Brazilian territory and is the largest Brazilian socio-geographic division encompassing nine states in the Amazon Basin (Acre, Amapá, Amazonas, Pará, Rondônia, Roraima and Tocantins as well as parts of Mato Grosso and Maranhão).

<sup>2</sup> The shares of harvested sugarcane and soybeans acreage are computed as a percentage of total harvested area for all other agricultural commodities.

states decreases. The substitution of soybean with sugarcane points to possible steady displacement of soybean from these states to the Legal Amazon: a phenomenon which could have serious implications on deforestation. To address this issue we estimate time-state fixed effects regression models in first differences that enable us to investigate the direct effect of changes in soybean and pasture acreages as well as how changes in sugarcane acreages in the five south-central states indirectly influence deforestation in the Legal Amazon. Our estimates show that pasture plays a significant role in contributing to deforestation in the Amazon. This result is consistent with the findings in the existing literature (e.g. Andrade de Sá 2013 etc.) which find pasture expansion as the main driver of deforestation in the Amazon. Unlike other studies which downplay the direct role of soybean, we find significant impact of soybean on deforestation such that as soy acreage increases, deforestation in the Amazon also increases. In order to examine whether sugarcane expansion in the five south-central states affect deforestation decisions in the Legal Amazon, we include the lag of sugarcane acreage in the individual south-central states as well as their interaction with current soybean acreage in the Amazon.

The significant positive coefficients for sugarcane in the state of Goias and for the interaction term between sugarcane acreage in Goias and soybeans acreage in the Amazon are suggestive of the indirect effect of sugarcane acreage expansion on deforestation which appears to materialize through increases in soybean acreage in the Legal Amazon. We also find similar results in the case of the combined effect of sugarcane expansion in the state of São Paulo and soybean acreage increases in the Amazon. In contrast, we find negative significant effects for the coefficients related to the states of Minas Gerais and Mato Grosso do Sul. This result implies that increases in sugarcane production in these states rather lessen the deforestation pressure on the Amazon. This means that displaced soybeans in these states are rather going to the new agriculture frontier in rainforest borders where agricultural expansion has been occurring into the Cerrado and its tropical Savanna. This phenomenon might be related to the efforts to slow destruction of the Amazon with environmental protection laws. Moreover, additional institutional impediments such as the so-called soy moratorium - which imposes trade limitations on soybeans cultivated in areas in Amazon Biome deforested after July 2006 - might contribute to the expansion of most cropland into the Cerrado and not within the Amazon Forest.

## Conclusions

The assessment of the issue of indirect land-use change is essential for a better understanding of the sustainability of agricultural-based biofuels. This understanding is essential for a country like Brazil which plans to significantly increase production of both ethanol and biodiesel in the coming years but also has to commit to environmental targets. Moreover, the important question as to which factors are driving deforestation in the country is not yet fully clarified. This paper sheds some light on these issues by showing that expansions in the areas for sugarcane and soybeans are related to direct and indirect land-use changes and have potential effects on deforestation. Additionally, some of the results suggest that although institutional rules might be effective in reducing deforestation, they might be causing an undesirable side-effect with substantial biodiversity losses in the Cerrado and its rich tropical savanna. Further research will be needed to give policy makers a better foundation for decisions on biofuels and agricultural policies as well as on environment protection laws.

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