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A multi-scale analysis of transforming agricultural markets in the context of globalization:

implications for natural resources, food prices and rural poverty in Latin America

TESIS DOCTORAL

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Für Katherina Weischer

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Summary

The world is in a state of rapid transition. Ongoing globalization, population growth, rising living standards and increasing urbanization, accompanied by changing dietary patterns throughout the world, are increasing the demand for food. Together with more open trade regimes, this has triggered growing international agricultural trade during the last decade. For many Latin American countries, which are gifted with relative natural resource abundance, these trends have fueled rapid export growth of primary goods. In just 30 years, the Latin American agricultural market share has almost doubled from 10% in 1980 to 18% in 2010. These market developments have given rise to a debate around a number of crucial issues related to the role of agricultural trade for global food security, for the environment or for poverty reduction in developing countries.

This thesis uses an integrated framework to analyze a broad array of possible impacts related to transforming agricultural and rural markets in light of globalization, and in particular of increasing trade activity. Specifically, the following issues are approached: First, global food production will have to rise substantially by the year 2050 to meet effective demand of a nine billion people world population which poses major challenges to food production systems. Doing so without compromising environmental integrity in exporting regions is an even greater challenge. In this context, the thesis explores the effects of future global trade liberalization on food security indicators in different world regions and on a variety of environmental indicators at different scales in Latin America and the Caribbean, in due consideration of different future agricultural production practices. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) –a global dynamic partial equilibrium model of the agricultural sector developed by the International Food Policy Research Institute (IFPRI)– is applied to run different future production scenarios, and agricultural trade regimes out to 2050. Model results are linked to biophysical models, used to assess changes in water footprints

and water quality, as well as impacts on biodiversity and carbon stocks from land use change by 2050. Results indicate that further trade liberalization is crucial for improving food security globally, but that it would also lead to more environmental pressures in some regions across Latin America. Contrasting land expansion versus more intensified agriculture shows that productivity improvements are generally superior to agricultural land expansion, from an economic and environmental point of view. Most promising for achieving food security and environmental goals, in equal measure, is the sustainable intensification scenario. However, the analysis shows that there are trade-offs between environmental and food security goals for all agricultural development paths.

Second, in light of the recent food price crisis of 2007/08, the thesis looks at the impacts of increasing agricultural market integration on food price transmission from global to domestic markets in six Latin American countries, namely Argentina, Brazil, Chile, Colombia, Mexico and Peru. To identify possible cointegrating relationships between the domestic food consumer price indices and world food price levels, subject to different degrees of agricultural market integration in the six Latin American countries, a single equation error correction model is used. Results suggest that global agricultural market integration has led to different levels of price path-through in the studied countries. Especially in the short-run, transmission rates depend on the degree of trade openness, while in the long-run transmission rates are high, but largely independent of the country-specific trade regime. Hence, under world price shocks more trade openness brings with it more price instability in the short-term and the resulting persistence in the long-term. However, these findings do not necessarily verify the usefulness of trade policies, often applied by governments to buffer such price shocks. First, because there is a considerable risk of price volatility due to domestic supply shocks if self-sufficiency is promoted. Second, protectionism bears the risk of excluding a country from participating in beneficial high-value agricultural supply chains, thereby hampering economic development. Nevertheless, to reduce households' vulnerability to sudden and large increases of food prices, effective policies to buffer food price shocks should be put in place, but must be carefully planned with the required budget readily available.

Third, globalization affects the structure of an economy and, by different means, the distribution of income in a country. Peru serves as an example to dive deeper into questions related to changes in the income distribution in rural areas. Peru, a country being increasingly integrated into global food markets, experienced large drops in extreme rural poverty, but persistently high rates of moderate rural poverty and rural income inequality between 2004 and 2012. The thesis aims at disentangling the driving forces behind these dynamics by using a microsimulation model based on rural household income generation models. Results provide evidence that the main force behind poverty reduction was overall economic growth of the economy due to generally favorable macroeconomic market conditions. These growth effects benefited almost all rural sectors, and led to declines in extreme rural poverty, especially among potato and maize farmers. In part, these farmers probably benefited from policy changes towards more open trade regimes and the resulting higher producer prices in times of elevated global food price levels. However, the results also suggest that entry barriers existed for the poorer part of the population to participate in well-paid wage-employment outside of agriculture or in high-value crop production. This could be explained by a lack of sufficient access to important rural assets. For example, poor people's educational attainment was hardly better in 2012 than in 2004. Also land and labor endowments, especially of (poor) maize and potato growers, rather decreased than increased over time. This leads to the conclusion that there is still scope for policy action to facilitate access to these assets, which could contribute to the eradication of rural poverty.

The thesis concludes that agricultural trade can be one important means to provide a growing and richer world population with sufficient amounts of calories. To avoid adverse environmental effects and negative impacts for poor food consumers and producers, the focus should lie on agricultural productivity improvements, considering environmental limits and be socially inclusive. In this sense, it will be crucial to further develop technological solutions that guarantee resource-sparing agricultural production practices, and to remove entry barriers for small poor farmers to export markets which might allow for technological spill-over effects from high-value global agricultural supply chains.

Resumen

Vivimos una época en la que el mundo se transforma aceleradamente. La globalización está siguiendo un curso imparable, la población mundial así como la población urbana siguen creciendo, y en los países emergentes los ingresos promedios aumentan, resultando en un cambio también acelerado de las dietas y hábitos alimentarios. En conjunto esos factores están causando un aumento fundamental de la demanda de alimentos. Junto con la apertura de los mercados agrícolas, estos procesos han provocado un crecimiento del comercio internacional de alimentos durante la última década. Dado que muchos países de América Latina están dotados de abundancia de recursos naturales, estas tendencias han producido un crecimiento rápido de las exportaciones de bienes primarios desde América Latina al resto del mundo. En sólo 30 años la participación en el mercado agrícola de América Latina casi se ha duplicado, desde 10% en 1980 a 18% en 2010. Este aumento del comercio agrícola ha dado lugar a un debate sobre una serie de cuestiones cruciales relacionadas con los impactos del comercio en la seguridad alimentaria mundial, en el medio ambiente o en la reducción de la pobreza rural en países en desarrollo.

Esta tesis aplica un marco integrado para analizar varios impactos relacionados con la transformación de los mercados agrícolas y los mercados rurales debidos a la globalización y, en particular, al progresivo aumento del comercio internacional. En concreto, la tesis aborda los siguientes temas: En primer lugar, la producción mundial de alimentos tendrá que aumentar considerablemente para poder satisfacer la demanda de una población mundial de 9000 millones personas en 2050, lo cual plantea grandes desafíos sobre los sistemas de la producción de alimentos. Alcanzar este logro, sin comprometer la integridad del medio ambiente en regiones exportadoras, es un reto aún mayor. En este contexto, la tesis analiza los efectos de la liberalización del comercio mundial, considerando distintas tecnologías de producción agraria, sobre unos indicadores de seguridad alimentaria en diferentes regiones del mundo y sobre distintos indicadores ambientales, teniendo en

cuenta escalas diferentes en América Latina y el Caribe.

La tesis utiliza el modelo “International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)” – un modelo dinámico de equilibrio parcial del sector agrícola a escala global – para modelar la apertura de los mercados agrícolas así como diferentes escenarios de la producción hasta el año 2050. Los resultados del modelo están vinculados a modelos biofísicos para poder evaluar los cambios en la huella hídrica y la calidad del agua, así como para cuantificar los impactos del cambio en el uso del suelo sobre la biodiversidad y los stocks de carbono en 2050. Los resultados indican que la apertura de los mercados agrícolas es muy importante para mejorar la seguridad alimentaria a nivel mundial, sin embargo, produce también presiones ambientales indeseables en algunas regiones de América Latina. Contrastando dos escenarios que consideran distintas modos de producción, la expansión de la tierra agrícola frente a un escenario de la producción más intensiva, se demuestra que las mejoras de productividad son generalmente superiores a la expansión de las tierras agrícolas, desde un punto de vista económico e ambiental. En cambio, los escenarios de intensificación sostenible no sólo hacen posible una mayor producción de alimentos, sino que también generan menos impactos medioambientales que los otros escenarios futuros en todas sus dimensiones: biodiversidad, carbono, emisiones de nitratos y uso del agua. El análisis muestra que hay un “trade-off” entre el objetivo de alcanzar la sostenibilidad ambiental y el objetivo de la seguridad alimentaria, independiente del manejo agrícola en el futuro.

En segundo lugar, a la luz de la reciente crisis de los precios de alimentos en los años 2007/08, la tesis analiza los impactos de la apertura de los mercados agrícolas en la transmisión de precios de los alimentos en seis países de América Latina: Argentina, Brasil, Chile, Colombia, México y el Perú. Para identificar las posibles relaciones de cointegración entre los índices de precios al consumidor de alimentos y los índices de precios de agrarios internacionales, sujetos a diferentes grados de apertura de mercados agrícolas en los seis países de América Latina, se utiliza un modelo simple de corrección de error (single equation error correction). Los resultados indican que la integración global de los mercados agrícolas ha dado lugar a diferentes tasas de transmisión de precios en los países investigados. Sobre todo en el corto plazo, las tasas de transmisión dependen del grado de apertura comercial, mientras que en el largo plazo las tasas de transmisión son elevadas, pero en gran medida independientes del régimen de comercio. Por lo tanto, durante un período de shocks de precios mundiales una mayor apertura del comercio trae consigo más inestabilidad de los precios domésticos a corto plazo y la resultante persistencia en el largo plazo. Sin embargo, estos resultados no verifican necesariamente la utilidad de las políticas comerciales, aplicadas frecuentemente por los gobiernos para amortiguar los shocks de precios. Primero, porque existe un riesgo considerable de volatilidad de los precios debido a cambios bruscos de la oferta nacional si se promueve la autosuficiencia en el país; y segundo, la política de proteccionismo asume el riesgo de excluir el país de participar en las cadenas de suministro de alto valor del sector agrícola, y por lo tanto esa política podría obstaculizar el desarrollo económico. Sin embargo, es indispensable establecer políticas efectivas para reducir la vulnerabilidad de los hogares a los aumentos repentinos de precios de alimentos, lo cual requiere una planificación gubernamental precisa con el presupuesto requerido disponible.

En tercer lugar, la globalización afecta a la estructura de una economía y, por medios distintos, la distribución de los ingreso en un país. Perú sirve como ejemplo para investigar más profundamente las cuestiones relacionadas con los cambios en la distribución de los ingresos en zonas rurales. Perú, que es un país que está cada vez más integrado en los mercados mundiales, consiguió importantes descensos en la pobreza extrema en sus zonas rurales, pero a la vez adolece de alta incidencia de pobreza moderada y de desigualdad de los ingresos en zonas rural al menos durante el periodo comprendido entre 2004 y 2012. Esta parte de la tesis tiene como objetivo identificar las fuerzas impulsoras detrás de estas dinámicas en el Perú mediante el uso de un modelo de microsimulación basado en modelos de generación de ingresos aplicado a nivel los hogares rurales. Los resultados indican que la fuerza principal detrás de la reducción de la pobreza ha sido el crecimiento económico general de la economía, debido a las condiciones macroeconómicas favorables durante el periodo de estudio. Estos efectos de crecimiento beneficiaron a casi todos los sectores rurales, y dieron lugar a la disminución de la pobreza rural extrema, especialmente entre los agricultores de papas y de maíz. En parte, estos agricultores probablemente se beneficiaron de la apertura de los mercados agrícolas, que es lo que podría haber provocado un aumento de los precios al productor en tiempos de altos precios mundiales de los alimentos. Sin embargo, los resultados también sugieren que para una gran parte de la población más pobre existían barreras de entrada a la hora de poder participar en el empleo asalariado fuera de la agricultura o en la producción de cultivos de alto valor. Esto podría explicarse por la falta de acceso a unos activos importantes: por ejemplo, el nivel de educación de los pobres era apenas mejor en 2012 que en 2004; y también las dotaciones de tierra y de mano de obra, sobre todo de los productores pobres de maíz y patata, disminuyeron entre 2004 y 2012. Esto lleva a la conclusión de que aún hay margen para aplicar políticas para facilitar el acceso a estos activos, que podría contribuir a la erradicación de la pobreza rural.

La tesis concluye que el comercio agrícola puede ser un importante medio para abastecer una población mundial creciente y más rica con una cantidad suficiente de calorías. Para evitar adversos efectos ambientales e impactos negativos para los consumidores y de los productores pobres, el enfoque debe centrarse en las mejoras de la productividad agrícola, teniendo en cuenta los límites ambientales y ser socialmente inclusivo. En este sentido, será indispensable seguir desarrollando soluciones tecnológicas que garanticen prácticas de producción agrícola minimizando el uso de recursos naturales. Además, para los pequeños pobres agricultores será fundamental eliminar las barreras de entrada a los mercados de exportación que podría tener efectos indirectos favorables a través de la adopción de nuevas tecnologías alcanzables a través de mercados internacionales.

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Acronyms

ADF	Augmented Dickey-Fuller Test
ADL	Autoregressive distributed lag
AIC	Akaike information criterion
AKST	Agricultural Knowledge and Science and Technology
BAU	Business-as-usual
BWF	Blue water footprint
C	Carbon
CEIGRAM	Research Centre for the Management of Agricultural and Environmental Risks
CPI	Consumer price index
CSE	Consumer support estimates
DSSAT	Decision Support System for Agrotechnology Transfer
ECLAC	Economic Commission for Latin America and the Caribbean
ENAHO	Encuesta Nacional de Hogares
FAO	Food and Agriculture Organization of the United Nations
FGLS	Feasible generalized least squares
FPU	Food producing unit
GCM	Global climate model
GHG	Greenhouse gas
GIGA	German Institute of Global and Area Studies
GMM	Generalized methods of moments
GWF	Green water footprint
ha	Hectare

IDB	Inter-American Development Bank
IFPRI	International Food Policy Research Institute
Iid	Identical independently distributed
IMF	International Monetary Fund
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
INEI	Instituto Nacional de Estadística e Informática de Peru
LA	Latin America
LAC	Latin America & the Caribbean
M2	Money supply
MI	marketing margins
N	Nitrogen
NUE	Nutrient use efficiency
OLS	Ordinary least squares
PA	Precision agriculture
PEN	Peruvian Nuevo Sol (local currency)
PP	Phillips-Perron
PSE	Producer support estimates
R&D	Research and Development
SAR	Species-area relationships
SEECM	Single equation error correction model
SRES	Special Report on Emissions Scenarios
SWAT	Soil and Water Assessment Tool
TOP	Trade openness indicator
UPM	Technical University of Madrid
WSM	Water simulation model

Chapter 1

Introduction

1.1 Motivation

> *"It has been said that arguing against globalization is like arguing against the law of gravity. But that does not mean we should accept a law that allows only heavyweights to survive. On the contrary: we must make globalization an engine that lifts people out of hardship and misery, not a force that holds them down. We must build partnerships strong enough to make sure that the global market is embedded in broadly shared values and practices that reflect global needs, so that globalization can benefit all the world's people [and nature]."*
>
> Kofi Annan, 2006

The quote points to the inevitable transition of markets and societies due to globalization and the possible drawbacks that these transformations involve. The global population is expected to grow to about nine billion people by 2050 (United Nations Department of Economic and Social Affairs Population Devision, 2007), and for the first time more people live in cities than in rural areas, even nowadays (United Nations Department of Economic and Social Affairs Population Division, 2015). Emerging economies experience rising living standards which are accompanied by shifts towards more westernized diets. The consumption of meat and milk products, oils and sugars, and vegetables and fruits is increasing substantially, whereas growth of direct human consumption of roots and tubers and grains is either slowing or declining in per capita terms (Pradhan et al., 2013a,b, Flachsbarth et al., 2015). These trends are increasing the global demand for food. Together with more open agricultural markets, this has triggered growing international food trade during the last decade. Many countries increasingly rely on imports to ensure adequate food supplies to the people. A few are becoming food baskets of the world. This trend of increasing agricultural market integration has given rise to a debate around a number of crucial issues. First, hotspots can be created in the exporting countries that do not have the capacity or the political willingness to curtail powerful exporting sectors on the basis of environmental constraints. Second, the recent experience during the international food price spike of 2007/08 was a painful lesson to some of the poorer trading nations. And third, the benefits of globalization might not be equally shared among the rural society in developing countries. There is the concern that the poor might be excluded from the opportunities that globalization can generate. All these aspects are of major relevance because they challenge the prospects for development in much of the world. Despite continued urbanization, the rural population is still massive and agriculture is the core activity and main source of income for many people living in rural areas (Losch et al., 2012). Thus, the evolution of agricultural markets will shape the process of economic, social, and environmental change.

These issues highlight that the impacts attributable to globalizing agricultural markets are complex and encompass different domains at different scales. This thesis provides a multi-scale impact analysis – from global to local – considering different spheres. As part of globalization, special emphasis is given to global agricultural market integration. *Agricultural trade* itself is a global phenomenon, and thus requires to be analyzed at the global scale. *Environmental impacts* due to increasing production for export markets range from being global (e.g. greenhouse gas emissions) to being local (e.g. local water scarcity). On the other hand, adjustments of *food prices* related to higher degrees of market integration after a global price shock take place at the national level, while changes in *income inequality* and *poverty* require a research focus at the household level. The thesis focuses on Latin America (LA), a continent particularly interesting for the analysis of agriculture for various reasons. LA is the region with the greatest agricultural land and water availability per capita in the world. This abundance of environmental resources, together with reductions in trade barriers, has fueled rapid export growth of primary goods (UNEP, 2010, Dingemans and Ross, 2012, Flachsbarth and Garrido, 2014). In just 30 years, the Latin American agricultural market share has almost doubled from 10% in 1980 to 18% in 2010 (WTO, 2012). Another aspect making LA an interesting study area is the fact that it remains the most unequal region in the world, despite decreasing poverty rates in rural areas (Tsounta and Osueke, 2014).

The introductory chapter proceeds with a literature review, presents the research questions of this thesis, and then describes the research context and research period. Following on, this thesis then features three independent chapters, each contributing to the literature commented below. In particular, Chapter 2 focuses on the analysis of trade-offs between increased future food production, due to liberalized trade regimes and different future production paths, and environmental sustainability. Trade flows are analyzed at the global scale, while the environmental impacts are investigated for the whole continent of Latin America and the Caribbean (LAC). Chapter 3 looks at the impacts of increasing agricultural market integration on food price transmission in six LA countries, namely Argentina, Brazil, Chile, Colombia, Mexico and Peru. Countries which have shown remarkable growth of agricultural exports and imports. Furthermore, except Argentina and Chile, the remaining four still face significant, though decreasing rates of food insecurity among the poorest (Willaarts et al., 2014a). Results of both Chapter 2 and Chapter 3 are discussed in light of the challenges of global and regional food security. Chapter 4 disentangles the driving forces of rural income and poverty dynamics in Peru at the household level. Results are discussed considering structural changes at the global and local scale. The thesis concludes with a summary of key findings and some ideas for future research avenues.

1.2 State of the art

In recent years, evidence about globalization effects on agricultural and food markets has emerged as a main research topic for many disciplines. Research from different disciplines –for instance, Development Studies, Economics, Geography, Environmental Studies, Political Sciences, Anthropology, and Sociology– has looked at different angles of the phenomenon from a theoretical as well as empirical point of view. The literature varies according to both the drivers of change as well as the impacts of globalization. In the following section, I will review the major strands of this emergent literature that are of particular importance to this thesis. Since the following chapters mainly focus on trade and global agricultural market integration, as part of globalization, the literature review will be limited to this specific driver. A more concise and limited scope of the literature is reviewed in the beginning sections of Chapter 2, Chapter 3 and Chapter 4.

Agricultural trade and the environment

Over the last decades, the consequences of trade liberalization on the environment have been discussed intensively. There have been two different lines of thought ever since: the anti-globalization group opposes market liberalization, arguing that it translates into a progressive lowering of environmental and labor standards. By contrast, advocates of free trade argue that market integration policies generate growth, leading to higher average incomes, which finally increases environmental standards. These two different perceptions have been discussed from a theoretical point of view as well as empirically. Generally, there may be three broad categories of agricultural trade impacts on the environment: scale or size effects, structural effects, and technology effects (Copeland and Taylor, 2004, Verburg et al., 2009). Scale or size effects are understood as environmental consequences from an increased natural resource depletion due to increased agricultural production and enhanced consumption induced by trade. Structural effects refer to those trade impacts that alter the composition of the economy as a whole. Trade can either foster a high-tech and services-based economy or one based on the extraction of primary resources, like agriculture. Technical effects are closely related to the concept of the Environmental Kuznets curve, which postulates that with proceeding economic development and higher incomes, also environmental standards increase (Grossman and Krueger, 1991, IBRD - World Development Report, 1992). As trade expands and wealth increases, production processes are likely to be cleaner due to the use of better technologies and environmental best practices. The overall environmental impact of trade liberalization depends on the compound of all three effects (Emerson et al., 2008).

Theoretical background

Generally, in the theoretical literature on trade and the environment either policy differences or income differences across countries explain how market integration impacts the environment in different world regions. Some regions benefit, while others lose. One of the earlier theoretical papers was published by Copeland and Taylor (1994). These authors find that trade leads to increased resource extraction in the exporting nation, because trade increases total demand (scale effect). Since opening new markets is especially beneficial to the (usually poorer) primary good exporting country, environmental standards are likely to be further relaxed or not incorporated, which in turn leads to higher resource extraction.

Theoretical papers that mainly refer to structural effects are, for example, the pioneering work of Chichilnisky (1994) or the studies published by Brander and Taylor (1997) or Karp et al. (2001). They use a Heckscher-Ohlin framework and treat the environment as an input factor. They assume that under free trade the “global South”, which are usually developing countries, specializes in the production of polluting or resource intensive sectors. Following this reasoning, Chichilnisky (1994) concludes that more liberalized trade regimes lead to environmental degradation in poor countries due to the absence of strict environmental regulations. Brander and Taylor (1997) and Karp et al. (2001) show that the results of Chichilnisky (1994) change when the natural resource gets depleted, because resource scarcity will lead to higher prices of the environmental good.

This higher price would in turn lead to a loss in competitive advantage in the poor country, shifting the resource intensive production back to more developed countries. Since developed countries enforce stricter environmental policies, trade will be beneficial from an environmental point of view. Antweiler et al. (2001) on the other hand, state that environmental policies should be treated endogenously. They assume that with increasing wealth accumulation induced by trade, also environmental regulations get stricter. They postulate that with economic development induced by trade, there will be technical improvements and better environmental practices in place (technical effect). Therefore, in the long-run, opening markets for trade will be environmentally beneficial. This aspect is also mentioned in the theoretical paper of Copeland and Taylor (1994).

Empirical evidence

While there is sufficient empirical literature on this topic that looks at polluting industries, studies about impacts of market integration on environmental outcomes within the agricultural sector are scarcer. A recently published study has looked at increasingly integrated world food systems and its contribution to global food security, water security, and environmental sustainability (Willaarts et al., 2014a). A fundamental question addressed in this work is whether the expansion of trade could worsen the environmental impacts of the production areas. Some empirical papers have found a positive impact of trade on the environment (Anderson, 1992, Hoekstra and Mekonnen, 2012), whereas others concluded otherwise (Walkenhorst, 2006, Lenzen et al., 2012). Empirical studies that investigate interdependencies between trade and the environment usually look at specific environmental indicators. For example, Dalin et al. (2012), Suweis et al. (2013), Rulli et al. (2013) and Ercin and Hoekstra (2014) look at trade impacts on water resources using the concept of virtual water trade. Recent studies on land-use impacts have been conducted by van Meijl et al. (2006), Eickhout et al. (2007), Grau and Aide (2008), Rulli et al. (2013). Tilman et al. (2011), Schmitz et al. (2012) and Willaarts et al. (2014a) consider C-sequestration and biodiversity loss due to increased trade-induced land-use change. Beyond the trade and environment nexus, different agricultural practices with their environmental effects have been discussed. The role of closing yield gaps and sustainable intensification in order to meet future food demand at lower environmental cost was analyzed by Finger (2011), Pretty et al. (2011), Mueller et al. (2012). Liu et al. (2010) and Bouwman et al. (2013) addressed issues related to nitrogen emissions to water environments resulting from different agricultural management practices and increased agricultural production.

Different outcomes of these studies point to the fact that impacts on the environment by agricultural trade vary depending on the environmental indicator under investigation as well as the agricultural practices applied by the farmer. So far, there is a lack of understanding about the environmental trade-offs that increasing trade activity can cause on different environmental indicators at different scales. Also, there is a literature gap when it comes to evaluating the trade-environment nexus, taking into account different agricultural management practices. Commonly, research papers focus on just one environmental indicator, like carbon sequestration, water scarcity or water pollution. But as a whole the literature appears to draw conflicting conclusions: trade can be good for one or detrimental to other indicator. Furthermore, most studies are ex-post analyses using econometric techniques, and the few studies that predict future trends, do not consider different possible future production pathways. Therefore, the thesis explores the effects of future global trade liberalization on different environmental indicators at different scales in LAC, in due consideration of different future agricultural production practices.

Agricultural trade and food security

Food security is defined as a state "...when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary need and food preferences for an active and healthy life" (FAO, 1996). According to this definition, food security encompasses four "pillars" and two temporal dimensions. The four pillars include: food availability, which refers to sufficient food supply, and food access which means the ability of people to obtain food when it is available. As both availability and access must be stable, the third pillar – stability – refers to ensuring adequate food at all times, while the fourth pillar – utilization – incorporates food safety and nutritional value. The temporal dimensions normally refer to food insecurity which can be chronic, resulting from a persistent shortage in supply or a systemic weakness that limits individuals' ability to access food, or transitory, arising because of a crisis. Recent examples of food crises are the global food price spikes of 2007/2008 and 2011, which affected millions of poor people in developing countries (Hoyos and Medvedev, 2011, McCorriston, 2012). Both chronic as well as transitory food insecurity need to be addressed at the same time, because individuals and communities facing chronic food insecurity lack safety nets and are highly vulnerable to transitory problems. On the other hand, an inappropriate response to a crisis may weaken the base for long-term food security by weakening local markets or creating dependencies (for details, see Staatz et al. (1990), Tweeten (1999), Barrett (2002), Nouve. (2004), FAO (2011b)).

Increasing agricultural trade can affect all four pillars of food security by different means. First of all, removing market distortions would probably stimulate global food production, especially in developing countries (Anderson and Martin, 2005, Godfray et al., 2010a). Globally, this would lead to higher food availability, not only impacting the first pillar of food security in a positive way, but also the second pillar, because, ceteris paribus, higher supply leads to lower prices. These assumptions are based on traditional trade theory. According to Ricardian's neoclassical theory of comparative advantages, trade flows are directed by differences in productivity and opportunity costs of production of different countries. A logical consequence of increasing trade, therefore, are global efficiency gains being accompanied by lower prices (Panagariya, 2002). The Heckscher-Ohlin-theorem is based on the assumption of different factor endowments to explain trade patterns. When trade begins, each country exports commodities that use the relatively abundant factor and imports those that use scarce factors more intensively. Therefore, agricultural production is likely to shift to developing countries where labor, and sometimes land and water, are abundant production factors (Willaarts et al., 2014a). Higher global food supplies are especially relevant with a view to future socioeconomic mega-trends and possible threats from climate change. Population is expected to grow to about nine billion people in 2050 and increasing urbanization along with income growth has induced dietary changes towards higher global meat consumption (Bruinsma, 2009, OECD, 2009, Godfray et al., 2010a). Global trade will be necessary to balance future supply and demand across regions, because the expansion of food production and the growth of population will occur at different rates in different geographic regions (Godfray et al., 2010a, Hoekstra and Mekonnen, 2012, Fader et al., 2013).

However, despite the described benefits at a global scale, a more disaggregate look at the phenomenon will unfold that there will be winners and losers from trade. Importing and exporting developing countries are affected differently by engaging in agricultural trade. Following the "Law of One Price", food exports increase domestic prices but are a source of revenue and economic growth, whereas imports may reduce food prices, but may harm poor rural households (Panagariya, 2002). Also within exporting countries, it is questionable whether the poor, that are most affected by food insecurity, are those that actually gain from trade. Some authors claim that agricultural trade has a negative impact on food availability in exporting nations, because staple crop production might be replaced by the production of cash crops (Austin et al., 2014, Bertelli and Macours, 2014). Others are concerned that small farmers could be excluded from global agri-food chains (Wollni and Zeller, 2007). By contrast, other authors state that if trade generates economic growth, it is likely that the rural poor will benefit Dollar and Kraay (2004), Pingali (2007).

The third pillar of food security is also affected by trade. Regional supply shocks (such as conflict, epidemics, droughts, or floods that are likely to increase in frequency as climate change progresses) can be buffered by substituting the temporarily lacking national supply by food imports. Furthermore, well-functioning markets can transmit price signals, which would allow changes in demand to be met by supply. When demand grows more rapidly than supply, producers react, increasing production in response to price signals and this increased production, in turn, helps to stabilize prices. By transmitting information in this way, trade can help to reduce price volatility and stabilize food access (Hebebrand et al., 2010). Conversely, a highly integrated food system may lead to a stronger participation in global shocks. Countries engaging in food trade would likely be more affected by global price shocks (Headey and Fan, 2008, Hoyos and Medvedev, 2011, Flachsbarth and Garrido, 2014).

The fourth pillar of food security is also affected by globalizing agricultural markets. The food system transformation is driven by changing consumer preferences, yet consumption patterns themselves may also be influenced by structural changes in food supply chains. Globalization and trade triggered a rapid change in dietary patterns towards foods with higher fat, caloric, and sugar content, entailing a significant rise in obesity (Phillips, 2006, Roemling and Qaim, 2012). On the other hand, the rise of supermarkets and changing consumer preferences towards high value products also demand higher quality food production in developing countries (Swinnen, 2007).

The discussion makes clear that the interlinkages between globalization, trade and food security are complex and can take place at many different scales. Equally diverse as the different aspects of the trade-food security nexus are the results of different authors. Thus, there is still scope for further research on this topic at different scales and different spheres of food security. Particularly, in light of the imminent challenges of feeding a growing and richer world population without causing further damage on the environment, the role of trade towards achieving this goal needs to be further investigated. Since the main attempt of this thesis cannot possibly cover such a broad range of trade aspects of food security, I focus on a few processes in the following chapters. Chapter 2 investigates the effects of trade liberalization on global food security in a very aggregate way, taking into account the mentioned future socio-economic mega-trends as well as climate change, and considering different future production paths. Chapter 3 discusses food prices in light of trade liberalization and the recent global food price crisis. Thus, it touches the aspect of food access due to deeper agricultural market integration. However, an isolated look at food price movements does not allow any final conclusions about food security outcomes. Chapter 4 is related to food security, because it analyzes the drivers of rural poverty and income inequality dynamics. Since poverty is one main cause of preventing sufficient food access, the chapter indirectly contributes to the food security literature, however, without specifically mentioning it as a major outcome.

Impacts of agricultural trade on food price transmission

After the global food price crisis of 2007/08, scientific interest arose about the causes and consequences of agricultural price spikes and food price volatility. Also, the domestic and international media picked up the issue, raising concerns about the adverse impacts on poverty and food security of high and volatile food prices in developing countries. According to FAO (2009b) and FAO (2011a) the agricultural commodity price spike of 2008 had an immediate impact on the poorest and most vulnerable. Between 2004 and 2009, globally, undernourishment increased by around 16%, from 872 million to 1,017 million people. While food commodity prices dropped after 2008, they spiked again during 2011/12. The more recent literature suggests that after this turbulent time, real global food prices are predicted to decline from their 2014 levels due to strong supply responses, but that they will remain above their pre-2007 levels. Despite the predicted falling trend of average real commodity prices, price spikes are still likely to happen over the next decade, though (OECD/Food and Agriculture Organization of the United Nations, 2015). Price volatility can be explained by a number of different supply and demand factors: proceeding climate change might increase the frequency of adverse weather events, which will generally lead to higher price volatility (Godfray et al., 2010b). Also, persistently low investments in agriculture, exacerbated by land diversion for non-agricultural purposes, will likely drive prices further upwards (Trostle, 2008). Another factor is the strong dependence of agricultural prices on oil prices, with oil prices being notoriously volatile. Movements of oil prices and agricultural prices are closely linked, because fossil fuel is used as an input in crop production. Furthermore, some agricultural products are used as raw materials in biofuel production, creating a link to fossil prices (Brümmer et al., 2013). On the demand side, global population growth, continued strong demand from emerging economies, and biofuel policies are long-run driving factors (FAO et al., 2011). Furthermore, low stocks or the lack of sufficient information about them can drive food price volatility (Brümmer et al., 2013). Also, the macroeconomic market environment has been identified as being very important in explaining food price movements. First, exchange rate movements lead to food price volatility, because agricultural commodities are usually traded in US Dollars (Gilbert, 2010, Baquedano and Liefert, 2014). Second, increased foreign exchange rate holdings by large countries like China can put additional pressure on the demand side (Mueller et al., 2011). Third, excess liquidity resulting from low interest rates as well as rebalancing portfolios towards commodity investments can aggravate food commodity price spikes. Fourth, speculations were widely discussed as a driving force of price spikes (Brümmer et al., 2013). Fifth, monetary expansion policies can lead to higher inflation rates, including food price inflation(Gilbert, 2010). And last, trade policy changes imposed by major agricultural trading nations can induce global supply shortages with the effect of even higher commodity prices during volatile periods (Headey and Fan, 2008).

Much of the discussion of recent developments of food prices has focused on world prices, yet the prices that matter to consumers and farmers are domestic prices. It has been argued that food price volatility imposes risks for the economy as a whole, especially in developing countries. Prices are not only relevant for the purchasing power of consumers, but also for food producers and governments. Crop production can be relevant for employment and overall economic growth, particularly when the crop represents a large proportion of a country's GDP (Bidarkota and Crucini, 2000, Dawe, 2001, Timmer and Dawe, 2007). Moreover, for governments, unexpected variations in export prices can distort budgetary planning and threaten to accomplish debt targets (Guillaume et al., 2014). Carvalho et al. (2010) worry that high price volatility could lead to an inefficient allocation of resources affecting producers and consumers. In the short-term price volatility might trigger an overproduction due to false signals of temporarily high prices, but most likely it would deter investment in capital and use of inputs due to uncertain market conditions, curtailing the supply. According to Gilbert and Morgan (2010) these factors hinder overall economic growth. Thus, a better understanding of how global food markets and domestic food prices interact is necessary for policymakers to protect the most vulnerable. In other words, it is crucial to quantify the degree of horizontal price transmission, from global food markets to domestic food markets. Horizontal price transmission is defined as the co-movement of prices between spatially differentiated markets at the same stage of the supply chain (Esposti and Listorti, 2013).[1]

Theoretical background

The key underlying theoretical idea of horizontal price transmission is the concept of spatial arbitrage and the consequent "Law of One Price". The theory implies that the difference between prices of equal products in different market places will never exceed transaction costs, otherwise arbitrageurs would immediately exploit profiting opportunities (Fackler and Goodwin, 2001). This results in the "Law of One Price", stating that homogeneous goods will have a unique price, when expressed in the same currency, net of transaction costs (Listorti and Esposti, 2012). In other words, domestic food price changes attributable to changes in global markets can be caused by two different transmissions channels: first, by changes in global food price levels denoted in foreign currency, and second, by exchange rate changes. Both a depreciation of the currency and an increase in the global food price level are expected to lead to an increase in the domestic price level. Thus, in theory, for tradable food items, the domestic market price should follow the world market price.

Empirical evidence

Empirical studies in this field usually aim at assessing to which degree the "Law of One Price" holds true. In fact, the universal validity of this theory is questionable, as its assumptions are unlikely to hold in reality. According to Listorti and Esposti (2012), one critical assumption of the theory is the static concept, because economic processes should rather be treated in a dynamic way, allowing prices to temporarily deviate from equilibria. Moreover, countries are not affected evenly by global food price shocks due to

[1] Horizontal price transmission can also refer to co-movements of prices between agricultural and non-agricultural commodities, however, we focus on agricultural markets.

several factors. Different economies show different macroeconomic market environments and have different domestic and border regulation policies. Market power, product heterogeneity and perishability, exchange rate risks, imperfect flow of information and price expectations also prevent complete price transmission from global to domestic markets (Dawe, 2008, Anderson and Nelgen, 2012, Evenett and Jenny, 2012, Listorti and Esposti, 2012, Garcia-German et al., 2014).

While the literature suggests that the relationship between world and domestic agricultural prices may be weak in normal times due to the above mentioned factors, price transmission was stronger during the global food crisis in 2008 (Minot, 2011, McCorriston, 2012). Many studies focus on Africa finding mostly high transmission rates (Cudjoe et al., 2010, Baquedano et al., 2011, Minot, 2011). Other studies analyze Asian agricultural markets showing lower transmission rates in some countries where border protection was higher, like China (Dawe, 2008, Robles, 2011). On the other hand, McCorriston (2012) observed particularly high food price inflation rates for most Asian countries during that time. Findings for LA where also mixed, where Robles and Torero (2010) found strong transmission rates, for example, in Guatemala, Honduras, Nicaragua and Peru, while de Janvry and Sadoulet (2010) and Robles (2011) report quite low transmission rates for different countries in Central America.

According to Timmer (2010), FAO et al. (2011) and García-Germán et al. (2013), the extent of horizontal price transmission to domestic food markets after a global price shock is most fundamentally determined by the degree of global market integration and trade policy. Trade policies can be broadly categorized into three groups: first, controls of trade quantities; second, export taxes; and third, import tariffs. During the food crisis of 2007/08, many governments adopted or strengthened trade policy measures in order to stabilize domestic food prices (Tangermann, 2011, Kim, 2011). Due to the importance of staple crop production for national food security and welfare of the rural population, policy makers shifted their attention to managing price instability of major grains (Demeke et al., 2012). Governments recognized export quantity restrictions or export taxes as options for price stabilization. Governmental policies of China and

India were targeted at stabilizing domestic prices of some grains during 2007/08 by imposing strict export quotas (Fang, 2010, Gulati and Dutta, 2010). One prominent LA-example of food price intervention by applying trade policies is Argentina. The country had raised export taxes, for example for wheat, for many years. When global prices spiked in 2007/08, Argentina increased export taxes even more, and additionally imposed quantitative controls of wheat trade in 2007 (Nogués, 2011, García-Germán et al., 2013). While these controls likely reduced the magnitude of a domestic wheat (and bread) price spike, it aggravated the situation on world markets, because global supply was shortened even more (Tadesse et al., 2014).

Border protection does not always deliver the desired effect, though. The Argentinian case illustrates that controls on trade volumes can serve to stabilize domestic prices, however, export taxes are only effective if the tax is adjusted in response to changing world prices. Imposing import tariffs will usually not avoid food price transmission. If tariffs are low, the margin for reduction is limited. But if tariffs are high, large decreases might have fiscal consequences (Timmer and Dawe, 2007, García-Germán et al., 2013). Furthermore, experience from some African countries has shown that even trade volume controls are not always effective in stabilizing food prices. Poorly designed governmental interventions, like subsidized imports due to domestic shortfalls in Zambia, impeded private investments in the food sector which in turn exacerbated food price volatility (Chapoto and Jayne, 2009).

Even when trade policy interventions are effective to buffer global food price shocks, there are costs associated with such policies. To name a few: trade policy interventions result in domestic efficiency losses in the food production market (Valdés, 2000), and revenues will be lower if exports are restricted compared to open markets (Sharma, 2011). Moreover, a pure policy of self-sufficiency could worsen price volatility due to domestic supply shocks (Abbott, 2012). If agricultural trade is not available to smooth domestic supply disturbances during times of bad harvests, it is likely that domestic food prices will be very volatile. In summary, trade policy targeting at stabilizing domestic food prices potentially reduces the exposure to global food commodity price shocks, however, it simultaneously increases the vulnerability to domestic production shocks.

Since stable food prices are a relevant political issue, especially in developing countries where food makes up a large share of the consumption basket, it is common practice of policymakers to take action by imposing border protection. These interventions, however, come at the above mentioned costs affecting domestic and global agricultural markets. It is thus crucial to better understand the effects of trade openness on food price transmission rates. According to Listorti and Esposti (2012) modeling the impact of policy intervention on price transmission, especially in the light of recent developments, has become a major challenge for empirical analyses. Many studies conclude that trade policies and the degree of market integration matter for price transmission rates, but the findings are grounded only on comparing estimation results of different countries that show different degrees of market integration. There is a knowledge gap, though, in actually quantifying to which extent pass-through rates depend on agricultural trade openness. This knowledge is crucial, though, in order to effectively plan safety nets for times of global price shocks, if developing countries are not to fall back into protectionism. Chapter 3 of this thesis contributes to the price transmission literature by filling this gap. Additionally, other macroeconomic policies that can buffer price shocks are investigated in six LA countries, namely Argentina, Brazil, Chile, Mexico, Peru and Colombia. Since these countries are very urbanized societies with still high levels of income inequality (Cohen and Garrett, 2009, Willaarts et al., 2014a), increasing food prices can be particularly devastating from a food security perspective. Also, these countries are progressively integrated into global food markets. Clearly, in times of rising global food prices, this makes the region very suitable for further investigation of food price transmission and its determinants, with a special focus on trade.

Agricultural trade and poverty reduction

The question of whether globalization and trade leads to a decline or rise in poverty and income inequality in developing countries has been one of the most debated issues. Several authors claim that (agricultural) trade is beneficial for the poor (e.g. Dollar and

Kraay, 2004, Bhagwati, 2007, Perry and Olarreaga, 2007, Salvatore, 2007, OECD, 2013, WTO, 2014), while others worry that the poor might be excluded from the gains of trade (e.g. Attanasio et al., 2004, Bardhan et al., 2006, Ravallion, 2006, Pingali, 2007). It is beyond dispute, however, that trade-poverty linkages are complex and diverse. They can be divided into three important pathways discussed below.

Trade induced growth

Economic theory explains why trade liberalization is expected to stimulate growth. Open trade gives access to new markets and to input factors and capital goods; it fosters technological innovation, which increased production, scale economies and competitiveness. The economy specializes in sectors in which it has comparative advantages, thereby fostering economic growth (Duncan and Quang, 2002, Edwards, 1993). The theory of long-run economic growth is based on the neoclassical model based on Solow (1963). In this framework, market distortions affect the allocation of resources in the economy as a whole leading to productivity losses. Open trade regimes would allow for a more efficient allocation of resources which would raise the steady-state level of income and the growth rate. This is especially important in the agricultural sector, because in developing countries a large portion of the poor live in rural areas. If more open agricultural trade generates growth in this sector, it is likely that the rural poor will benefit (Cain et al., 2010, Cervantes-Godoy and Dewbre, 2010, Bakhshoodeh and Zibaei, 2007). However average GDP growth does not necessarily lead to poverty reduction, because it might be offset by simultaneous worsening in income distributions. But, when growth of GDP per capita increases the mean of the income distribution, and if inequality of the distribution does not change, absolute poverty declines. Alternatively, poverty can decline if mean income is stable, but the dispersion of the distribution declines. This means that even though trade induced growth can worsen inequality, this effect has to be strong enough if it is to increase poverty (Giordano and Li, 2012, Sala-i-Martin, 2007).

Despite this theoretical accordance that more open trade should lead to economic growth and thus poverty reduction, empirical findings are ambiguous. A microeconomic approach is used by Ravallion (2006) who conducts case studies in China and Morocco which indicate considerable heterogeneity in the welfare impacts of trade reforms, with both winners and losers among the poor. A microeconomic approach is also used by Castilho et al. (2012) who studies the impact of globalization on household income inequality and poverty using micro-data across Brazilian states from 1987 to 2005. Results suggest that trade liberalization leads to an increase in poverty and inequality in urban areas, but may be linked to reductions in inequality and possibly poverty in rural areas. Edwards (1998) analyzes comparative data for 93 countries, among them 10 LAC, and finds that trade openness favors growth and that capital accumulation plays an important role in reducing poverty. Dollar (2005) counters that those countries being increasingly integrated into world markets are those where poverty has increased most since the 1980s.

Prices, income and consumption patterns

Integrating agricultural markets into the world economy affects agricultural prices and relative prices in an economy. Price changes affect real income of poor households, since agriculture represents their main source of income and food their main consumption expenditure. To which degree price changes transmit to poor households' income depends however on different side-specific factors. Besides market access and the households' ability to benefit from the new opportunities arising from trade, it depends on the capacity to adjust to price variations (Hassine et al., 2010). If supply and demand of the poor producers and consumers cannot be adjusted, the new price situation rather harms than benefits, at least in the short run.

A number of studies have illustrated the importance of relative price shifts after liberalizing markets. Porto (2006) analyzes the impacts of Mercosur for Argentina and finds a pro-rich shift in relative prices. While price decreases of agricultural goods benefit poor urban households, rural farm households may be hurt by such a price effect. Goldberg and Pavcnik (2005) conclude that the Colombian trade reforms may have reduced poverty through lower prices of goods consumed primarily by the poor. Taylor et al.

(2010) confirm positive net rural welfare effects of agricultural trade liberalization using the example of the Central American Free Trade Agreement (CAFTA). They use a disaggregated rural economy-wide model nesting a series of agricultural household models and find that lower trade barriers lead to a reduction nominal incomes for nearly all rural household groups in El Salvador, Guatemala, Honduras and Nicaragua. However, they also lower food expenditures substantially leading to a positive net effect on rural households' welfare.

Wages and employment

Another mechanism by which trade can affect the income of the poor is through its impact on wages and employment. Trade can affect relative wages through Stolper-Samuelson effects (Stolper and Samuelson, 1941). According to the Stolper-Samuelson-theorem in the Heckscher-Ohlin trade theory, countries specialize in the production of those goods in which they have a comparative advantage. With labor as a non-mobile factors, developing countries will specialize in the production of low-skilled labor-intensive products which boosts demand for low-skilled labor and in turn leads to higher wages in these sectors and finally poverty reduction. Despite the predicted overall gains of these effects, trade reforms may generate winners and losers. While jobs are created in some sectors, employment opportunities diminish in other sectors. In developing countries, some people might have to return to subsistence agriculture if they cannot participate in high-value agricultural export sectors. The resulting occupational shifts can have relevant welfare implications and may be related to large changes in individual labor productivity and thus labor earnings. Liberalizing markets can also alter wages by trade-induced technological change. This will raise the demand for high-skilled workers rather than for those with low qualifications (see e.g. Nelson and Phelps, 1966, Griliches, 1969).

There are quite a few empirical studies on labor market effects of trade reforms that analyze Stolper-Samuelson effects. Most of them, however, focus on the manufacturing sector and ignore agricultural trade liberalization. One exception is Bussolo et al. (2011)

who examine in a global CGE-analysis the effects of agricultural trade liberalization on welfare. They find that in 29 out of 40 countries unskilled agriculture wages decline. Since unskilled workers in agriculture tend to be the poorest part of the population, these results suggest that income inequality may be intensifying in many regions. However, the losses and gains in agricultural wages exhibit strong regional differences: real wages of unskilled farmers rise in LA, the Middle East, and East Asia and the Pacific, while they decline in African regions. This shows that the Stolper-Samuelson effects should operate in favor of the poor in LA. However, in the LA context, this story may be too simple. With China's entry into the global economy and due to LA's abundant natural resources, the continent's comparative advantage is rather in the production of natural resource intensive goods than in the production of unskilled-labor-intensive products (Wood, 1997). According to Goldberg and Pavcnik (2004), this argument explains part of the increase in wage inequalities observed in post-liberalization periods in LA. Another empirical study by Harrison and Hanson (1999) investigated the relationship between trade reform and rising wage inequality, focusing on the 1985 Mexican trade reform, while Attanasio et al. (2004) analyzed trade reforms and wage inequality in Colombia. In both cases the initial structure of tariffs protected unskilled workers, and thus trade liberalization reduced their wages. On the other hand Porto (2006) shows a pro-poor distributional effect that he attributes to the Stolper-Samuelson theorem after Argentina's Mercosur entry. Another source of wage inequality is skill-biased technological change, which might be in part explained by trade-liberalization. In this context, the trade literature stresses the role of firm entry and exit as well as learning effects due to export participation to explain aggregate productivity gains. For example, Justino et al. (2008) and McCaig (2011) find poverty in Vietnam decreased due to trade-induced employment increases leading to higher incomes.

The vast amount of literature shows that the trade-poverty nexus has already been looked at from many different angles. Methodologically, two main approaches have been used to assess the poverty and distributional implications of trade. Mainly Computable General Equilibrium (CGE) models are used to assess welfare implications of market liberalization (e.g. Winters et al., 2004, Anderson et al., 2010). Econometric models on the basis of micro data have only been applied more recently (e.g. Porto, 2006, Nicita, 2009). Generally, results show that trade-induced poverty changes are complex and in many cases theory and empirical findings do not coincide. Also, results vary among empirical studies as they are very context specific. The thesis does not attempt to add another study that tries measure the direct effects from trade liberalization to poverty changes through one of the described channels. Instead, Chapter 4 of this thesis wants to disentangle the various drivers of rural poverty and income inequality changes, using a holistic approach. The focus lies on Peru, a country that has experienced significant GDP growth in the last decade. The study takes into account structural changes in the agricultural sector and rural non-farm sectors as well as occupational shifts between sectors. Some of the driving forces behind the dynamic changes in the income distribution in rural Peru might be related to increasing agricultural trade, while others might not. Of course, the scientific literature has already looked at possible causes of rural development beyond the trade-poverty nexus. However, most of these studies investigate one specific phenomenon and its contribution to poverty changes (e.g. Escobal, 2001, Escobal and Torero, 2005, Chong et al., 2009, Jonasson, 2009, Hinojosa, 2011). But there seems to be a lack of studies that provide deeper insights into poverty dynamics, taking into account different drivers of change. Thus, the thesis moves beyond the examined outcomes of the existing trade and development literature by providing a more holistic view of rural income changes. Changing macroeconomic market conditions, occupational shifts between sectors, adapting agricultural production towards more export oriented products, changes in price levels or productivities, or altering characteristics of the rural population could all drive rural income growth and the related distributional effects in rural societies. Disentangling some of the effects, without claiming to be able to make true causal inferences from the analysis, still helps to design effective trade and development policies. For example, if occupational shifts into important agricultural export sectors show positive rural income effects, market liberalization and policies that reduce entry barriers into the participation of global agricultural supply chains can help to reduce rural poverty and income inequality.

1.3 Research questions and structure of the thesis

The thesis centers on questions related to the ongoing globalization of agricultural markets with its environmental and socio-economic impacts at different scales. I identified several gaps in the literature that this thesis seeks to fill.

First, in light of the challenges of the coming decades to feed a growing global population with less use of natural resources, there is a strong demand for holistic approaches. While there are many studies that either focus on the role of trade for global and regional food security or on environmental impacts of trade in different regions, there are only few that discuss the trade-offs between these possibly conflicting goals. Moreover, the discussion of how different future production pathways can alter trade impacts for global food security and environmental outcomes is largely missing. Also, there is a lack of discussion about the fact that the trade-food-security-environment nexus occurs at different scales. While trade is a global phenomenon, food security and environmental impacts are multiscale phenomenons. Therefore, Chapter 2 asks:

1.1. *What are the trade-offs between improving global food security via further trade liberalization and environmental outcomes in large agricultural exporting regions like LA?*

1.2. *How do different agricultural production pathways change future outcomes of trade for food production, global food security, and environmental sustainability and natural resource use in LA?*

1.3. *Where are future agricultural trade-induced environmental hotspots in LA and at what scale do environmental changes show their impacts?*

Chapter 2 addresses these questions by applying the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) –a global dynamic partial equilibrium model developed by the International Food Policy Research Institute (IFPRI)– to run different production pathways scenarios, considering more liberal agricultural markets. As an advantage to many other economic models, IMPACT is coupled to a biophysical crop model as well as a hydrological model that allows to treat future water demand and supply in an endogenous way. Complementarily, we couple IMPACT model results to the Soil and Water Assessment Tool (SWAT) to quantify the emissions of nitrogen-based pollutants related to different future production paths. Furthermore, IMPACT model output provides information on future land conversion, used for the assessment of biodiversity and carbon sequestration losses. This holistic approach does not only allow to compare environmental outcomes of different production systems, but also takes into account a complex economic system with supply and demand side feedback-effects.

Second, the ongoing trend of globalizing agricultural markets in conjunction with recent experience of global food price spikes demands for a better understanding of how world market integration, global food price shocks and domestic price volatility are intertwined. As a reaction to global food price shocks, policy makers tend to protect their borders to smooth food price transmission. This has its justification, because the immediate effects of increasing food prices can be detrimental for poverty and food security. However, given that the effectiveness of such trade policies is unclear, and that returning to a policy of self-sufficiency also entails food price risks and can hamper economic growth, more research is needed about how agricultural market integration actually affects domestic food price volatility. This could help to promote open markets to policy makers, especially if other domestic macroeconomic variables can be identified to buffer price shocks. On these grounds, Chapter 3 asks:

2.1. *How do different degrees of agricultural market integration affect horizontal food price transmission rates in LA?*

2.2. *How did these different food price transmission rates affect large LA agricultural trading nations after the 2008-price shock?*

2.3. *Did other macroeconomic factors moderate or reinforce price transmission rates?*

Chapter 3 addresses these questions by using a single equation error correction model (SEECM) to identify possible cointegrating relationships between the domestic food consumer price indices (CPI) and a set of trade related and domestic variables in six LA-trading nations (Argentina, Brazil, Chile, Colombia, Mexico and Peru). Special emphasis is given to the estimation of the interaction term between the global food price index and a trade openness indicator. Estimating the marginal effect of world price changes on domestic food CPI, depending on the level of trade openness, sheds light on whether trade policy can be effective in sheltering domestic markets from global price spikes in the future. Alternatively, quantifying the short-run and long-run price path-through rates, dependent on the level of trade openness, can reduce the level of uncertainty. This could help to promote open markets rather than protectionism, if effective safety nets are put in place to buffer global (and not least domestic) future price shocks.

Third, globalization affects the structure of an economy and thereby, in one way or another, the distribution of income. While the literature usually investigates the direct trade impacts on income via the described transmission channels by using CGE models, there are less studies that apply econometric techniques using micro data at the household or individual level. Hence, Chapter 4 of the thesis adds to the newer strand of research and uses microeconometric techniques to answer some trade related questions with a special focus on agriculture, a sector being up to date underrepresented in the literature. Furthermore, there is a knowledge gap in understanding the whole story behind poverty and inequality changes over time, considering different dynamics, instead of a limited view of trade effects. Hence, in light of the current global and domestic rural market transformations, the overarching objective of Chapter 4 is to examine the drivers of rural poverty dynamics and changes in income inequality in Peru between 2004 and 2012. More specifically, Chapter 4 asks:

3.1. *To what extend has income diversification into non-agricultural sectors contributed to changes in poverty and income inequality?*

3.2. *What were the main dynamics outside of farming having distributional impacts?*

3.3. *In the agricultural sector, was a shift towards higher value export crops responsible for the reduction in poverty and changes in income inequality?*

3.4. *Did the changing global agricultural market environment contribute to welfare changes of poor staple food producers?*

Chapter 4 approaches these questions by using a microsimulation model based on rural household income generation models to decompose observed changes in the Peruvian income distribution into its different components. Some of these changes might be related to agricultural traded while others are not. Thus, instead of estimating the direct effects of agricultural trade liberalization, Chapter 4 relies on historical counterfactual scenarios, successively isolating the distributional effect of occupational shifts between sectors, shifts away from staple crops to export crops, as well as structural and price impacts within different rural sectors. Although, the approach does not allow for causal inference, it can focus attention on the elements that are quantitatively important in describing welfare changes in rural areas. This should help to formulate effective trade and development policies.

Figure 1.1 summarizes the derived research questions that I want to address and gives an overview of the structure of the thesis.

1.4 Research context

Most of the research of this thesis was funded by grants of the joint Research Center CEIGRAM (Research Centre for the Management of Agricultural and Environmental Risks) at the Technical University of Madrid (UPM) and the Water Observatory of the

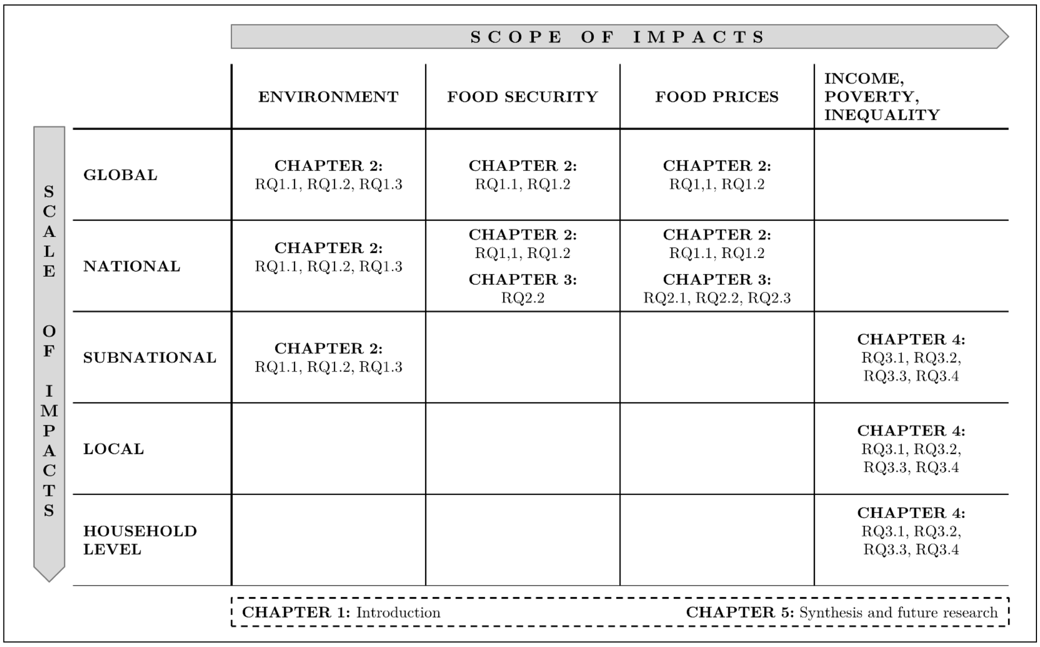

Figure 1.1: **Structure of the thesis**.
Note: RQ refers to research question.

Botín Foundation. Since December 2010 until the end of 2013, the research of Chapters 2, 3 and 4 was carried out within the project titled “Water and Food Security in Latin America” funded by the Water Observatory of the Botín Foundation and conducted within the CEIGRAM. Between early 2014 until July 2014 the CEIGRAM provided further funding to accomplish the goals of the doctoral thesis. The Water Observatory of the Botín Foundation is supported by two teams: one team works in the CEIGRAM and the other team operates in the Faculty of Earth Sciences at the Complutense University of Madrid. The two teams combine expertise in the field of natural sciences and economics as well as social sciences. The Water Observatory does interdisciplinary research around issues related to water that are important at both the national and global levels. On the other hand, CEIGRAM’s activity focuses on development and innovation, dissemination and training, in the field of analysis and management of agricultural and environmental risks.

The thesis was initiated towards the end of year 2010. My research during the first year was primarily concerned with the analysis of virtual water trade related to agricultural production in six LA countries, namely Argentina, Brazil, Chile, Colombia, Mexico and Peru. Results were presented at the Strategic Workshop on "Accounting for water scarcity and pollution in the rules of international trade", held on 25$^{\text{th}}$-26$^{\text{th}}$ of November 2010, Science Centre NEMO, Amsterdam, The Netherlands and the EAAE 2011 Congress "Change and Uncertainty - Challenges for Agriculture, Food and Natural Resources", held on 30$^{\text{th}}$ of August, 2011, ETH Zurich, Zurich, Switzerland. The findings helped to formulate relevant research questions for the work presented in Chapter 2.

Between September 2011 and June 2012, I participated at the doctoral program "Doctorado en Economía Agraria, alimentaria y de los recursos naturales". The title of the final report presented was "Globalization and food security in Latin America: Interactions of trade and domestic food prices and its implications for food security", which served as a base for the later research conducted about the effects of trade openness on food price transmission from global to domestic markets, presented in Chapter 3.

Between September 2012 and December 2012 I was a visiting research fellow at the Environment and Production Technology Division at the Food Policy Research Institute (IFPRI) in Washington D.C. (United States of America). During my stay, I commenced the study about the role of LA's land and water resources for agricultural trade, global food security and environmental impacts, presented in Chapter 2. I gained knowledge about the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), a global dynamic partial equilibrium model of the agricultural sector. Furthermore, working at IFPRI gave me the opportunity to collaborate with IFPRI staff from different disciplines. This research stay was supported by the UPM student mobility grant "Ayudas de Investigación de la UPM – Estancias Breves en España y en el Extranjero".

Another research stay was carried out at the Institute of Latin American Studies, being part of the German Institute of Global and Area Studies (GIGA) in Hamburg (Germany) from August 2013 through July 2014. I benefited from the expertise in poverty analysis as well as microeconomic and microeconometric modeling at the household data level of the group, headed by Junior Prof. Dr. Jann Lay. Together with Prof. Dr. Jann Lay, I initiated a new study on the distributional effects of structural changes in rural Peru. The results are presented in Chapter 4 in this thesis. This research stay was again financed by the UPM student mobility grant “Ayudas de Investigación de la UPM – Estancias Breves en España y en el Extranjero”.

Chapter 2

The role of Latin America's land and water resources for global food security: environmental trade-offs of future food production pathways*

Abstract One of humanity's major challenges of the 21st century will be meeting future food demands on an increasingly resource constrained-planet. Global food production will have to rise by 70 percent between 2000 and 2050 to meet effective demand which poses major challenges to food production systems. Doing so without compromising environmental integrity is an even greater challenge. This study looks at the interdependencies between land

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and water resources, agricultural production and environmental outcomes in Latin America and the Caribbean (LAC), an area of growing importance in international agricultural markets. Special emphasis is given to the role of LAC's agriculture for (a) global food security and (b) environmental sustainability. We use the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) –a global dynamic partial equilibrium model of the agricultural sector– to run different future production scenarios, and agricultural trade regimes out to 2050, and assess changes in related environmental indicators. Results indicate that further trade liberalization is crucial for improving food security globally, but that it would also lead to more environmental pressures in some regions across Latin America. Contrasting land expansion versus more intensified agriculture shows that productivity improvements are generally superior to agricultural land expansion, from an economic and environmental point of view. Finally, our analysis shows that there are trade-offs between environmental and food security goals for all agricultural development paths.

Keywords sustainable intensification, carbon sequestration, species risk, deforestation, CO2 emissions, biodiversity loss, water quality, nitrogen leaching, agricultural trade, global food security, yield gap analysis, food demand in 2050, trade liberalization

JEL Classification F17, F18, Q16, Q17, Q24, Q25

2.1 Introduction

Latin America and the Caribbean (LAC) globally has the greatest agricultural land and water availability per capita. With 15% of the world's land area, it receives 29% of global precipitation and has 33% of globally available renewable resources (Mejía, 2014). Large availability of land and water resources fueled rapidly growing exports of primary goods (UNEP, 2010, Dingemans and Ross, 2012). At the same time, globally, dietary patterns are shifting towards increased consumption of meat and milk products, oils and sugars, and vegetables and fruits, whereas growth of direct human consumption of roots and tubers and grains is either slowing or declining in per capita terms. These dietary shifts are highly resource intensive (Grau and Aide, 2008, Rosegrant et al., 2001, Thornton, 2010, Pradhan et al., 2013a,b). This increasing global demand pressure gives LAC a pivotal role for meeting global food demands (OECD, 2013, Willaarts et al., 2014a). Over the last 30 years LAC's agricultural market share has almost doubled from 9.5% in 1980 to 18.1% in 2010 (WTO, 2012). De Fraiture and Wichelns (2010) and Hoekstra and Mekonnen (2012) suggest that enhancing agricultural trade leads to natural resource "savings" compared to a world without trade due to global efficiency gains. Thus, trade can play an important role in terms of global food security and environmental efficiency (OECD, 2013) in meeting the estimated 70% increase in global food demand (FAO, 2009a). However, growing food trade requires increasing agricultural production in exporting nations with potential adverse impacts on their natural resource base.

Several studies have evaluated the relationship between trade liberalization and the environment. Some of these studies find a positive impact of more liberal markets on the environment, (see e.g. Anderson, 1992, Antweiler et al., 2001, Frankel and Rose, 2005, Hoekstra and Mekonnen, 2012, Lenzen et al., 2012), while others emphasize the negative effects of trade on different environmental indicators, (see e.g. Chichilnisky, 1994, Cole, 2004, Frankel and Rose, 2005, Managi et al., 2009). For example Frankel and Rose (2005) use advanced econometric studies to disentangle the causal relationship between trade liberalization and greenhouse gas (GHG) emissions and other pollutants, and find that trade reduces emissions for most pollutants. On the contrary, Schmitz et al. (2012) conclude that further trade liberalization until 2045 leads to higher economic benefits, at the expense of emitting more CO_2. Ercin and Hoekstra (2014) compare agricultural water consumption volumes under globalization versus regional self-sufficiency, and find that trade liberalization is only a minor factor in changing water footprints.

The literature focuses on the linkage between agricultural trade liberalization and the environment, but does not specifically distinguish between different possible production systems in exporting regions. There are two dominating views on how to increase agricultural production while minimizing negative environmental impacts, i.e. the so-called land sharing and land sparing argument(Fischer et al., 2008, Phalan et al., 2011). The land sharing argument advocates for jointly considering conservation and production objectives on the same land, while the land sparing view supports land specialization with high-yield agriculture coexisting with other areas devoted to nature conservation. Promoting a land sharing strategy requires extensification of agricultural production as agricultural inputs on farm decrease. This could increase the agricultural land footprint to keep up with production levels. As agricultural land footprints increase, the risk of deforestation and land clearing also rises. This in turn might threaten biodiversity and lead to GHG emissions (Tilman et al., 2011, Willaarts et al., 2014b). A land sparing approach on the contrary will require further intensification of agriculture to increase average yields per hectare (ha). Yield improvements depend on the adoption of various conventional and agro-ecological management practices, including the use of high-yielding cultivars, and enhanced management practices to reduce abiotic and biotic plant stresses (Finger, 2011). In this study we implement land sparing through the following management practices: (1) supplemental water through irrigation (or rainwater harvesting) and (2) supplemental nutrients through additional fertilizers. However, overexploitation of water resources and climate change make it difficult to further expand irrigation in some areas (Ringler et al., 2010, Nelson et al., 2010). Furthermore, fertilizer use can lead to water and soil pollution, causing negative impacts on freshwater and terrestrial ecosystems (Tilman et al., 2011). In order to respond to these pressures, finding ways for "sustainable intensification" has become central. This could mean increasing yields on underperforming landscapes while reducing adverse environmental impacts of agricultural systems (Mueller et al., 2012, Garnett et al., 2013). Some studies focus on closing yield gaps by optimizing management practices (Licker et al., 2010, Tilman et al., 2011, Mueller et al., 2012, Valin et al., 2013), usually using static methods referring to just one point in time. Others focus on combining supply and demand side measures, e.g. by applying traditional and modern breeding techniques to improve yields, while emphasizing the need to limit food waste and over-consumption (Tester and Langridge, 2010, Garnett et al., 2013).

Our study aims at investigating the role of LAC's agriculture for global food security and associated environmental trade-offs of contrasting scenarios of agricultural production out to 2050. Specifically, we explore changes in water footprints and water quality, as well as impacts on biodiversity and carbon stocks from land use change by 2050 from alternative agricultural production pathways and identify related environmental hotspots. We focus on LAC because the region has become one of the main food producers globally and is likely to continue on this trajectory under further agricultural market liberalizations.

2.2 Materials and Methods

2.2.1 Scenarios

In our modeling exercise, we contrast five alternative agricultural development pathways with a Business-as-Usual (BAU) scenario, which reflects what we believe are most likely changes in key human and agricultural development parameters out to 2050. Note that while assumptions under the BAU scenario are applied globally, alternative future scenarios focus on LAC. The BAU scenario (1) uses the UN medium variant projections with respect to population growth United Nations (2005). The economic growth assumptions are based on the TechnoGarden scenario of the Millennium Ecosystem Assessment

(MEA, 2005). BAU assumes climate change based on the "A1B" scenario specified in the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC, 2013). We apply different global climate models (GCMs) as climate inputs to the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). (IMPACT model details are described in the following section.) However, we only present results from MIROC model runs, because results between different GCMs do not deviate much. (For details on the sensitivity between different GCMs see Appendix A1). The BAU scenario assumes a continuation of past trends in irrigated and rainfed area growth rates as well as crop and livestock productivity growth rates with a gradual slow down in growth. Current trade policies are kept constant over time, so no further trade liberalization is assumed. Details on the BAU assumptions and values used in the base year can be found in Nelson et al. (2010).

The following alternative future scenarios are analyzed: (1a) A global liberalized trade scenario, (2) a LAC intensification scenario, (3) a LAC sustainable intensification scenario, (4) a LAC closed yield gaps scenario and (5) a LAC extensification scenario. The distinct features of each scenario are summarized in Table 2.1. The numbers should be interpreted as the deviation from the BAU scenario. The selection of parameters is described in further details below. Note that due to high agricultural specialization in LAC, we focus our analysis on those food crops that together accounted for more than 70% of agricultural production in 2010: maize, rice, wheat, soybeans, sugarcane, potatoes and sorghum. Livestock products included in the study are cows, sheep, goats, pigs and chickens. However, for the pasture land estimations only cows, sheep and goats are considered (for details see Appendix A2).

The liberalized trade scenario (1a) uses the same assumptions as BAU, but with globally gradually liberalizing trade regimes, following an historically derived pathway. Based on the literature, we implemented a 10% trade barrier reduction in each decade starting 2010 until 2050 (Healy et al., 1998, Conforti and Salvatici, 2004, Schmitz et al., 2012).

The intensification scenario (2) and the sustainable intensification scenario (3) deviate

Table 2.1: **Alternative future scenarios for 2010 to 2050 (changes compared to BAU (1))**

Parameters	**(1a) BAU liberal**	**(2) Intensification**	**(3a) sustainable intensification (higher NUE)**	**(3b) sustainable intensification (PA)**	**(4) Closing yield gaps**	**(5) Extensification**
Livestock number growth	n.c.	n.c.	n.c.	n.c.	n.c.	+ 30% (LAC)
Livestock yield growth	n.c.	+ 30% (LAC)	+ 30% (LAC)	+ 30% (LAC)	+ 30% (LAC)	- 30% (LAC)
Crop* yield growth changes	n.c.	+ 60% (LAC)	+ 60% (LAC)	+ 60% (LAC)	closed yield gaps (LAC)	- 60% (LAC)
Irrigated crop* area growth	n.c.	+ 25% (LAC)	+ 25% (LAC)	+ 25% (LAC)	+ 25% (LAC)	- 25% (LAC)
Rainfed crop* area growth	n.c.	Zero exogenous area growth (LAC)	Zero exogenous area growth (LAC)	Zero exogenous area growth (LAC)	Zero exogenous area growth (LAC)	+ 15% (LAC)
Basin efficiency (ratio between 0 and 1)	n.c.	n.c.	+ 15 %-points (LAC)	+ 15 %-points (LAC)	n.c.	n.c.
Increased NUE*	n.c.	n.c.	increased NUE by 20% (LAC)	n.c.	n.c.	n.c.
Precision Agriculture*	n.c.	n.c.	n.c.	optimized nitrogen use (LAC)	n.c.	n.c.
Trade distortions	- 40% (globally)	- 40% (globally)	- 40% (globally)	- 40% (globally)	- 40% (globally)	- 40% (globally)

Note: NUE = nutrient use efficiency, PA = Precision Agriculture, n.c. = no change compared to Business-as-Usual (BAU) assumptions (for base year details see Nelson et al. (2010) Nelson et al. (2010), * = applied to maize, rice, wheat, soybeans, sugarcane, potatoes, sorghum. LAC means that changes are applied to Latin America and the Caribbean, Globally means that changes compared to BAU are applied globally.

from the BAU scenario following the high-AKST (Agricultural Knowledge and Science and Technology) scenarios of the IAASTD report (IAASTD, 2009). Here, we assume more agricultural research and development (R&D) in the future, and therefore higher crop and livestock yield growth as well as expansion of irrigation. This scenario also assumes no additional growth in rainfed area to simulate land use policies that promote land sparing. Note that even under the assumption of zero exogenous rainfed area growth, growth of rainfed area can still be triggered by price increases, because farmers' production decisions depend on prices. The sustainable intensification scenario (3) further assumes improved basin water use efficiencies through advanced irrigation technologies and sound management in those regions in LAC that suffer from water stress (affected spatial units are listed in Appendix A3). Compared to the BAU scenario, basin efficiency is 15%-age points higher by 2050 in those spatial units. The sustainable intensification scenario is further sub-divided into (3a) and (3b) to explore environmental impacts of two alternative agricultural technologies. Both, assume high yield growth rates, but at lower N-emission rates due to optimized fertilization and plant uptake. Under (3a) higher nutrient use efficiencies (NUE), expressed in crop yield per kg nutrient applied, are considered and under (3b) precision agriculture is assumed to be widely in use.

Scenario (4) on closing yield gaps follows the same assumptions as the intensification scenario (2), but crop yield growth rates are increased according to existing yield gaps, instead of the high-AKST growth rates. Yield gaps could be closed by improved management practices or through accelerated technological change. The yield gap is defined as the difference between observed yields and potentially attainable yields. We close 75% of the yield gap as closing 100% is unlikely to be economically sensible. We also conducted a sensitivity analysis where we close 100% of the yield gap. However, the main food security and environmental results do not change substantially. Therefore, we do not report results from the sensitivity analysis. We follow the approach of Mueller et al. (2012) and identify attainable yields for each crop in each low-yielding area in LAC by matching them to the corresponding high-yielding world areas within zones of similar climates. For a detailed description of the methodology see Mueller et al. (2012). Our modeling exercise (described below) is conducted at the subnational level. To obtain attainable yields per crop at this spatial resolution in LAC, we aggregate the high-yield information of different climate zones within each spatial unit (available at a 0.5 by 0.5 degree longitude-latitude grid resolution). Weights are chosen to reflect the share of area harvested in each climate zone within one spatial unit. Some initially low-yielding areas can close yield gaps under the BAU scenario (1) already. In scenario (4) we only increase yield growth rates compared to BAU growth rates in those regions where BAU yield growth rates were not sufficiently high to close yield gaps by 2050. For the other regions, BAU growth rates without additional yield growth are assumed. (Areas with remaining yield gaps (area abbreviations are explained in Appendix A4) are listed in Appendix A5.)

We contrast the described intensive scenarios (2/3a/3b/4) to a scenario that assumes more extensive agricultural practices in the future. Specifically, scenario (5) assumes lower crop and livestock yield growth and less expansion of irrigation, but instead higher rainfed area growth rates and accelerated livestock numbers' growth. The values are chosen following the low-AKST scenario of the IAASTD report (IAASTD, 2009).

Note that all scenarios, except for the BAU scenario assume further trade liberalization. Scenario (1a) serves to isolate the effects of trade liberalization from those of choosing the different production systems described in scenarios (2) to (5).

2.2.2 Modeling framework

Here, we give a brief overview of the methodology applied in the study. A more detailed methodology description as well as all relevant model equations for the study can be found in the Appendix A.

The IMPACT model

We use IMPACT to analyze the above described scenarios. A complete mathematical description of the model can be found in Rosegrant (2012). IMPACT is a global multi-market, dynamic partial-equilibrium model of the agricultural sector that provides long-term projections of global food supply, demand, trade, prices, and food security developed by the International Food Policy Research Institute (IFPRI). It covers 46 agricultural commodities, including all cereals, soybeans, roots and tubers, meats, milk, eggs, oils, meals, vegetables, fruits, sugar and sweeteners, and other foods. Dietary changes are taken into account by adjusting demand elasticities to accommodate the gradual shift in demand from staples to higher value commodities like meat and milk products, especially in developing countries. This assumption is based on expected economic growth, increased urbanization, and continued commercialization of the agricultural sector.

As described in the scenarios, the focus of this study lies on modeling trade liberalization and changes in supply side factors, developed to analyze LAC's contribution to meet higher future calorie demand. The alternative scenarios (1a, 2-5) assume trade liberalization by a gradual reduction of producer support estimates (PSE), consumer support estimates (CSE) and marketing margins (MI) globally until they are 40% lower in 2050 compared to 2010 levels. The different future agricultural production pathways are simulated by adjusting BAU growth rate assumptions in LAC according to the scenario specific assumptions. The parameters affected are exogenous crop and livestock yield shifters, exogenous rainfed and irrigated area shifters, and exogenous livestock number shifters embedded in a set of equations. Apart from these exogenous factors, crop and livestock specific yields, area harvested and the number of slaughtered animals react endogenously to price movements. Furthermore, we account for the biophysical effects from climate change in all world regions. The Decision Support System for Agrotechnology Transfer (DSSAT) uses changes in precipitation and temperature to model climate change productivity effects by calculating location specific yields in different years, and converting these to a growth rate which is then used as a yield shifter. For details on how climate change is modeled in IMPACT see Nelson et al. (2010). Water stress (sometimes aggravated by climate change) is captured as part of a loosely coupled hydrology model which provides gridded output of hydrological fluxes, namely effective rainfall, potential and actual evapotranspiration, and runoff. These parameters are in turn used as inputs to a Water Simulation Model (WSM) that balances water availability and uses within various economic sectors, at the global and regional scale. Globally, IMPACT uses a disaggregation of 280 spatial units, from now on called"food-producing units" (FPU), which represent the spatial intersection of 115 economic regions and 126 river basins. For LAC, IMPACT includes 31 FPUs which are illustrated in Appendix A6 and Appendix A4 in the Appendix. (For a more detailed IMPACT model description with the model equations relevant for our study see Appendix A7.)

Firstly, we use the IMPACT model to simulate scenario-specific 2050 changes of global agricultural trade flows, international food prices, and the total number of malnourished preschool children (under five years old) in different world regions. The number of malnourished children serve as an indicator for food security in our analysis. The relationship used to estimate this food security indicator is based on a cross-country regression model developed by Smith and Haddad (2000). (For more details on the food security estimation see Appendix A8.) Note that all variables used for the malnutrition regression (see Appendix A8) are assumed to be exogenous, and IMPACT results only alter calorie availability due to changes in supply and demand and resulting world prices. This is a somewhat simplistic assumption as different trade assumptions might also influence some of the other variables. However, regional and global trends are well reflected in this structure.

Secondly, as an advantage over many other economic models, IMPACT treats future water demand and supply endogenously, responding to sectors providing and demanding water. We use this feature in order to calculate water footprints of agricultural production and identify water scarcity hotspots under alternative production systems. More specifically, we differentiate between the green water footprint of production (GWF) and the blue water footprint of production (BWF). The GWF is defined as the rainwater evaporated or incorporated into a specific crop by FPU, while the BWF reflects the volume of surface or groundwater evaporated or incorporated into a specific crop or livestock in an FPU (Hoekstra et al., 2011). (For details on how GWF and BWF are calculated see Appendix A9.) Irrigation water scarcity is analyzed with a water stress index, which measures the gap of water supply and demand in each FPU. In stressed FPUs, with a water stress index below one, water supply cannot meet crop demands, leading to yield reductions.

Furthermore, an IMPACT model validation (with respect to area harvested which is one major variable used in our study) is illustrated in Appendix A10.

Water quality assessment

Impacts of expanded or intensified agricultural activity on the water environment are assessed by quantifying variations of nitrogen-based pollutants over time under each of the scenarios considered. This involves linking IMPACT results to the Soil and Water Assessment Tool (SWAT). SWAT is a physically-based watershed model equipped with functions to simulate the main processes of nitrogen cycles in agricultural river basins (Arnold et al., 1998). The model has been extensively applied to investigate water quality issues related to agricultural nitrogen emissions (N-emissions), (see e.g. Santhi et al., 2001, Driscoll et al., 2003, Ullrich and Volk, 2009). In this study, we parameterize the SWAT model on a 0.5 by 0.5 degree longitude-latitude grid to estimate annual rates of agricultural N-emissions (including emissions from both crop and pasture land) across different FPUs in LAC according to determined nitrogen input rates on agricultural land and climate conditions in the base year and under future scenarios. The term N-emissions refers to the discharge of particulate and dissolved nitrogen-based pollutants from land to water environments. In addition to estimating the effects of more or less intensified agricultural production systems, we constructed two sustainable intensification scenarios (3a/3b). Under the sustainable intensification scenario with NUE improvement (3a), input rates of fertilizer and manure nitrogen on crop land are adjusted to mimic NUE enhancement by +20%. To represent precision agriculture techniques in the sustainable intensification scenario (3b), we invoke an auto-fertilization function in the SWAT model (Neitsch et al., 2005) to determine the quantity and timing of nitrogen fertilizer/manure applications, given nitrogen requirements of the major crops. A more detailed methodological description can be found in Appendix A11.

Carbon assessment

We quantify the impacts on carbon stock losses linked to the projected expansion of cropland and pasture areas due to livestock production in LAC between 2010 and 2050 for each of the agricultural production scenarios. Land use dynamics are complex and the link between agricultural expansion and deforestation in LAC is not straightforward, i.e. many cropland areas are now expanding on existing pastures, but indirectly such expansion is pushing the agricultural frontier beyond as cattle ranching activities are displaced (Wassenaar et al., 2007, Lapola et al., 2010). Since IMPACT does not provide information on the likely land use transitions, our carbon (C) impact estimations assume the following alternative land use pathways: (i) all new cropland area expands over former natural vegetation; or (ii) all new cropland area expands over existing pastures. Estimating carbon stock changes for these different land use pathways provides us with a lower and upper bound estimation of carbon storage losses linked to cropland expansion. For livestock production, we assume that all future pasture expansion will expand over former natural vegetation. In those FPUs where a reduction in the agricultural area is expected, we assume that the new abandoned agricultural areas are able to restore their C stocks back to their original values i.e. those of the original natural vegetation, due to natural succession and forest regrowth.

To calculate the carbon trade-offs we first estimate aboveground and belowground carbon contents of natural vegetation, pastures and croplands of the seven different crops considered in this study by FPU. Then, we estimate the changes in carbon stocks resulting from the conversion of (1) natural vegetation to land dedicated to each of the seven crops, (2) natural vegetation to pastures, and (3) pastures to land of each crop type, by FPU and under each of the different scenarios of agricultural production. For a detailed description of the calculation of the projected crop and pasture area up to 2050 we refer to Appendix A2. Please see Appendix A12 for a complete description on the data and methodology used to estimate carbon stocks and changes.

Biodiversity assessment

We use species-area relationships (SAR) to account for potential biodiversity trade-offs associated with each of the scenarios of agricultural production in LAC. Specifically, we apply a countryside model (Pereira and Daily, 2006) to predict changes in endemic bird's risk of extinction and endangerment (expressed as an index in %) associated with the projected increase in cropland and pasture area between 2010 and 2050. We limit the study to birds since taxon's sensitivity to different forms of land use change is well studied, and data on their conservation status and spatial range are most reliable, updated, and available. To avoid the scale dependency factor (Brooks et al., 2002) when assessing the extinction and endangerment rate we limit our study to endemic birds i.e., species with breeding range limited to LAC region.

As with the carbon assessment, the birds' risk of extinction and endangerment due to cropland expansion is assessed by taking into account the different land use pathways to obtain a lower and upper bound of biodiversity trade-offs. As for pastures, the risk index is estimated assuming that future pasture areas will expand over former natural vegetation. Again, we account for agricultural abandonment and forest regrowth when estimating the total impacts on biodiversity.

To assess the bird's risk of extinction and endangerment by FPU and under the different scenarios we estimated: (i) the actual number of birds and the %-age of threatened species by FPU; (ii) the area of the main land uses per FPU (natural vegetation, pastures, cropland, urban/artificial); and (iii) the linear relationship between the %-age of threatened species and habitat availability and suitability. A detailed description of the country-side model and data used can be found in Appendix A13.

2.3 Results

2.3.1 Global food security in 2050

With increasing globalization, population growth and dietary changes, LAC will likely supply even larger amounts of food to the rest of the world by 2050. We find that, depending on the production scenario, LAC can further strengthen its net export position for some of the seven crops and the livestock products investigated in this study. Although for some staple crops, like maize and potatoes, markets will still be dominated by North America and Europe under all scenarios in 2050, LAC will grow production and by 2050 become a maize and potato net exporter. Under BAU liberal (1a), as well as under the intensification scenarios (2/3) this trend is even more pronounced. This means that no substantial additional land for these crops will be required if more irrigation is applied and rainfed and irrigated yield improvements are sufficiently high. The same holds for the closing yield gaps scenario (4) for some crops. Under BAU (1), yields gaps in potato production remain pronounced up to 2050. Therefore, gradually closing those gaps between 2010 and 2050 would lead to a stronger market position. For maize, yield gaps in LAC are rather small, so net exports are even smaller than under BAU (1), because we assume a much slower rainfed area growth without substantial improvements in yield growth rates. The extensification scenario (5) assumes increased rainfed area growth, and slowing irrigated area expansion rates and yield growth rates. The results show that only increasing rainfed area cannot compensate for the productivity slowdown and it even eliminates the positive effects of trade liberalization. LAC's strongest agricultural export products are soybeans and sugar with sugar made of sugarcane. For both products, world trading volumes increase substantially until 2050, with trade liberalization reinforcing LAC's net export position. For soybeans, however, intensifying production without allowing for rainfed area growth (scenarios (2/3/4)) reduces LAC's net export position compared to BAU (1). This can be explained by the fact that soybeans are largely produced under rainfed conditions, and further production expansion without area expansion is rather difficult. In the case of sugarcane, intensification (2/3) augments net sugar exports. Also for beef, market liberalization combined with the assumption of accelerated yield growth under scenarios (2), (3) and (4) strongly reinforce LAC's net export position. Growing livestock numbers without substantial yield improvements, as assumed under the extensification secenario (5), reduces LAC's comparative advantage in beef production compared to BAU liberal (1a), but net exports are still higher than under BAU (1). For wheat, rice and sorghum LAC remains at a net importing position, regardless of the scenario assumed for the future.

Figure 2.1a shows the %-change in world prices of each scenario from the BAU (1) price level in 2050. From "BAU liberal" (1a) it is clear that trade liberalization itself has the strongest effect on prices. This is due, firstly, because liberalization is implemented globally, and secondly changes in yield, livestock numbers and area growth rates are only assumed for LAC. If additional productivity improvements were implemented globally, the effects on world production, and in turn on prices, would likely be much more pronounced. In Figure 2.1b we see that real world prices will increase in all scenarios between 2010 and 2050, with the steepest increases for almost all products under BAU (1). One exception is sugar whose price would increase more under all alternative scenarios than under BAU (1). Sugar is one of the world's most highly protected agricultural commodities (Elobeid and Beghin, 2006), thus reducing market distortions leads to shifts in production and consumption, and consequently to higher world prices. Intensifying production of sugarcane or closing yield gaps (scenarios (2/3/4)) can attenuate this effect, while extensification (scenario 5) further exacerbates pressure on sugar prices. In contrast to sugar, trade liberalization (scenario 1a) has price reducing effects for the other six crops and beef. This also holds for soybean prices. However, the price increase of soybeans between 2010 and 2050 cannot be reduced through extensification (scenario 5), or intensification (scenarios 2/3) or closing yield gaps (scenario 4). The extensification scenario (5) assumes 60% slower yield growth rates due to lower agricultural inputs which cannot be compensated by the 15% accelerated rainfed area growth. The intensification scenarios (2/3) and, to a much lesser extent, the closing yield gaps scenario (4), assume accelerated yield growth rates, but no further exogenous rainfed area growth. Since soybeans are mostly produced under rainfed conditions, the assumed zero future rainfed area growth leads to higher world prices compared to a situation with faster area growth. Thus, to further augment soybean production, trade liberalization, accelerated yield improvements, and allowing for rainfed area expansion seem to be equally important. For all other crops (wheat, maize, sorghum, potatoes, rice) the intensification scenarios (2/3), and for potatoes the closing yield gaps scenario (4), reinforce the price reducing effect of trade liberalization. On the contrary, allowing for more rainfed area growth, but reducing productivity growth (scenario 5) does not show positive effects. In general, the yield gaps scenario (4) has rather limited production effects, because for most crops (except for potatoes), many areas in LAC are already among the world's high-yield areas.

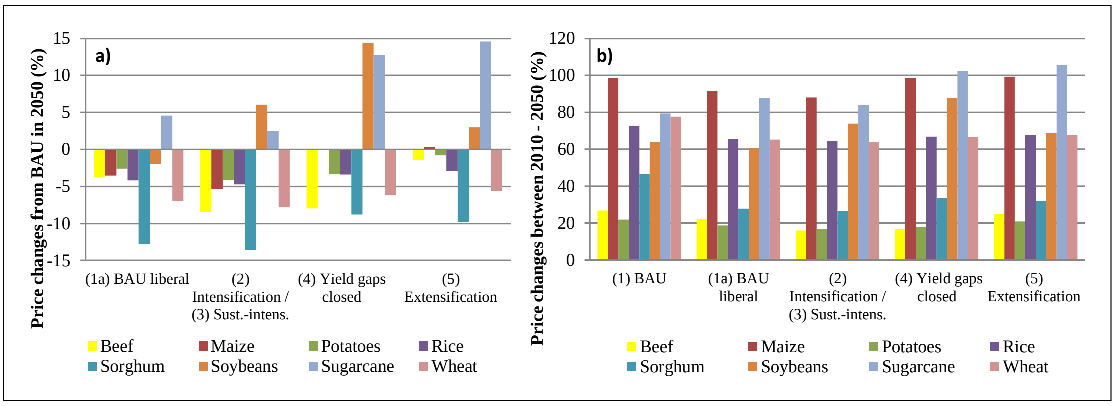

Figure 2.1: **(a) World price deviations in % compared to BAU (1) in year 2050; (b) World price changes in % within each scenario from 2010 to 2050.** BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 2.1. The intensification (2) and sustainable intensification (3) scenarios are presented together, because both scenarios have the same productivity assumptions and they only differ in terms of of natural resource efficiencies. Thus, the implications for agricultural markets are the same under both scenarios.
(Source: own elaboration)

Changes in global food supply and food prices affect people's ability to access food across the world, particularly in developing countries. Hence, different production conditions in LAC and the trend towards more open food trade will have effects on future food security globally. Figure 2.2 illustrates that the number of malnourished children is projected to decrease by 2050, though less under BAU assumptions (scenario 1) and the most under the intensification scenarios (2/3). Trade liberalization (scenario 1a) has positive effects on calories availability, reducing food insecurity. Intensifying food production (scenarios 2/3) in LAC reinforces the positive effect of trade liberalization slightly. However, the largest improvements in food security are achieved by assuming trade liberalization, because all countries benefit whereas the accelerated productivity gains are focused on the LAC region only. In addition, soybeans and sugarcane are not only food crops, but also used for the production of feedstuff or biofuel. Beef is often a luxury product consumed by richer segments of the world population. Therefore, the relevance of these products for improving food security is somewhat more limited. Moreover, we see that food security in LAC (Figure 2.2a) and in the Southeast Asia & Pacific region (Figure 2.2c) improves fast with a linear trend, while Central-West Asia (Figure 2.2d) and Sub-Saharan Africa (Figure 2.2b) show less improvements. This can be explained by the fact that Sub-Saharan Africa is expected to experience very rapid population growth without concomitant food production growth, and continued lack of access to safe water as well as continued limited improvement in female secondary education, key variables limiting food security gains (see Appendix A8 for details on these variables). Therefore, these socio-economic factors seem to be very dominant in explaining food insecurity. However, we also see that the region would especially benefit from more liberal agricultural markets, despite its remaining difficulties.

2.3.2 Environmental trade-offs

This section describes the different environmental impacts of our different future production pathways. Results for environmental indicators include a temporal scale and a spatial scale. This means that we show changes between 2000 and 2050, and also differences between LAC's regions in 2050 to highlight environmental hotspots.

Impacts on water resources

From an environmental perspective, it is crucial to establish whether the water used in agriculture originates from rainwater lost in evapotranspiration and evaporation during the production process (green water) or from surface and/or groundwater sources (blue water). It has been argued that the use of green water in crop production is considered more sustainable than blue water use, although this is not necessarily the case if either

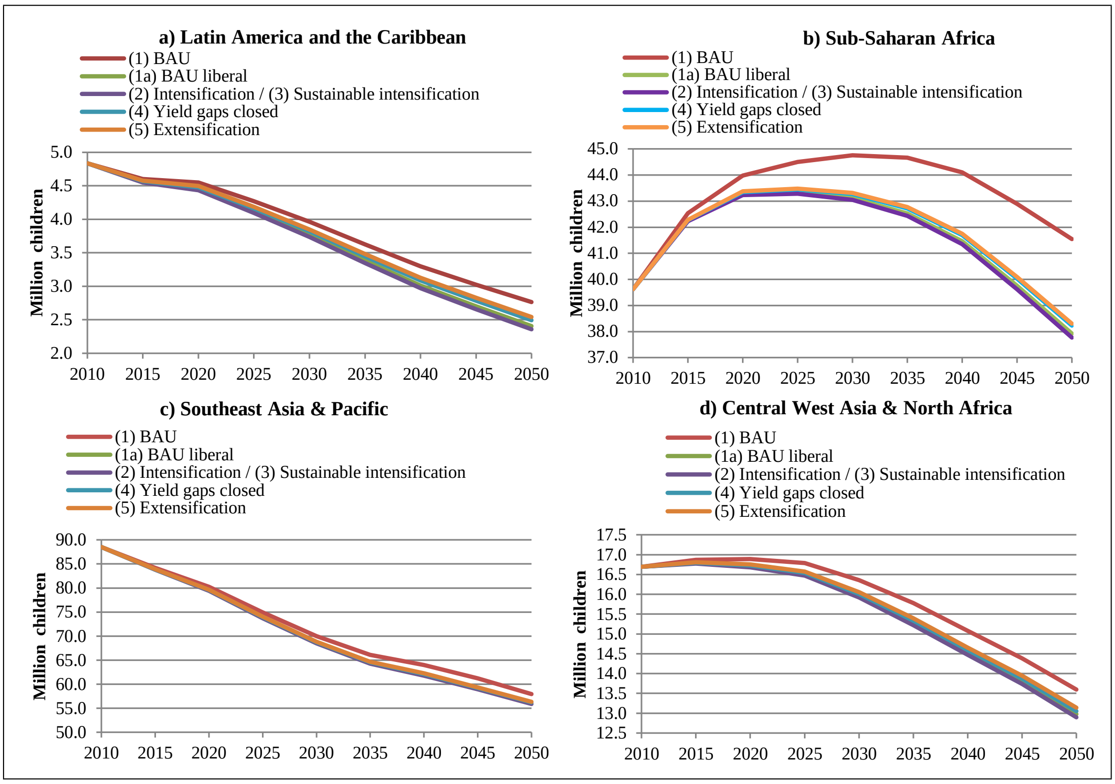

Figure 2.2: **Number of malnourished children from 2010 to 2050 associated with different future scenarios.** BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 2.1. The intensification (2) and sustainable intensification (3) scenarios are presented together, because both scenarios have the same productivity assumptions and they only differ in terms of of natural resource efficiencies. Thus, the implications for agricultural markets are the same under both scenarios.
(Source: own elaboration)

blue water resources are sustainably managed (Garrido et al., 2010) or expanding rainfed agriculture is associated with massive land clearing and deforestation. Due to its favorable climate, most of LAC's agriculture is rainfed. The lines in Figure 2.3a show how the GWF evolves over time in LAC under the different future scenarios. The GWF increases overall, although the increase is smaller under those scenarios in which intensification is greater. As expected, extensifying (5) food production leads to the highest increase in green water use, followed by the trade liberalization scenario (1a) which does not consider accelerated yield growth. An expansion of rainfed agricultural production is usually associated with an increase in area harvested, because the potential for productivity improvements is lower than for irrigated agriculture. The bars in Figure 2.3a confirm this relationship. This means that the environmental costs are rather related to land conversion than to water. These trade-offs will be discussed below in the sections related to carbon stock losses and risk of biodiversity losses.

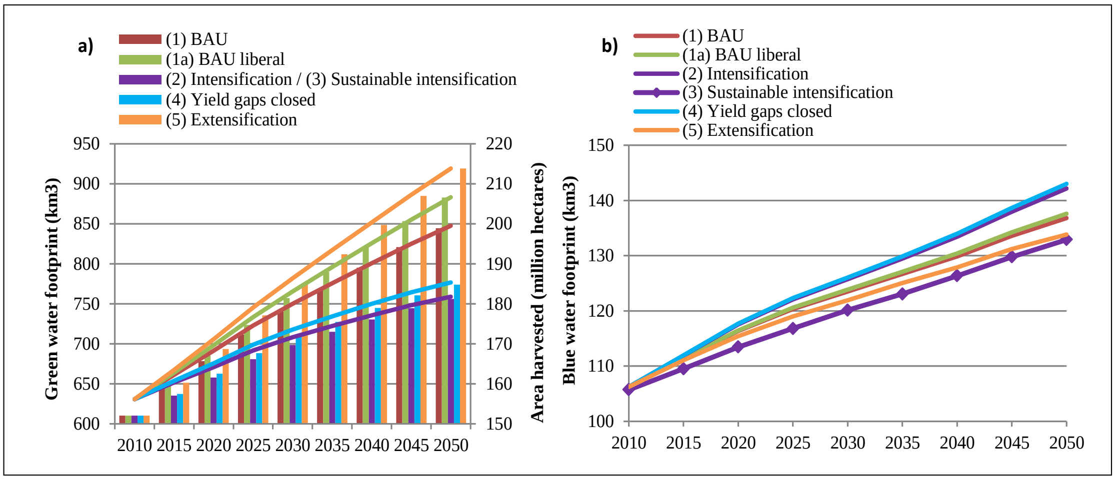

Figure 2.3: **(a) Evolution of the total Green Water Footprint (represented as the line chart on the left axis) and area harvested (represented as the bar chart on the right axis) of all crops in Latin America and the Caribbean from 2010 to 2050. (b) Evolution of the total Blue Water Footprint of all crops and livestock in Latin America and the Caribbean from 2010 to 2050.** BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 2.1. For green water, the intensification (2) and sustainable intensification (3) scenarios are presented together, because both scenarios have the same productivity assumptions and they only differ in terms of blue water use.
(Source: own elaboration)

In contrast to land expansion, agricultural production can also increase by expanding irrigation. Expanding irrigated area directly affects water resources. Figure 2.3b shows the BWF over time for all scenarios. Liberalizing trade slightly increases the BWF from crop and livestock production. The highest blue water use is associated with scenarios (2) and (4) demonstrating the trade-offs between achieving higher yields and conserving water. As expected, extensifying agriculture (5) would save blue water compared to the

BAU scenario (1). The sustainable intensification scenario (3) reduces the BWF even more while maintaining high yields. This highlights the importance of investments in water saving technologies and adequate water management practices. Note that even though productivity and area changes are only implemented for the seven major crops, water footprints per FPU are calculated for all IMPACT commodities. We do this, because in some regions fruits and vegetables, cotton or even livestock are the main water consumers rather than the seven crops studied in detail for LAC. Furthermore, improved basin efficiencies are introduced at the river basin scale and thus apply to all IMPACT crops.

Since LAC as a region is rather water abundant, increasing blue water use would not necessarily lead to unsustainable extraction rates. However, in some water scarce areas, expanding irrigated area would exacerbate water stress. Appendix A14 in the Appendix lists those FPUs in LAC where irrigation demand cannot be fully met. In most water stressed FPUs water scarcity increases over time, with the exception of the Caribbean (CAR_CCA) and Yucatan (YUC_CCA) in Central-America, and Uruguay (URU_URU)as well as Brazil at the border to Uruguay (URU_BRA) in South America. Here (effective) precipitation increases over time, leading to an increasing ratio of water supply over demand. A water-stressed hotspot in Central America is Cuba (CUB_CCA), while in South America Tocantins in Brazil (TOC_BRA) and Coastal Peru (PEC_PER) rank among the most water stressed regions. In all water scarce regions, irrigation supplies suffer the most under the more intensive scenarios (2) and (4), followed by the BAU scenarios (1) and (1a). Again we see that extensifying agricultural production systems (5) would slightly alleviate stress on water resources. Pressure is lowest under the sustainable intensification scenario (3).

This shows that increasing irrigation should go hand in hand with better water management and technologies and adequate irrigation practices. A large share of irrigated areas is subject to both land and water degradation as a result of poor irrigation management, eventually affecting crop yields and long-term productivity of the land. In LAC, additionally, water stress also emanates from its large urbanized centers. Right now 23% of LAC's population (125 million people) live in water scarce basins (Willaarts et al., 2014a).

Water quality impacts

Excessive amounts of nitrogen, together with excess phosphorus, in water bodies often cause eutrophication. Agriculture is a major human source of N-emissions. For Latin America as a whole, the risk of water quality degradation due to N-emissions increases until 2050, irrespectively of the future production scenario considered (see Figure 2.4). Under BAU assumptions (1), total N-emissions will increase by about 103% in 2050. If trade is liberalized (1a), the increase will be even larger, at around 113%. As expected, the extensification scenario (5) shows a relief on N-emissions due to the assumption of a slower increase in fertilizer application rates. In contrary, the intensification scenario (2) would lead to the highest risk of water quality degradation, because accelerated yield growth will in part be achieved by higher N application rates. However, even though N-emissions per ha increase under the intensification scenario (2), intensifying agriculture also leads to less area expansion which partially offsets the augmented total N-emission rates. The closed yield gaps scenario (4) results in lower N-emissions than the BAU path (1), because yield growth is assumed to be higher only for selected crops and total area growth is reduced. From a water quality perspective, this is good news, however total production volume is reduced due to the assumption of no increase in rainfed area. If this assumption were relaxed, N-emissions would very likely be higher under scenario 4 than under BAU (1). Very promising results are reflected in the sustainable intensification scenarios (3a) and (3b). While maintaining high yields, and thus production and trade volumes (with the positive effects for food security), the risk for water quality degradation would be much lower.

Under all scenarios, except for the sustainable intensification scenarios (3a) and (3b), there is an absolute increase in N-emissions between 2000 and 2050 in almost all important LAC's agricultural production areas. (Appendix A15 in the Appendix ranks all FPUs according to their water degradation risk). Exceptions are those areas where

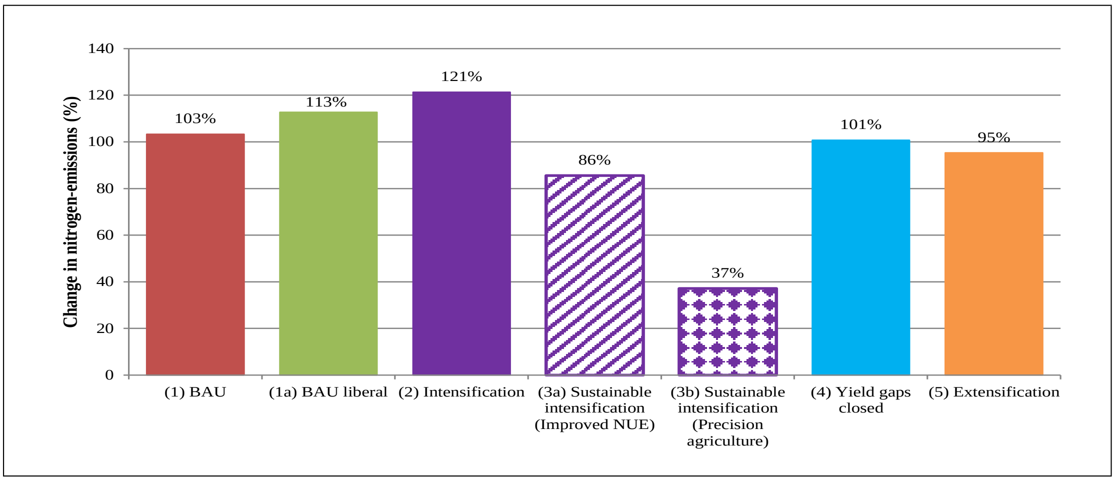

Figure 2.4: **Changes in nitrogen-emission rates in Latin America and the Caribbean between the base year 2000 and 2050 (in %).** BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 2.1. (Source: own elaboration)

yields are projected to decrease over time. Unsurprisingly in most FPUs, the steepest increase in N-emissions occur under the intensification scenario (2). Future hotspots of water degradation could be North-East Brazil (NEB_BRA), Amazon in Colombia (AMA_COL) and Coastal Peru (PEC_PER). However, if Precision Agriculture was applied (3b) in many FPUs the absolute amount of N-emissions would be reduced which would substantially reduce the risk for water degradation. For instance, in Middle Mexico (MIM_MEX) intensification (2) would increase N-emissions by almost 190% by 2050; however if Precision Agriculture was applied, total emissions could be almost 60% lower. This would not only mean a slower risk for degradation than under any other scenario, but a true improvement in 2050 compared to the base year 2000. One future hotspot with high risks for water pollution is the FPU North-South-America-Coast (NSA_NSA). The sharp increase in N-emissions is mainly caused by the N-emission increase on pasture land related to livestock production. The projected scale of excreta nitrogen produced in livestock production is relatively large with respect to the size of cropland and pasture land in this FPU, and therefore causes a sharp increase in N input rates on pasture land.

Impacts on carbon stock losses

Figure 2.5 illustrates changes in C stock losses from cropland expansion, while Figure 2.6 shows C losses from future pasture land expansion due to livestock production in LAC. Significant net losses of C stocks are expected to occur in LAC by 2050, irrespectively of the scenario of agricultural development considered.

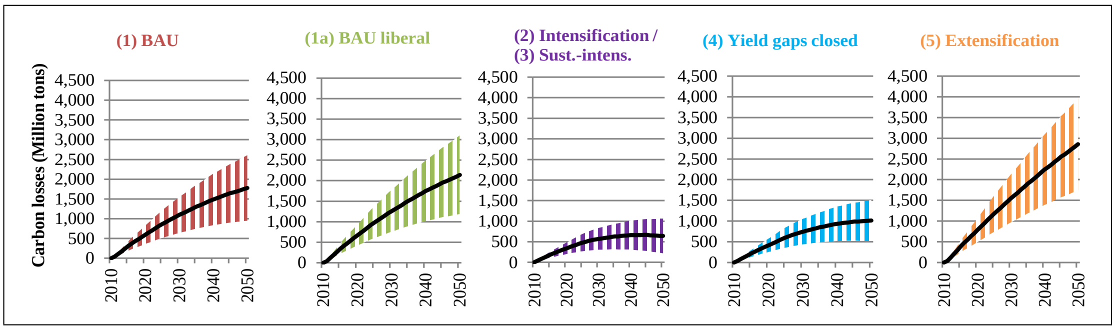

Figure 2.5: **Annual net changes in carbon stock losses due to crop production under different scenarios in Latin America and the Caribbean (2010 - 2050).** The values represent carbon stock losses from additional land conversion occurring in each year between 2010 and 2050. The shaded area illustrates carbon storage losses between a defined lower and upper bound due to different land expansion pathways. The lower bound reflects carbon storage losses if 100% of crop land expands over existing pasture land, while the upper bound reflects carbon storage losses if 100% of crop land expands over natural vegetation. The line illustrates the mean of the lower bound and upper bound. BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 2.1. The intensification (2) and sustainable intensification (3) scenarios are presented together, because both scenarios have the same productivity assumptions and they only differ in terms of water consumption and nitrogen-emissions.
(Source: own elaboration)

We find that C losses due to pasture land expansion from livestock production are even higher than C losses associated with crop production by 2050. This holds true, despite the fact that the conversion of natural land to pasture land releases less C than the conversion from natural land to croplands would do. As expected, the extensification scenario (5) would lead to the highest amount of carbon stock losses. Under this scenario approximately 106.7 million ha of natural land would be converted to pasture land. However, it is remarkable that the BAU scenario (1) shows lower C stock losses than the more intensive scenarios (2/3/4) which assume improved livestock yields. This finding points to the fact that further trade liberalization would strongly foster LAC's comparative advantage in livestock production. This would in turn lead to expanding pasture land areas with the associated C stock losses. C stock losses from cropland expansion show a different picture. Here, the magnitude of total C stock losses do not only depend on the production scenario, but also on the land conversion pathway. If cropland spreads over natural vegetation, the C stock losses will be between 2.6 to 4.8 times larger compared to cropland expansion over existing pasture land. This can be explained by the fact that converting natural land releases much higher amounts of C than converting pasture land to cropland. Again, trade liberalization would augment C losses due to increased production of the seven crops for export markets (see scenario 1a). As expected, under the extensification scenario (5) the effect of trade liberalization would be exacerbated, because lower yields and higher rainfed area growth would lead to higher cropland expansion. Under this scenario, up to 53.6 million ha could be cleared for cultivation by 2050, implying a net change in carbon stocks between 1,747 and 3,966 million tons of C, depending on the land expansion pathway. The intensification scenarios (2/3/4) appear to be the paths with the lowest C footprint. Under these scenarios, new cultivated area in 2050 is expected to stay below 23 million ha, which would be equivalent to C stock losses of 222 to 1,511 million tons.

LAC features several hotspots of C losses due to crop production across FPUs in LAC (for details see Appendix A16). Around 84% of the land cleared for crop cultivation is likely to occur in C-rich areas (FPUs with an average C content above 150 t/ha). Brazil and northern Argentina contribute the greatest carbon losses in absolute numbers due to substantial land conversion rates. The top FPUs experiencing C stock losses in Central America are Central America (CAM_CCA), Middle Mexico (MIM_MEX) and Yucatan (YUC_CCA). In the Central American FPU this can be attributed to high land conversion rates, while large losses in Yucatan are associated with substantial carbon storage in tropical forests. Hotspots of C losses from livestock production are different

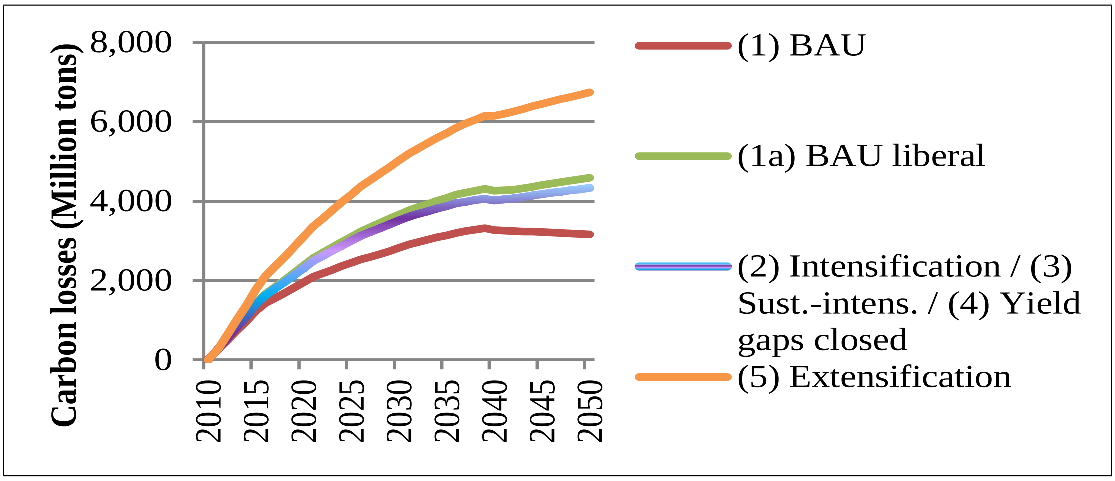

Figure 2.6: **Annual net changes in carbon stock losses due to livestock production under different scenarios in Latin America and the Caribbean (2010 - 2050).** The values represent carbon stock losses from additional land conversion occurring in each year between 2010 and 2050. BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 2.1. The intensification (2) and sustainable intensification (3) scenarios are presented together, because both scenarios have the same productivity assumptions and they only differ in terms of water consumption and nitrogen-emissions. (Source: own elaboration)

from those associated with cropland expansion (for details see Appendix A17). In South America C losses will be highest in the Orinoco river basin in Northern-South-America (ORI_NSA), North-East Brazil (NEB_BRA), and the Amazon in Central-South America (AMA_CSA) and Peru (AMA_PER). In these areas pasture land increases from livestock production by 2050 will be between 42% and 47% under the BAU scenario (1) and between (57% and 90%) assuming extensification (5). In Central America highest C losses occur in the Caribbean (CAR_CCA) and Cuba (CUB_CCA). A few areas see gains in C stocks due to reduced cultivated and pasture areas by 2050, or because the new land is able to store more C than the original vegetation.

Impacts on biodiversity

Figure 2.7 shows that species' risk of extinction and endangerment resulting from cropland expansion are likely to increase under all scenarios. However, the extent to which biodiversity will be at risk highly depends on the future production and land expansion pathway. Trade liberalization with its effects for agricultural production in LAC would increase the risk of biodiversity loss. Even more so, if yield growth rates slowed down and land growth rates accelerated as assumed under the extensification scenario (5). Intensifying production and closing yield gaps (scenarios 2/3/4) would lead to a much lower increase in species' risk of extinction, even if the upper bound was considered. However, biodiversity impacts are overall less significant compared to C losses. 84% of the projected increase in cropland under all scenarios is likely to be concentrated in a few FPUs, mostly those located in central, east and southern Brazil and northern Argentina. These FPUs contain 35% of the endemic bird richness of LAC. Yet, 60% of the Latin American birds' endemicity is concentrated in FPUs where land clearing for crop cultivation will only make up 12% between 2010 and 2050, even if the extensification scenario (5) was considered. In these rich birds areas, current average species' risk (S_{new}/S_{org}) is close to 34% which is likely to remain without major changes. Details on changes of biodiversity losses due to crop production across FPUs in LAC are given in Appendix A18.

The overall increase in species' risk of extinction and endangerment associated with pasture land expansion from livestock production will be higher than for cropland expansion (see Figure 2.8). As with the carbon trade-offs, intensifying livestock production cannot offset the negative biodiversity effects from pasture land expansion resulting from trade liberalization. Biodiversity will be most affected by livestock production in FPUs located in South America, among them Tocantins in Brazil (TOC_BRA) or the Orinoco river basin in Northern-South-America (ORI_NSA). Especially the FPU Tocantins in Brazil already showed a relatively high risk of biodiversity loss in 2010. By 2050 more than half of the species will be critically endangered as a result of pasture land expansion. Although the risk of biodiversity loss in the Orinoco river basin was lower compared to Tocantins in 2010, by 2050 the share of species endangered will increase substantially due to livestock production. Under the BAU scenario (1) without trade liberalization risk will increase by 5.9%-age points, while under the extensification scenario the risk will

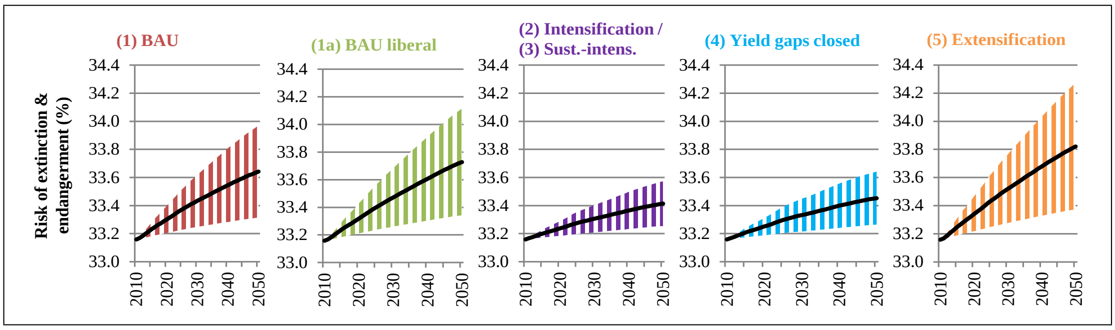

Figure 2.7: **Annual species risk of extinction and endangerment due to crop production under different scenarios in Latin America and the Caribbean (2010 - 2050).** The risk is expressed as an index in %. The shaded area illustrates the risk of biodiversity loss being between a defined lower and upper bound due to different land expansion pathways. The lower bound reflects the risk of biodiversity loss if 100% of crop land expands over existing pasture land, while the upper bound reflects the risk of biodiversity loss if 100% of crop land expands over natural vegetation. The line illustrates the mean of the lower bound and upper bound. BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 2.1. The intensification (2) and sustainable intensification (3) scenarios are presented together, because both scenarios have the same productivity assumptions and they only differ in terms of water consumption and nitrogen-emissions.
(Source: own elaboration)

even increase by 10.5%-age points. Details on risk of biodiversity losses due to livestock production across FPUs in LAC are provided in Appendix A19.

2.4 Discussion and conclusion

Combining the analysis of agricultural trade with its various economic and environmental impacts has gained growing interest, especially for large exporting regions like LAC. This study presents an integrated approach assessing the effects of trade liberalization and different possible future production paths. We compare a global BAU scenario, which assumes a continuation of past trends in productivity improvements, area growth and technological change, with alternative future production paths developed for LAC. In terms of economic impacts, our model results are in line with the conclusions of other authors, (see e.g. Godfray et al., 2010a, Schmitz et al., 2012), showing that further

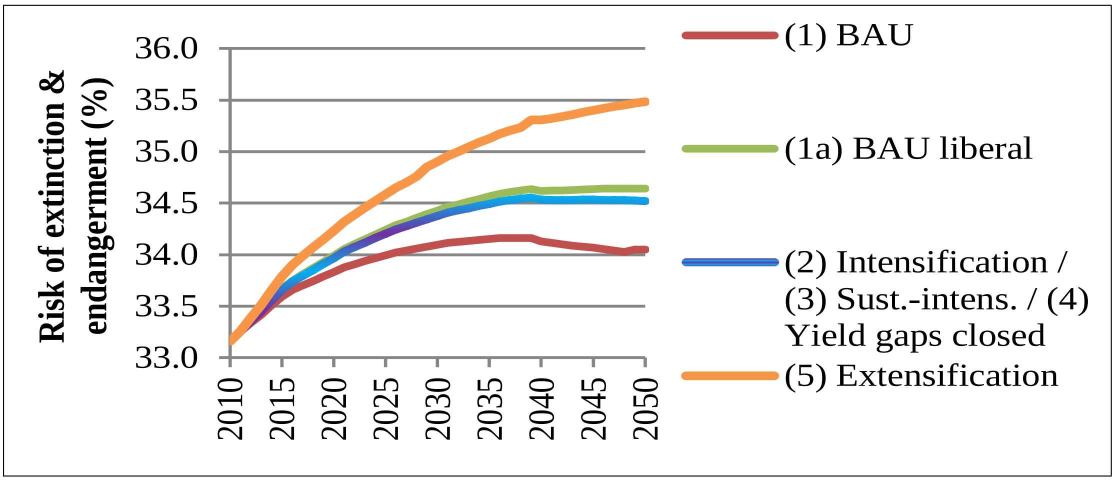

Figure 2.8: **Annual species risk of extinction and endangerment due to livestock production under different scenarios in Latin America and the Caribbean (2010 - 2050).** The risk is expressed as an index in %. BAU refers to the Business-as-Usual scenario.BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 2.1. The intensification (2) and sustainable intensification (3) scenarios are presented together, because both scenarios have the same productivity assumptions and they only differ in terms of water consumption and nitrogen-emissions.
(Source: own elaboration)

trade liberalization leads to lower global prices for most crops and livestock products. Production, especially for export markets, shifts to those regions that hold comparative advantages in food production. Especially LAC's livestock production would benefit from more open agricultural markets. This implies that trade liberalization is one way to improve global food security via higher global food supplies and lower prices. This does not mean, however, that there will not be regional winners and losers from trade policy reforms. In addition to agricultural trade, we find that different food production pathways will have differing effects on global food security.

On the basis of our partial equilibrium modeling, we find that extensifying agricultural production with low productivity improvements leads to lower production, net exports, and higher international food prices. An exception is soybean, where potential for productivity enhancement is lower, and the greatest opportunities for increased production are seen with rainfed land expansion, with clear trade-offs between land use and food production. However, land conversion is associated with substantial biodiversity losses and GHG emissions, a finding that is also confirmed by the literature, Fargione et al. (see e.g. 2008). We find these trade-offs will likely be concentrated in Brazil and northern Argentina. This points to the outstanding role of these two countries as global food – especially soybean– providers. The good news is that most of these FPUs are not among the biodiversity richest areas in LAC; but C stock losses would be considerable. The literature suggests that soybean expansion was the main driver of deforestation before 2005. But due to technical improvements and increased yields, followed by production expansion in previously cleared land, deforestation rates are now predominantly decoupled from soybean production (Macedo et al., 2012, Willaarts et al., 2014a). Following this argument, we suggest to interpret our results of the environmental trade-offs in these Brazilian and Argentinian FPUs (see Tables S5 and S7) to be closer to the lower bounds of C stock and biodiversity losses, because new cropland will most likely not directly expand over natural vegetation. The literature also finds that bovine meat exports from South America continue to be correlated with the growth of permanent pastures, mostly at the expense of forests (Macedo et al., 2012, Gasparri et al., 2013). Our findings confirm that livestock production will lead to more natural land conversion than crop production in LAC by 2050, independent of the future production scenario. This holds true even under the assumption that only additional livestock farming will lead to an increase in pasture land by 2050. This will probably underestimate the reality though, because often crops expand over pasture land, which in turn crowds out livestock into forests (Macedo et al., 2012, Gasparri et al., 2013). Thus, the risks of biodiversity and C stock losses associated with livestock production should be interpreted as a lower bound in our study. Also, water resources will be affected, aggravating water scarcity and water pollution in some regions. Vast amounts of N fertilizers are used to grow farm animal feed, primarily composed of maize and soybeans (Koneswaran and Nierenberg, 2008). So, if further global demand pressure leads to a continuation of past trends in soybean and livestock production, these countries will likely hit environmental limits with regional and global environmental consequences. Therefore, reducing meat consumption and thereby the demand for feedstuff as well as more responsible handling of food waste could be important ways to reducing demand pressures. Improvements in feeding efficiency (ratio of soybeans needed/kg meat produced) or promoting the consumption of meats with lower feed conversion losses (poultry) could make a contribution to reduce natural resource use. Even though it is difficult to change consumer habits, better information about healthy diets as well as environmental impacts of food consumption have shown some promise in the developed world (Willaarts et al., 2014a).

Aside from soybean production, our results show that improving productivities would be the most effective way to ensure sufficient food production in the future. If yield growth were sufficiently high, even zero rainfed area growth could not offset higher production quantities and trade which would imply improved global food security. We should note though that a substantial fraction of LAC' agricultural exports can be ascribed to energy crops (sugarcane). So increasing exports of these crops should have rather limited effects on improving global food security. Reconsidering biofuel policies in the developed world could create more area for food crops (Fargione et al., 2010). Our study also shows that more conventional intensification will come with environmental costs by further increasing water footprints and placing pressure on scarce water resources in some regions. Ercin and Hoekstra (2014) come to similar results for water footprints in the future comparing different scenarios. Our results show that increasing basin efficiencies by improving irrigation technologies could offset the overuse of water to a certain extent. For instance, sub-surface drip irrigation technologies, coupled with modernized irrigation systems, have the potential to significantly increase water efficiencies. These techniques can be applied to crops like maize, sugarcane, alfalfa, cotton, and soybeans. Also, agriculture increasingly competes with other water users. Given continued growth in urbanization, the principles of cross-sectoral water resources management should offer strategies to harmonize competing uses and protect ecosystem services.

Moreover, conventional agricultural intensification would increase the risk of water quality degradation due to increased N-loadings. Water pollution could be offset by improving NUE or through the adoption of Precision Agriculture. These findings are in line with results from studies conducted by Liu et al. (see e.g. 2010) and Bouwman et al. (2013). In the sustainable intensification scenario we assume an increase in NUE expressed as a fixed percentage rate of fertilizer input to crop output. This could be achieved through enhanced fertilizer use policies or breeding efforts. Precision Agriculture permits applying fertilizers where needs are most pressing, or where they generate the highest yield impacts. This however would mean large investments in new technologies, which might not be readily accessible by poorer farmers in those countries expecting the N pollution increases.

Results of the scenario in which yields gaps are closed show that closing yield gaps only in LAC is not sufficient to meet future global food demands, especially when combined with strict land conservation policies. The reason is that the discussed commercial crops already perform well in LAC compared to other world regions and therefore only a few areas in LAC show substantial yield gains. This does not mean that closing yield gaps is not valid to increase agricultural production to meet global food demand in 2050. For example, for many African countries, it will be important that yields catch up with other world regions (Ittersum van et al., 2012). Moreover, our results of potatoes in LAC show that closing yield gaps of this commodity will have strong positive market effects which could be environmentally friendly if natural resources were managed carefully.

Applying the global model IMPACT combined with environmental analyses yields many advantages, because it integrates inter-linked components, such as changes in climate, hydrology, water resources, or crop productivity. However, this is not without limitations. Due to the relatively coarse spatial resolution of the model, modeling water allocation at a more granular level is not possible, which might underestimate water scarcity in some areas of larger river basins. Furthermore, the hydrological model allows for groundwater pumping subject to an imposed capacity constraint, which might be an unrealistic assumption. Also, direct changes in livestock numbers currently do not feed back into the water supply and demand module, and are thus not reflected in scenarios of increased livestock numbers. In the extensification scenario, the BWF might therefore be underestimated. Finally, the agricultural research and development growth assumptions would imply close to immediate, significant investment. This is feasible, but agricultural research and development would have to move up on the priority scale in an increasingly urbanized society.

Apart from the limitations concerning the IMPACT model, there are other critical assumptions underlying our analysis. First of all, our alternative future scenarios only reflect production changes in LAC, while the rest of the world remains at BAU growth rates (except for trade liberalization which is assumed globally). Since our study looks at global food security indicators, it would likely be more meaningful if the improvements were applied at a global scale. However, our approach allows us to identify the specific role of a resource rich area like LAC for global food production. Another, more technical issue of our study is that the calculation of cultivated area is based on cropping intensities of the year 2000, approximately. This might lead to an overestimation of cultivated area with the corresponding environmental impacts in our study. Also, our pasture land estimations assume that live animals are based in the same FPUs as slaughtered animals, because IMPACT provides numbers of slaughtered animals. But animals are sometimes slaughtered in FPUs different from where they were raised. For example, according to Ramankutty et al. (2010) some Central American FPUs show pasture areas in the base year, but without equivalent volumes of slaughtered animals in IMPACT. However, the key livestock producing FPUs in South America are well covered. Furthermore, we assume that the share of different livestock production systems (agro-pastoral, mixed extensive, mixed intensive) per FPU to remain constant at year 2000 levels. This will not fully reflect the reality, because LAC might further intensify livestock production in the future, a trend that will also be influenced by future climate change (Koneswaran and Nierenberg, 2008, Thornton, 2010). Most importantly, our calculations are based on new pasture land from increasing livestock numbers only. This approach ignores possible dynamics between crop land expansion and displacements of pasture land from current livestock production (Arima et al., 2011, Macedo et al., 2012, Gasparri et al., 2013). In fact, pasture expansion, indirectly caused by farmland expansion and increasing exports of bovine meat, is considered the main cause of deforestation in the Brazilian Amazon (Arima et al., 2011). Hence, our future pasture land estimates are likely to be too conservative. In parts, we approach these interdependencies between cropland and pasture land expansion by defining a lower and upper bound of future cropland expansion. However, there is a further source of complexity making it difficult to attribute direct causes of land use change. Reduced deforestation in one region can lead to land conversion in other regions. These highly dynamic processes make a precise modeling exercise in space extremely difficult, especially if the model operates at a large regional scale, like the IMPACT model. Efforts are therefore underway to integrate a land use model into IMPACT in order to capture these interdependencies.

Our study also intends to tackle environmental impacts of future reforestation in some regions in LAC. Aide et al. (2013) found that between 2001 and 2010 LAC experienced intense deforestation (-541,835 km^2), but also reforestation (+362,430 km^2) processes. Forest transition (expansion and recovery of degraded forests) is common in Central America, Mexico, and in peri-urban ecosystems in South America, Andean forests and desserts and semi-arid ecosystems (Grau and Aide, 2008). Since IMPACT results do not only provide increases in area harvested, but also decreases in some FPUs, we account for a possible recovery of natural vegetation. We assume that C stocks and biodiversity regain their original levels. However, the C stock losses and adverse biodiversity impacts may not be fully reversible. Grau and Aide (2008) state that although marginal agricultural lands are being abandoned in many regions of Latin America, there is no guarantee that this will always lead to the recovery of natural ecosystems. On the one hand this might lead to an overestimation of the positive environmental impacts of reforestation in our study. On the other hand, a reduction in area harvested by 2050 is only estimated in a few FPUs in LAC, while the majority of FPUs show net increases.

In summary, we can state that Latin America is gaining in importance for supplying the rest of the world with food commodities. Due to market forces, LAC dedicates a large fraction of agricultural area to the production of livestock, feedstuff and biofuel crops. This means that wealthier population segments would benefit from the expansion of these products, rather than the poorest who consume staples. Nevertheless, limiting production by either insufficient yield increases or too strict land policies would not only reduce the production of soybeans and sugarcane, but also affect staple crops due to feedback effects between different agricultural commodities. So, increasing the amount of production is crucial (as are appropriate trade policies) for stabilizing world prices, and thereby improving food access of the poor. However, an increase of production comes at environmental costs in exporting nations. In order to reduce the environmental footprint of agricultural production without sacrificing future food security, policies must focus on promoting technological innovation that leads to higher yields without overusing water resources or polluting aquatic systems. Substantial yield increases could avoid excessive land use change with its devastating effects. Priority should be given to the adoption of existing sustainable technologies, good natural resource management inside and outside of agriculture, and most especially to investments in R&D in the agricultural sector (including, nutrients, pests, water and soils management, and improving plants' performance in semi-arid conditions and salty soils). Furthermore, LAC could switch away from extensive livestock farming to feedlot systems, which would reduce pasture land expansion and associated adverse environmental consequences. Future research should be geared to identifying the economic and environmental impacts of global solutions, instead of focusing on specific regions.

Chapter 3

The effects of agricultural trade openness on food price transmission in Latin American countries*

Abstract Trade of agricultural commodities has grown significantly in most countries in Latin America over the last two decades. However, after the international food price surges in 2006-08 and 2011-12 concerns about food access of the poor arose. Within a panel framework containing six LA countries (Argentina, Brazil, Chile, Colombia, Mexico and Peru), we used a single equation error correction model to identify possible cointegrating relationships between the food consumer price index (CPI) and a set of trade related and domestic variables. The main focus of the study was to examine how different levels of trade openness impact international food price transmission to domestic markets. Our results confirm that deeper market integration increases global price transmission elasticities. In other words, more agricultural trade openness proves to elevate food CPIs during global price spikes. Thus, for poor consumers world price shocks can be deteriorating in the short-run and domestic food prices will slowly converge to a higher long-run equilibrium. Especially in increasingly integrated economies, effective poli-

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cies to buffer food price shocks should be put in place, but must be carefully planned with the required budget readily available. We also found that exchange rate appreciations can buffer price shocks to a certain extent and that monetary policies seem to be an appropriate means for stabilizing food prices to safeguard food access of the poor population.

Keywords international food trade, market liberalization, global price shock, food security, food access, error correction model, consumer food prices

JEL Classification E31, Q11, Q17

3.1 Introduction

Since the mid-1980s, reducing agricultural and non-agricultural trade distortions has led to structural changes in Latin American (LA) countries, affecting food prices as well as economic development (Anderson et al., 2011). According to the "Law of One Price", trade liberalization leads to a price increase of exported food products and a price decrease of imported food, because domestic prices adjust towards global price levels (Goodwin et al., 1990, Miljkovic, 1999). However, the recent experience during the international food price crisis of 2006-08 and 2011-12 was a painful lesson to some of the poorer importing countries (Headey and Fan, 2008, Hoyos and Medvedev, 2011, Attanasio et al., 2013, Rodriguez-Takeuchi and Imai, 2013). Mendoza and Machado (2008)) states that food exporters that increasingly sell into international markets have experienced accelerated food price inflation. In this context, the transmission of high international prices into domestic prices has received attention (Benson et al., 2008, Dawe, 2008, Alemu and Ogundeji, 2010, Cudjoe et al., 2010, Jalil and Tamayo, 2011, Minot, 2011, Baquedano and Liefert, 2014). All these studies show country and crop specific results, suggesting different price transmission rates from international agricultural commodity markets to developing countries' domestic markets. Since food prices to a large extent determine poor consumers' ability to access sufficient food, these findings are very relevant in the global and regional food security discussion. Especially in those countries where food purchases comprise a large share of households' total expenditure, high transmission rates in times of rising international prices can push people into deeper poverty causing malnutrition and hunger. Many authors argue that countries that are more integrated into world markets might show higher world price transmission rates. However, the impact of trade openness on transmission rates has not been empirically investigated. From a national and sectoral policy perspective though, it would be crucial to be able to directly relate world price transmission to trade liberalization tendencies in the agricultural sector. Deeper knowledge about these interdependencies would help to design effective national food security programs (Dorward, 2012, Dawe and Maltsoglou, 2014).

The aim of this study is to examine the degree of cointegration between world food commodity prices and domestic food consumer prices. Specifically, we evaluate the impacts of liberalized agricultural trade regimes on price transmission rates for a panel of large LA trading nations (Argentina, Brazil, Chile, Colombia, Mexico and Peru). The choice of these six countries is based on a combination of factors. First, the sample includes the two largest emerging world food exporters (Argentina, Brazil), one of the most opened and export-oriented in the world for two decades (Chile), one of the most import-dependent for staple goods and with growing market integration in a trade block (Mexico and North American Free Trade Agreement, NAFTA), and two mid-size countries which recently changed its trade regimes (Colombia and Peru). Secondly, the six countries show remarkable growth of agricultural exports and imports (Willaarts et al., 2014a). And thirdly, except Argentina and Chile, the remaining four still face significant, though decreasing rates of food insecurity among the poorest. We use our estimation results to calculate actual transmission rates in crises years. Complementary to international market forces, we follow Durevall et al. (2013) and include some domestic macroeconomic causes possibly influencing food price movements.

Thus, our study complements and expands existing literature in several ways. Although the error correction model has been widely used with respect to price transmission analyzes (e.g. Cudjoe et al., 2010, Minot, 2011, Baquedano and Liefert, 2014), the effect of trade openness is still unsettled in the literature. Moreover, most previous studies on price transmission do not control for domestic food price determinants or the effects from movements in exchange rates. To our knowledge, only Dawe and Slayton (2010), Baek and Koo (2014) and Baquedano and Liefert (2014) take into account exchange rate effects, and Durevall et al. (2013) also consider agricultural supply and demand shifters. In contrast to many other papers, our analysis studies changes in food consumer price indices (CPI), instead of specific food items. We choose this approach, first because idiosyncratic food habits and the composition of the food basket vary significantly across the selected sample of countries. Secondly, the recent literature on food price transmission both for developed, mid-income and emerging countries has emphasized the role of macro-economic aspects (Dorward, 2012). And thirdly, using the food CPI allows for more general conclusions with regard to food security issues, because price changes of different products might lead to substitution effects within the food consumption basket.

Altogether, the results allow for drawing some conclusions about interactions of global market integration and urban food price changes in LA, considering current global market trends and different trade regimes. Although our results do not allow us to directly make conclusions about the effects of trade on food access of the poor, certainly changing urban food prices is one major driver for improving or exacerbating malnutrition.

3.2 Material and methods

3.2.1 Methods

Our empirical analysis is motivated by a composition of price determinants of tradable and non-tradable food items. We define the data generating process of the general price level as a function of the prices of tradable (P_{agT}) and non-tradable (P_{agNT}) goods:

$$P_A = f(P_{agT}, P_{agNT}) \qquad \text{(Eq. 3.1)}$$

Following the ""Law of One Price"", the price of tradable goods in a small open economy is determined in the world market. Depending on policy circumstances, such as tariffs, trade quotas or export taxes, the price can deviate from the world price level. This implies that the price of tradable goods (P_{agT}) is determined by the world market (Pw_{ag}), the exchange rate (xrt) as well as marketing margins ($margin$) and tax/subsidy wedges (ta) (Diaz-Bonilla and Robinson, 2010):

$$P_{agT} = xrt * Pw_{ag} * (1 + ta) * (1 + margin) \qquad \text{(Eq. 3.2)}$$

Non-tradable products cannot be imported or exported, and thus follow the market clearing condition (Gros and Hefeker, 2002). This means that their price is determined endogenously by the interaction between domestic demand (Q^d_{agNT}) and domestic supply (Q^s_{agNT}):

$$Q^d_{agNT} = Q^s_{agNT} \tag{Eq. 3.3}$$

In developing and emerging countries where a large share of the total household expenditure is on food, the demand for agricultural products is expected to be highly influenced by aggregate demand (Ahsan et al., 2011). Thus, we used money supply ($M2$) or alternatively the national unemployment rate ($Unemp$) as a proxy for total demand. Aggregate supply was proxied by world oil prices (Pw_{oil}) because an increase in oil prices is followed by an increase in input costs which in turn affects agricultural supply (Hanson, 1993, Nazlioglu and Soytas, 2011, Durevall et al., 2013) and also has been considered in the literature as shifter in the formation process of marketing margins in food chains (Leibtag, 2009, Davidson et al., 2011). If we subsume marketing margins ($margin$) and trade wedges (ta) under a trade openness indicator (top), domestic agricultural consumer food prices can be expressed by the following function:

$$P_A = f(Pw_{ag}, xrt, top, M2^1, Pw_{oil}) \tag{Eq. 3.4}$$

3.2.2 Empirical model

In general when dealing with macroeconomic time series data, one has to test whether the variables contain unit roots (non-stationarity), and if so whether they are cointegrated (Österholm, 2004). Our data showed these features, so we formulated an error correction model which permitted us to describe both the long-run equilibrium relationship and

[1] Alternatively for M2 (in local currency units or as a share of GDP) the unemployment rate is used to proxy demand.

the short-run dynamics between some independent variables and the dependent variable that were derived in Eq. 3.4. More specifically, we could estimate the extent to which consumer prices reacted to changes in world prices, exchange rate or money supply movements and the time it takes to adjust domestic consumer food prices to the new long-run equilibrium after a shock of one of the three variables (Baquedano et al., 2011). In addition to these three variables an interaction term between the world price index and trade openness was introduced to obtain insights about the effect of trade liberalization tendencies on long and short-term price transmission rates.

According to De Boef and Keele (2008), in time series analysis an explanatory variable may have only short term causal effects on the dependent variable or both short and long-run causal effects as described above. Short-run effects may occur at any lag, but the effect does not persist into the future. Thus, apart from the described variables with possibly long-run effects, we included an agricultural supply shifter, namely world prices of crude oil as derived above, where we assume only short-run effects.

To formulate the error correction model, we depart from an autoregressive distributed lag (ADL) model as described in Eq. 3.5. This general form of the model is reported as an ADL(1,1) process which means that one lag of the dependent and one lag of the possibly cointegrated independent variables are considered as regressors. However, we make no a priori assumptions about appropriate lag length in the model, but in our estimation procedure we follow a general to specific approach and eliminate insignificant lags to obtain a more parsimonious model.[2]

$$\begin{aligned} P_{A_{it}} &= \alpha_0 + \alpha_1 P_{A_{it-1}} + \psi_0 Pw_{AG_{it}} + \psi_1 Pw_{AG_{it-1}} + \phi_0 xrt_{it} + \phi_1 xrt_{it-1} \\ &\quad + \zeta_0 M2_{it} + \zeta_1 M2_{it-1} + \beta_0 top_{it} + \beta 1 top_{it-1} \\ &\quad + \omega_0 (Pw_{AG_{it}} * top_{it}) + \omega_1 (Pw_{AG_{it-1}} * topit - 1) + \eta_0 Pw_{oil_{it}} + \tau yd_t + \nu_i + \varepsilon_{it} \end{aligned} \qquad \text{(Eq. 3.5)}$$

[2] We begin with an ADL(8,8) which implies eight lags for dependent and independent variables. Taking the AIC and BIC criterion we eliminate insignificant lags.

where i represents the cross-section (country), t the different years of the panel and yd are year dummies, ν_i are country fixed effects and ε represents the iid error term.

The standard modeling approach when dealing with non-stationary and cointegrated variables has been the two step Engle and Granger (1987) error correction model. In our study, however, we rely on a single equation error correction model (SEECM), because it has the advantage that not all time series variables need to have unit roots (Banerjee et al., 1998, Lütkepohl, 2005). For the panel data we applied unit root tests following Levin et al. (2002) and Im et al. (2003). For the world price data which repeat in each cross-section, we used the regular Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) stationarity tests.

To derive the unrestricted SEECM, we add and subtract lags of the variables in Eq. 3.5 which yields in Eq. 3.6:

$$\begin{aligned}\Delta P_{A_{it}} &= \alpha_0 + (\alpha_1 - 1)P_{A_{it-1}} + \psi_0 \Delta Pw_{AG_{it}} + (\psi_0 + \psi_1)Pw_{AG_{it-1}} + \phi_0 \Delta xrt_{it} \\ &\quad + (\phi_0 + \phi_1)xrt_{it-1} + \zeta_0 \Delta M2_{it} + (\zeta_0 + \zeta_1)M2_{it-1} + \beta_0 \Delta top_{it} \\ &\quad + (\beta_0 + \beta_1)top_{it-1} + \omega_0(\Delta Pw_{AG_{it}} * \Delta top_{it}) + (\omega_0 + \omega 1)(PW_{AG_{it-1}} * top_{it-1}) \\ &\quad + \eta_0 \Delta Pw_{oil_{it}} + \tau yd_t + \nu_i + \varepsilon_{it}\end{aligned} \qquad \text{(Eq. 3.6)}$$

After substituting and factoring common parameters, we arrive at:

$$\begin{aligned}\Delta P_{A_{it}} &= \alpha_0 + \delta P_{A_{it-1}} + \lambda_0 \Delta Pw_{AG_{it}} + \lambda_1 Pw_{AG_{it-1}} + \theta_0 \Delta xrt_{it} + \theta_1 xrt_{it-1} \\ &\quad + \kappa_0 \Delta M2_{it} + \kappa_1 M2_{it-1} + \mu_0 \Delta top_{it} + \mu_1 top_{it-1} + \pi_0(\Delta Pw_{AG_{it}} * \Delta top_{it}) \\ &\quad + \pi_1(Pw_{AG_{it-1}} * top_{it-1}) + \eta_0 \Delta Pw_{oil_{it}} + \tau yd_t + \nu_i + \varepsilon_{it}\end{aligned} \qquad \text{(Eq. 3.7)}$$

where $\delta = (\alpha_1 - 1)$; $\lambda_0 = \psi_0$; $\lambda_1 = (\psi_0 + \psi_1)$; $\theta_0 = \phi_0$; $\theta_1 = (\phi_0 + \phi_1)$; $\kappa_0 = \zeta_0$;

$\kappa_1 = (\zeta_0 + \zeta_1)$; $\mu_0 = \beta_0$; $\mu_1 = (\beta_0 + \beta_1)$; $\pi_0 = \omega_0$; $\pi_1 = (\omega_0 + \omega_1)$. Collecting common terms after rearranging Eq. 3.7, we obtain the following SEECM equation:

$$\begin{aligned}\Delta P_{A_{it}} &= \alpha_0 + \vartheta \Delta Pw_{AG_{it}} + \rho \Delta xrt_{it} + \kappa \Delta M2_{it} + \mu \Delta top_{it} + \pi(\Delta Pw_{AG_{it}} * \Delta top_{it}) \\ &+ \eta \Delta Pw_{oil_{it}} + \delta(P_{A_{it-1}} - \gamma Pw_{AG_{it-1}} - \varphi xrt_{it-1} - \xi M2_{it-1} - \epsilon top_{it-1} \\ &- \chi(Pw_{AG_{it-1}} * top_{it-1})) + \tau yd_t + \nu_i + \varepsilon_{it}\end{aligned} \qquad \text{(Eq. 3.8)}$$

where $\vartheta = \lambda_0$; $\rho = \theta_0$; $\kappa = \kappa_0$; $\mu = \mu_0$, $\pi = \pi_0$ and $\eta = \eta_0$ are the short-run elasticities. The long-run elasticities are given by $\gamma = (1 - \lambda_1/\delta)$; $\varphi = (1 - \theta_1/\delta)$; $\xi = (1 - \kappa_1/\delta)$; $\epsilon = (1 - \mu_1/\delta)$; $\chi = (1 - \pi_1/\delta)$; δ represents the error correction term which indicates the speed of adjustment to the new long-run equilibrium. To obtain consistent standard errors of the long-run coefficients we perform the Bewley's transformation (for details see De Boef and Keele (2008) and footnotes in Baquedano and Liefert (2014).

A cointegration relationship assumes that ($\gamma \neq 0$, $\varphi \neq 0$, $\xi \neq 0$, $\epsilon \neq 0$) and ε_{it} is stationary I(0). If none of the long-run coefficients is significantly different from zero the variables are not cointegrated, while a coefficient of one would mean complete transmission. Coefficients can also take on values larger than one, which would mean that the dependent variable over-shoots when the independent variable experiences a shock.

Eq. 3.8 was estimated using a panel approach and controlling for country fixed effects to limit omitted variable bias. After testing for serial correlation in the idiosyncratic errors, following Wooldridge (2002), we assumed the error term of this model follows a first order autoregressive process. Further, we needed to correct for heteroscedasticity. Thus, the model was estimated using STATA's xtpcse and xtgls commands which execute a Praise Winsten estimator and a Feasible Generalized Least Squares estimator, respectively.[3] These models assume weak exogeneity of all independent variables, mean-

[3] For details on methods see Greene (2003).

ing that causality runs from world prices, exchange rate and money supply to domestic consumer food prices. Since this might be a strong assumption for the exchange rate, money supply, and maybe even world prices[4], we treated those variables as endogenous using a system GMM estimator (Blundell- Bond)[5] to check whether the simultaneous equation bias is severe. To guarantee the robustness of the estimator, we tested the moment conditions for no serial correlation in the idiosyncratic errors. Further we tested whether the moment conditions used are valid by implementing the Sargan test (for details see Arellano and Bond (1991).

Applying the relatively new approach of using panel data in an error correction model[6] instead of single country estimates has some advantages and disadvantages. Since trade data are only available annually, this approach allowed us to estimate a possible long-run relationship between variables, even though the time dimension would have been too short for making reliable inference for any single country estimation. A weakness of the panel data estimation might have to do with sample selection bias in the estimates. To check whether our estimates suffered from this bias, we compared model results from the full six country panel with results from only including five countries in the regression (omitting either Argentina or Brazil or Chile or Colombia or Mexico or Peru).

Our study is meant to discuss food price transmission after recent food price spikes with a specific focus of evaluating the effects of more trade openness in a sample of LA countries. First, we applied actual degrees of agricultural trade openness within each country in the year of the price spike to compare food price transmission across countries. Secondly, we constructed a set of counterfactual degrees of trade openness in the year of the price shock to measure by how much food price transmission depends on the degree of trade liberalization. SEECM provides the long-run coefficients γ, χ and

[4] World prices and domestic prices would only be endogenously determined if the country was a large importing or exporting nation with enough market power to change the world price. Since our sample includes very large agricultural trading nations like Brazil and Argentina, simultaneous endogeneity might be problematic. However, we are using food price indices containing many different products, so it more likely that all countries are price takers.

[5] For details see Blundell and Bond (1998).

[6] Panel data methods for non-stationary data were first developed in the early 1990s and only recently applied more frequently. For details see (e.g. Kao, 1999, Maddala and Wu, 1999, Levin et al., 2002).

the speed of adjustment $|\delta|$ as well as the short run coefficients ϑ and π. Employing such a multiplicative interaction model allowed us to calculate the marginal effect of world price changes on domestic food CPI, depending on the level of trade openness, which is given as by:

$$\frac{\partial P_A}{\partial Pw_{AG}} = \gamma + \chi * top \qquad \text{(Eq. 3.9)}$$

(respectively for short-run world price elasticities). Note that the marginal effect can still be significantly different from zero even if the coefficient of the interaction term were insignificant, because the standard error of the marginal effect is not a direct output of the regression result, but must be calculated as follows (Brambor, 2005):

$$\hat{\sigma}_{\frac{\partial P_A}{\partial Pw_{AG}}} = \sqrt{var(\hat{\gamma}) + (top)^2 var(\hat{\chi}) + 2(top)cov(\hat{\gamma}\hat{\chi})} \qquad \text{(Eq. 3.10)}$$

Furthermore, we calculated the median lag-length of the 2008 shock's effect on domestic food prices. We followed Baquedano and Liefert (2014) and defined the median lag-length as the number of periods at which at least half of the new equilibrium value of the domestic food price from the world price shock is reached. Mathematically, this can be expressed as follows (De Boef and Keele, 2008):

$$m = \frac{\sum_{t=0}^{T} \nu_t}{\sum_{t=0}^{\infty} \nu_t} \qquad \text{(Eq. 3.11)}$$

where $\sum_{t=0}^{\infty} \nu_t$ is the long run transmission elasticity of the world price. $\sum_{t=0}^{T} \nu_t$ is the summation across the number of periods T of the adjustment process towards the new food price equilibrium. Thus, the median laglength is reached when $m \geq \gamma + \chi * top$.

Table 3.1 summarizes some hypotheses of the effects of each variable on domestic consumer food prices. Note that we limit ourselves to interpreting the marginal effect of the interaction term, instead of the constitutive terms "world price index" and "trade openness". The reason is that in the applied multiplicative interaction model, γ captures the marginal effect of a one percent increase in world prices when trade openness is zero which is an unrealistic assumption.

Table 3.1: Hypotheses of the relevant variables' effect on domestic food price levels

Variable	**Hypothesis**	**Ground**
Interaction term between world agricultural prices and agricultural trade openness indicator (Trade openness * World price index)	Food prices increase	World food price transmission is expected to increase with higher degrees of trade openness, because countries would be more affected by international price fluctuations than rather closed economies.
Exchange rate	Food prices increase	In the short-run, a currency depreciation makes imports more expensive, and thus prices of tradables rise. A depreciation also makes exports more competitive in the world market, thereby increasing demand for LA's food products and hence prices.
Money supply	Food prices increase	If money supply increases, aggregate demand increases which leads to a higher price level in the economy, including food prices.
Unemployment rate	Food prices decrease	If unemployment increases, aggregate demand decreases which leads to a lower price level in the economy, including food prices.
World oil prices	Food prices increase	If input costs in agricultural production increase, aggregate supply decreases which leads to increasing food prices.

3.2.3 Data

Our dataset contains six cross-sections (Argentina, Brazil, Chile, Colombia, Mexico and Peru) and includes time series data from 1995 until 2013 which adds up to 114 observations. Appendix B1 gives an overview of all data with sources and Appendix B2 shows the corresponding descriptive statistics of each variable.

Figure 3.1 illustrates the dynamics in our six LA countries, with respect to global and domestic food price movements, the general CPI trend as well as changes money supply and the exchange rate between 1995 and 2008. There was a certain co-movement of world food prices and domestic food prices, especially in Argentina, Chile and Peru. In all countries, except Argentina, food prices rose faster than the general price level after 2007 which coincides with the recent high price trend in international food commodity markets. Appendix B3 visualizes developments of trade openness in the agricultural sector between 1995 and 2013. In the early 2000's, agricultural trade as a share of agricultural GDP began to rise sharply, particularly in Brazil, Chile and Mexico.

3.3 Results

Before discussing the long-term and short-term determinants of domestic consumer food prices in light of agricultural trade openness, we give a brief overview of the stationary properties of our data. Table 3.2 shows that most time series in levels contain unit roots, but are stationary in first differences. Only the unemployment rate, and maybe the exchange rate and trade openness (depending on the unit root test applied) are also stationary in levels.[7] This indicates that the SEECM is the appropriate method, because the model is not restricted to non-stationary data. An alternative way to treat non-stationary data would be to estimate a model with variables transformed to first differences. However, this approach does not capture the long-run properties of cointe-

[7] All tests were conducted with and without a deterministic trend. Because of space constraints, we present only the results without trend, as they do not change our conclusions about the stationarity properties of our data series. The tests were initially conducted with a maximum of 8 lags. However, the tests results were no different when using a more parsimonious lag structure. The results of the non reported tests are available from the authors upon request.

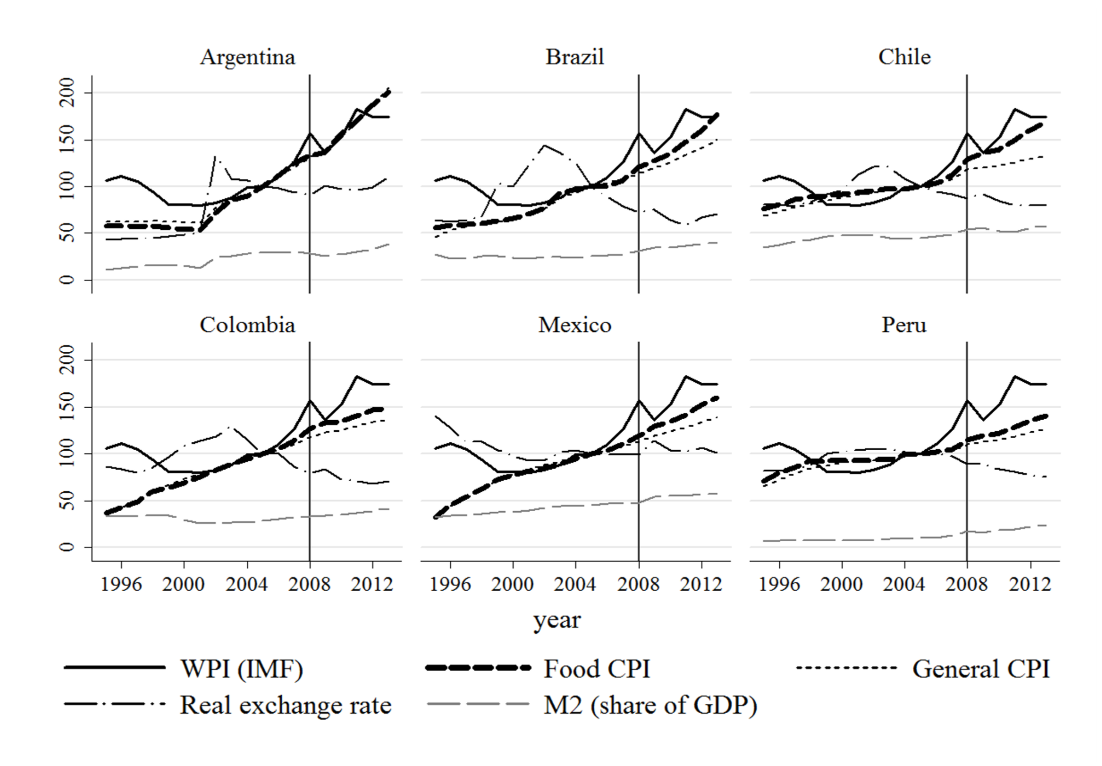

Figure 3.1: **Evolution of the world price index (food and beverages IMF), domestic general consumer price indices (CPIs), domestic food CPIs (base year 2005), and money supply (expressed as a percentage of GDP) and real exchange rate movements (expressed as an indicator).**
(Source: Data obtained from FAO (2014), ECLAC (2014) and Inter-American Development Bank (2014))

grated variables. We therefore only performed SEECM estimations.

Our estimates of domestic food price determinants are reported in Table 3.3, showing the results of the Praise Winsten regressions. Other model specifications and estimations using the FGLS estimator or the system GMM estimator are omitted because they yield very similar results to the Praise Winsten regression. This shows that endogeneity of world price indices, the exchange rate and money supply is not problematic. Table 3.3 is structured so that the first column shows results of estimations using the world price index of the International Monetary Fund (IMF), while the second column shows the same results using instead the world price index provided by FAO. The last two columns

Table 3.2: Unit root tests

	in levels		in differences	
Panel unit root tests	**LLC**	**IPS**	**LLC**	**IPS**
Food CPI (log)	-6.86	-0.20	**-1.20****	**-3.82****
Trade openness	- 2.94	**-1.46***	**-2.53*****	**-9.32*****
World price index (IMF) (log)* Trade openness	- 3.28	-1.00	**-1.87*****	**-8.13*****
World price index (FAO) (log)* Trade openness	- 3.10	-0.98	**-2.71*****	**-8.10*****
Exchange rate (log)	**-12.18****	-0.04	**-3.25*****	**-4.09*****
M2 (in local currency) (log)	- 3.81	-0.25	**-2.05*****	**-4.70*****
M2 (as share of GDP) (log)	- 3.62	-1.02	**-2.76*****	**-6.43*****
Unemployment rate (log)	**-1.67****	**-3.24*****	**-7.17*****	**-3.39*****
Unit root tests for world prices	**ADF**	**PP**	**ADF**	**PP**
World food price index (IMF)	-0.25	-0.14	**-2.82***	**-3.32****
World food price index (FAO)	0.00	-0.29	**-3.02****	**-3.50*****
World prices crude oil	-0.12	-0.43	**-3.52*****	**-4.60*****

Note: LLC = Levin et al. (2002), IPS = Im et al. (2003). The statistics are asymptotically distributed as standard normal with a left hand side rejection area. Total number of observations (N * T) are 114. ADF = Augmented-Dickey-Fuller and PP = Phillips-Perron test applied for all world price variables 19 years being the number of observations. For all tests *, **, *** denote rejection of the null hypotheses of non-stationarity at 0.1, 0.05, 0.01 significance levels. All tests were performed in levels and first differences. Maximal lag length is selected by Schwert's rule of thumb, optimal lag length selection according to the Akaike information criterion (AIC). Method used to estimate the long-run variance of each panel's series according to Levin et al. (2002). Estimated with STATA's xtunitroot and dfuller/pperron commands.

are reported to demonstrate robustness of the results with respect to sample selection bias. Since Brazil represents a very large exporting nation and Mexico a very large importing nation, we report five country panel estimates without these two countries. We also ran regressions without Argentina, Chile, Colombia or Peru, but the main coefficients remain stable, so results are not reported.[8] Even though selection bias is not severe, depending on the countries included, estimates of price transmission deviate from each other to a certain extent. However, the main trends remain unchanged, so we ignore these slight differences and interpret only the six-country panel estimate that uses world prices provided by the IMF. Postestimation diagnostic tests are reported for all models demonstrating validity of the estimation.

All coefficients of the significant variables have the expected sign, independent of the model specification or the estimator. We are primarily interested in the marginal effect of the world food price index on the domestic food price index with varying levels of trade openness. Hence, Table 3.4 shows the calculated marginal effects and the corresponding standard errors according to Eq. 3.10. Note that although the short-run coefficient of the

[8] They are available from the authors upon request.

Table 3.3: Long-run and short-run elasticities of food price determinants

	Panel of six countries		**Panel of five countries (without Brazil)**	**Panel of five countries (without Mexico)**
	World price index IMF	**World price index FAO**	**World price index IMF**	**World price index IMF**
Long run elasticities				
EC	**-0.2323*** **	**-0.2282*** **	**-0.2316*** **	**-0.1914*** **
Standard error	(0.028)	-0.028	-0.025	-0.032
World price index	**0.6801*** **	**0.6271*** **	**0.5368*** **	**0.8050*** **
Standard error	(0.023)	-0.018	-0.016	-0.055
TOP	**-0.0030*** **	**-0.0026*** **	**-0.0082*** **	**-0.0026*** **
Standard error	(0.000)	(0.000)	(0.000)	(0.000)
TOP*World price index	**0.0006*** **	**0.0005*** **	**0.0018*** **	**0.0005*** **
Standard error	(0.000)	(0.000)	(0.000)	(0.000)
Exchange rate	**0.5834*** **	**0.5921*** **	**0.5662*** **	**0.6100*** **
Standard error	(0.002)	(0.002)	(0.002)	(0.004)
M2 (local currency)	**0.0530*** **	**0.0454*** **	**0.0247*** **	**0.0197*** **
Standard error	(0.003)	(0.003)	(0.002)	(0.005)
Short run elasticities				
World price index	**0.1850*** **	**0.1577*** **	**0.1598*** **	**0.2238*** **
Standard error	(0.042)	(0.033)	(0.039)	(0.050)
TOP	**-0.0010*** **	**-0.0009** **	**-0.0008** **	**-0.0009** **
Standard error	(0.000)	(0.000)	(0.000)	(0.000)
TOP*World price index	0.0032	0.0018	0.0035	0.0033
Standard error	(0.003)	(0.002)	(0.003)	(0.003)
Exchange rate	**0.3067*** **	**0.3171*** **	**0.3194*** **	**0.2841*** **
Standard error	-0.034	-0.034	-0.034	-0.037
M2 (local currency)	**0.1259*** **	**0.1280*** **	**0.1372*** **	**0.0896** **
Standard error	(0.039)	(0.039)	(0.036)	(0.045)
Crude oil prices	-0.0044	-0.0039	-0.0053	-0.0116
Standard error	(0.014)	(0.014)	(0.013)	(0.016)
Post-estimation				
Observations	108	108	90	90
R^2	0.76	0.76	0.85	0.7
Wooldrige test for autocorrelation (p–value)	-0.113	-0.183	-0.452	-0.211
Levin-Lin-Chu unit-root test of residuals (p-value)	(0.000)***	(0.000)***	(0.000)***	(0.000)***
IPS unit-root test of residuals (p–value)	(0.037)**	(0.020)**	(0.003)***	(0.066)*

Notes: *** $p \leq 0.01$, ** $p \leq 0.05$, * $pp \leq 0.1$. TOP = Trade openness indicator. All estimations were performed using the natural log of each variable and with country fixed effects, except "TOP" which was performed in levels, because it is already a relative measure in %. EC = Error correction term or speed of adjustment. Unit root test: Ha = residuals are stationary confirming cointegration. Tests for autocorrelation: Ha = no serial correlation of the error term.

interaction term is insignificant (see Table 3.3), the marginal effects of the parameters become statistically significant until trade openness reaches 140%. Since all countries of interest (except for Chile after 2003) are within this range, insignificance of higher degrees of trade openness does not affect our interpretations severely. Table 3.4 illustrates that increasing levels of trade openness especially impact the degree of price transmission in the short-run. In other words, if there is a global food price shock, the instantaneous reaction of the domestic food CPI highly depends on the level of market integration. Long-run transmission rates are also positively influenced by higher degrees of trade-openness and significant at all levels. However, the effect of trading activity is more moderate in the long-run than in the short-run.

We applied the discussed results to six LA countries and estimated price transmission rates after the international food price spike of 2008. All countries showed different degrees of agricultural market integration during the price shock: Argentina 107%, Brazil 45%, Chile 220%, Colombia 45%, Mexico 80% and Peru 70% (see Appendix B3). This has led to different world food price transmission rates, varying between 100% in Brazil and Colombia, 110% in Peru, 120% in Mexico, 130% in Argentina and 170% in Chile[9] (short-run plus long-run transmission) in our six studied countries.

In 2008 world food prices (International Monetary Fund) rose by 24% compared to year 2007. This means that, ceteris paribus, food CPIs adjusted 25% in Brazil and Colombia, 27% in Peru, 29% in Mexico, 31% in Argentina and 41% in Chile as a reaction to the 2008 price shock. Figure 3.2 depicts this nexus, showing that for example Argentina's food CPI strongly reacted in the short-run (13% CPI adjustment), but that the long-run trend was similar to the one of the other countries. In contrast, Colombia's short-run food CPI adjusted only by eight percent due to its much lower agricultural market integration. As mentioned, the long-run adjustment rates varied less among countries. A notable effect on long-run price transmission rates only shows at very high degrees of trade openness, like in the case of Chile. Here, the long-run price transmis-

[9] Chile's long-run coefficient of the marginal effect is statistically significant. But the short-run coefficient is not, so there are higher uncertainties in the interpretation of the effects of trade openness on total price transmission than for the other countries.

Table 3.4: Short and long-run marginal effects of world price shocks under different degrees of trade openness

	Panel of six countries		Panel of five countries (without Brazil)		Panel of five countries (without Mexico)	
Degrees of TOP	Marginal effect short-run	Marginal effect long-run	Marginal effect short-run	Marginal effect long-run	Marginal effect short-run	Marginal effect long-run
0	0.185***	0.680***	0.160***	0.537***	0.224***	0.805***
	(0.041)	(0.033)	(0.039)	(0.027)	(0.050)	(0.048)
20	0.250***	0.693***	0.230***	0.574***	0.289***	0.817***
	(0.064)	(0.030)	(0.060)	(0.024)	(0.070)	(0.045)
40	0.315***	0.706***	0.301***	0.611***	0.355***	0.828***
	(0.111)	(0.027)	(0.106)	(0.022)	(0.119)	(0.042)
60	0.380**	0.719***	0.371**	0.648***	0.420**	0.840***
	(0.164)	(0.025)	(0.156)	(0.021)	(0.174)	(0.040)
80	0.445**	0.732***	0.441**	0.685***	0.486**	0.851***
	(0.219)	(0.025)	(0.207)	(0.021)	(0.231)	(0.038)
100	0.510*	0.745***	0.512*	0.721***	0.551*	0.863***
	(0.273)	(0.025)	(0.259)	(0.021)	(0.289)	(0.037)
120	0.575*	0.758***	0.583*	0.758***	0.617*	0.874***
	(0.328)	(0.027)	(0.311)	(0.023)	(0.345)	(0.037)
140	0.640*	0.771***	0.653*	0.795***	0.683*	0.886***
	(0.383)	(0.027)	(0.362)	(0.025)	(0.405)	(0.038)
160	0.704	0.784***	0.724*	0.832***	0.748	0.897***
	(0.438)	(0.033)	(0.414)	(0.028)	(0.463)	(0.040)
180	0.769	0.797***	0.794*	0.869***	0.814	0.909***
	(0.493)	(0.036)	(0.466)	(0.032)	(0.522)	(0.042)
200	0.834	0.811***	0.865*	0.906***	0.879	0.921***
	(0.548)	(0.040)	(0.518)	(0.035)	(0.581)	(0.045)
220	0.899	0.824***	0.935	0.943***	0.945	0.932***
	(0.603)	(0.045)	(0.571)	(0.039)	(0.639)	(0.048)

Note: *** $p \leq 0.01$, ** $p \leq 0.05$, * $pp \leq 0.1$. Standard errors are given in parentheses below the parameter estimates. TOP = Trade openness indicator. The marginal effects measure the reaction of world food price changes on domestic food prices, considering different degrees of trade openness. Trade openness is measured as the sum of export and import values over agricultural GDP. Marginal effects were obtained from estimates using the World price index (IMF).

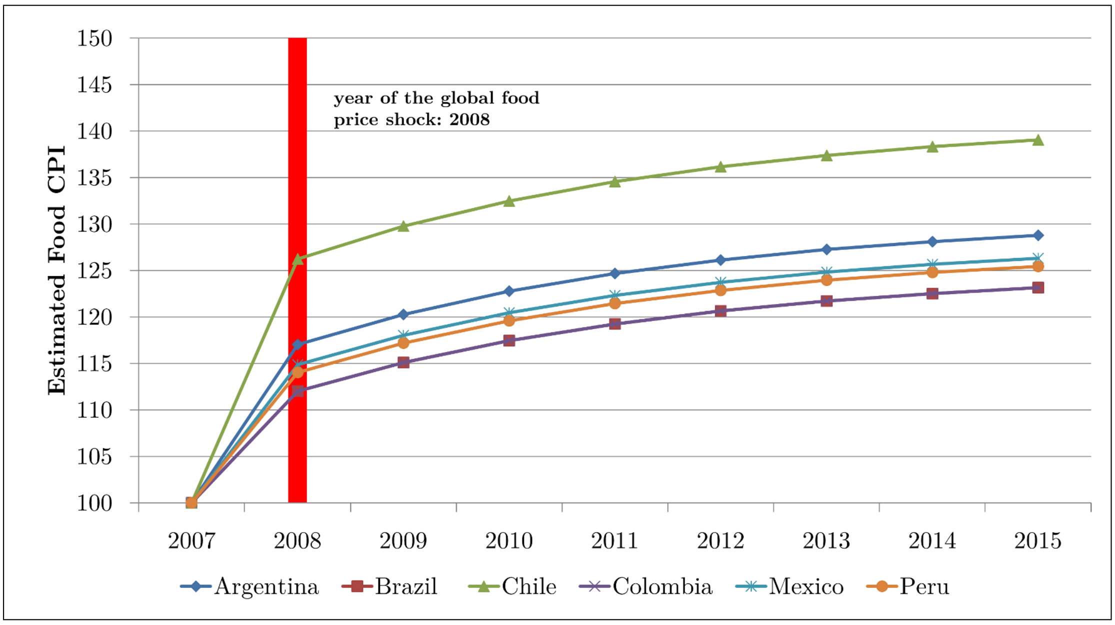

Figure 3.2: **Short-term and long-term estimated food CPI (measured as an index) in each country after a 24% world price shock in year 2008 (ceteris paribus), taking into account different trade openness levels in the different countries.** Trade openness levels are as follows: Argentina: 107%, Brazil: 45%, Chile: 220%, Colombia: 45%, Mexico: 80% and Peru: 70%. Short-run price transmission rates vary between 35% and 147%, long-run price transmission elasticities vary between 66% and 89%, depending on the level of trade openness. In 2015 about 90% of total price transmission is reached. Food CPI base year 2007.
(Source: own elaboration)

sion elasticity is about 11% higher than in Brazil, being the country showing less market integration. The estimated long-run transmission elasticities translated into a long-run food CPI adjustment of 17% in Colombia or Brazil and 20% in Chile after the world food price shock of 2008. The other countries were in between 17 and 20%. Figure 3.3a illustrates these long-run adjustment pathways in our six countries. Figure 3.3b shows the speed of the long-run adjustment beginning in 2008. The median lag-length was reached within the first three years after the price shock. Hence, the bulk of food price adjustment took place in the short-run.

To get a very clear picture of how transmission rates change according to different

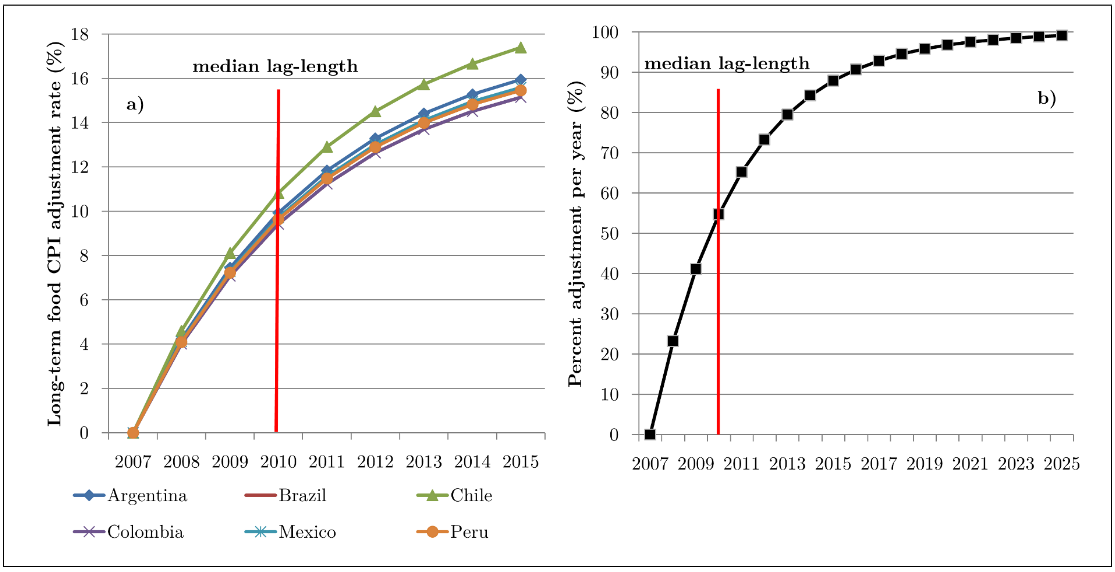

Figure 3.3: **a) Long-term food CPI response in each country due to a 24% world price increase between year 2007 and 2008, taking into account different levels of trade openness in the six countries (in %). b) Yearly percent adjustment rates of total long-term CPI adjustment.** Median lag length is reached in period 3 (year 2010). (Source: own elaboration)

levels of trade openness, we constructed three different counterfactual scenarios of trade openness. If the level of agricultural trading activity in LA had only been around 20%, total price transmission rates would have been reduced to 94%. Thus, as a reaction to the 2008 price spike, domestic food CPIs would only have increased by 23%. In contrast, if a country had had degrees of trade openness of 100% or 200%, the estimated price transmission rates would have been at 125% or 163%, respectively. This would have caused total food CPI adjustments of 30% or 39% (short plus long-run effects).

Apart from world market integration and volatile global food prices, we investigated the role of some macroeconomic factors that influence food prices (see Figure 3.1). These variables can be relevant from a policy perspective. Table 3.3 shows that exchange rate movements have quite strong positive short-run and long-run effects on domestic food prices. This means that imports get more expensive if a currency depreciates, making domestic food more expensive. Simultaneously, a depreciation makes export markets more competitive which in turn increases foreign demand for domestic food products, and hence food prices. Related to year 2008, exchange rate movements were rather moderate, so appreciations or depreciations did not have a strong effect during that time. Argentina, Chile and Mexico showed almost no movement in exchange rates. Only Brazil, Colombia and Peru saw their domestic currencies appreciate against the US dollar by five to six percent. These currency appreciations had a food price depressing effect between 1.6 and two percent in the short-run, and around 3.5% in the long-run starting in 2008. Opposed to the exchange rate, real money supply increased between 2007 and 2008 at rates between 10% in Mexico and almost 60% in Peru. According to Table 3, a 100% increase in money supply increases food prices by 13% in the short-run and an additional five percent in the long-run.

3.4 Discussion

Globally, hunger still affects 868 million people, of which 49 million are located in LA (FAO, 2012). However, over the last decade Latin America stands among the regions that achieved larger improvements in fighting hunger. FAO (2012) states that food security is not only about sufficient disposable food supplies in quantitative terms, but primarily about the challenge of food access in economic terms. Since food makes up a large share of poor consumers' consumption basket, price changes are one factor affecting their purchasing power. Thus, food security is partially linked to food price developments, especially in urban areas. Note that Latin America is a more urbanized society than other developing and emerging countries Poelhekke (2011). We investigated the dynamics in six LA countries, namely Argentina, Brazil, Colombia, Chile, Mexico and Peru. These countries showed large improvements in foodsecurity indicators over the last decade, but still suffer from incidences of food insecurity. At the same time, all six countries are increasingly integrated into global food markets, being both large importers and exporters. Especially in light of the global food price crises in 2007/08 and 2011/12, questions of the impacts of agricultural trade and more market integration on food security in developing and emerging countries arose. In order to analyze the relationship between global food price shocks, trade openness and domestic food price movements, we used an error correction framework to estimate how different degrees of agricultural market integration influenced world price transmission rates.

In line with other authors, we find that increasing world prices will transmit into domestic prices. Although some authors claim that in many countries price transmission is not high (e.g. Benson et al., 2008, Minot, 2011, Baquedano and Liefert, 2014), we estimated quite elevated long-term price transmission rates between 0.71 and 0.82 in LA. Our findings show that international trade and market integration has led to different degrees of price transmission rates in the studied countries. Especially in the short-run, world price shocks affect countries' food prices differently, depending on the degree of trade openness. Argentina and Chile are very dependent on food imports and exports which resulted in high transmission rates. In these two countries, the 2008 world price shock of 24% led to an over-proportionate instantaneous increase in domestic food prices, and the long-run price equilibrium was an additional 18 to 20% higher than in 2007. On the contrary, a country like Brazil trades very large volumes of agricultural commodities, however, their agricultural sector still produces even larger amounts for their domestic market. Our results show that this lower degree of agricultural market integration has also led to a lower degree of food price transmission, especially in the short-run. These findings are particularly relevant with regard to the expected growing global food demand in the future. It is projected that global food commodity prices will be higher and more volatile than in the past. So, countries that are very dependent on food imports and exports will strongly participate in these global developments. Especially the drastic short-run price transmission rates can be devastating for countries with high degrees of trade openness. Hence, domestic policies should be in place to buffer price shocks. This is not only crucial because higher prices hurt urban food consumers, but also because food price transmission also leads to more domestic food price volatility, leading to higher price uncertainty. It has been argued that stocks holding could be one appropriate policy to be able to react counter-cyclical in times of price shocks (Trostle, 2008, Serra and Gil, 2013). However, this would further drive total global demand in order to build up stocks which in turn further increases world prices (Headey, 2011). According to FAO (2012), the six countries of investigation have implemented a few policies to guarantee food access of the poor as a reaction to increasing world market prices. To mention a few: besides price intervention by establishing maximum food prices for certain commodities, policies were put in place for redistributing food and providing food in elementary schools, and cash transfer programmes like Bolsa Familia in Brazil or Progresa in Mexico.

Although our results confirm higher world price transmission rates with increasing degrees of trade openness, it does not mean that trade only harms food consumers. First, trading nations can buffer domestic supply shocks by substituting lower food production by imports. Secondly, trading nations turn to the production of those products for which they have comparative advantages, and thus produce at lower costs which should lower consumer prices (Vousden, 1990). Therefore, policies should not necessarily aim at returning to protectionism, but rather focus on establishing effective safety nets to stabilize food prices in times of global shocks.

Our results also illustrate that currency appreciations can in parts buffer world price transmission. For example the Brazilian, Colombian and Peruvian currencies appreciated between five and six percent between 2007 and 2008 which made food imports less expensive and exports less competitive and thereby decreased the Peruvian food CPI. Apart from international market forces, our results show that food prices are also affected by domestic macroeconomic factors. A policy relevant variable is money supply. By managing money supply through effective monetary policies, a country can also regulate food price (inflation) to a certain extent. Inflation targeting regimes have been adopted in Brazil, Chile, Mexico and Peru. All countries show relatively strong financial systems, however Brazil and Peru show rather weak fiscal systems (García-Solanes and Torrejón-Flores, 2009). Gonçalves and Salles (2008) confirm that developing countries adopting an inflation targeting regime did not only experience greater drops in inflation, but also in volatility of CPIs. Thus, promoting macroeconomic stability and well-functioning institutions seem to be a crucial factor in stabilizing food prices, safeguarding sufficient food access to the poor.

A possible weakness of our analysis could result from the fact that we modeled six LA countries within a panel framework. On the one hand, this allows for drawing more general conclusions on trade and food price transmission than conducting country-specific estimates. On the other hand, we cannot differentiate between effects from trade openness in net importing and net exporting nations. Due to the fact that we have to deal with yearly trade data, country observations would not be sufficiently reliable over a time period of 19 years, though. Another constraint of this study might be caused by the fact that we only look at the total food CPI and do not look at different subgroups of the food CPI. Specific grains, meat and fruits and vegetables CPIs might have been impacted differently by world price shocks and trade openness. Unfortunately, in most of the six countries, the subgroups were not available for the entire period of investigation. Too short time spans make the econometric analysis unreliable. We therefor, stick to the overall food consumption basket. So, future research should provide more detailed results on different food items and allow for different outcomes depending on a countries net trade position.

As a reaction to the international commodity price spikes, the recent scientific literature has been abundant with analyses on price transmission, impacts of price shocks and policy responses to manage and cope with them (Attanasio et al., 2013, Rodriguez-Takeuchi and Imai, 2013, Baek and Koo, 2014, Baquedano and Liefert, 2014). However, little attention has been paid to the empirical analysis of the interaction between price transmission rates and the level of trade openness. Therefore, the main novelty of this study lies in the examination of the interdependencies between food price transmission rates and varying degrees of agricultural market integration. We also consider different macroeconomic variables that can be relevant for policy advice. We found that increasing levels of trade openness elevate food price transmission rates after price shocks, especially in the short-run. Short-run price transmission elasticities vary between 33 and 89% in the six countries of investigation, depending on the degree of market integration. Long-run transmission elasticities are more independent of trade openness, being at rates between 71 and 81%. Hence, more trade openness brings with it more price instability in the short-term under world price shocks and the resulting persistence in the long-term.

Clearly, immediate effects require different policy approaches to a world price shock than long-term effects. To reduce households' income shocks caused by a sudden and large increase of the price of food, some degree of price management for basic staples may be warranted, coupled with income support or cash transfers. Besides price interventions by establishing maximum food prices for certain commodities temporarily, policies for redistributing food as well as providing food in elementary schools and the poorest households can be appropriate, but must be carefully planned with the required budget readily available.

The study shows that with increasing global market integration, a large proportion of consumer food prices are determined by global forces. But a significantly large proportion too is also due to other macroeconomic factors (exchange rate and money supply). The exchange rate shows an elasticity of 0.31 in the short-run and 0.58 in the long-run. Thus, currency appreciations can buffer shocks from world prices. The elasticity of money supply is 0.13 in the short-run and 0.05 in the long-run. Thus, monetary policies that promote macroeconomic stability seem to be an appropriate means for stabilizing food prices, safeguarding sufficient food access of the urban poor in LA.

Chapter 4

Rural Income and Poverty Dynamics in Peru: The Role of Non-Farm versus Farm-Activities*

Abstract Peru, a country increasingly integrated into world markets, enjoyed growth rates averaging above 6% during the last decade. While particularly urban areas benefited from this trend, also absolute extreme rural poverty more than halved from 44% in 2004 to 21% in 2012. And yet, the rural population remained to be vulnerable with moderate poverty rates above 30% and persistently high income inequality in 2012. In this paper, we analyze the driving forces behind rural poverty and income inequality dynamics in Peru between 2004 and 2012 by modeling the rural income generation process and using a microeconometric decomposition methodology. We focus on the role of income diversification into rural non-farm activities and changing agricultural market conditions for rural poverty and income inequality changes. We find that generating new employment opportunities in on-farm and off-farm wage-employment showed effects for poverty and inequality reduction, even though they were small. Structural changes within the farming sector led to production shifts away from staple crop production towards cash crops, like coffee. However, these shifts did not have large impacts on the rural income distribution. Rather, spill-over effects from favorable macroeconomic condi-

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tions led to higher returns in all sectors. The macroeconomic growth effect in non-agricultural sectors lifted a large fraction out of moderate poverty, but increased income inequality. This indicates that the extreme poor were left out and that the population at the lower end of the income distribution benefited less from the improving conditions in rural non-farm wage-employment. Unsurprisingly, for extreme rural poverty reduction the agricultural sector was crucial. Increasing returns to rural assets of maize and potato farmers lifted 11% of the rural population out of extreme poverty. The main force within agriculture was again the improved income situation due to macroeconomic forces, like increasing agricultural prices. Thus, due to the continuing relevance of agriculture for rural livelihoods, supporting agricultural research, training and financial services to poor farmers should be targeted. Furthermore, the participation of the poor in Peru's cash crop sector will require overcoming challenges, such as a lack of infrastructure in remote poor areas or a complicated land tenure situation. Finally, to give the poor a stake in profitable non-agricultural sectors, capacity raising through better public educational institutions and employment skills trainings will be needed. This holds especially for women and the population living in regions that have a limited potential for further agricultural production improvements due to unfavorable growing conditions.

Keywords rural poverty, income distribution, microsimulation, agriculture, income diversification, Peru

JEL Classification I32, O12, O13

4.1 Introduction

While most countries in Latin America (LA) have shown rather moderate economic growth rates over the last decade, Peru's economy stands among the fastest in developing countries. On average, LA's GDP grew annually 3.85% between 2004 and 2012, but Peru showed an average growth rate of 6.79%, even outpacing the East Asia and Pacific region which grew on average 4.3% per year (WDI, 2015). This economic growth has translated into a sharp decline of extreme poverty and inequality. Between 2004 and 2012 the share of people living in poverty declined from about 59% to 26% (INEI, 2014). The share of malnourished population dropped from about 16% in 2007 to about 11% in 2012 (FAO, 2012). In 2004 the lowest 20% of the income distribution held only 3.3% of total income per capita; in 2012 this share had increased to 4.1%. While these developments are especially encouraging for urban areas, Peru still shows severe poverty incidences and increasing income inequality in its rural areas. Notwithstanding the Peruvian urbanization trend, in 2012 still about one quarter of the population lived in rural areas of which 53% remained poor. However, despite persistently high moderate poverty rates (42% in 2004 and still around 35% in 2012), extreme rural poverty dropped substantially between 2004 and 2012 (44% in 2004 to 21% in 2012) (INEI, 2014). Concurrently, the GINI index increased from 38.8% to 40.2%. Yet, there are large disparities among regions. While the coastal regions, hereafter referred to as "Costa", performed well in poverty reduction, the mountain regions, in the following referred to as "Sierra", lagged behind the national trend. The jungle region "Selva", although still being among the poorer regions, showed some poverty reduction between 2004 and 2012. Since the Selva is one of the larger agricultural production regions, especially of traditonal export crops, a reason for the social ascent could have been increasing agricultural profits. More details on trends of household income, poverty and income inequality in rural Peru over the last decade are described in Appendix C1. Despite these perceptions, the underlying factors of income and the poverty dynamics in rural areas in Peru are still unsettled issues.

There are different channels that could account for rural income dynamics. First, wage-employment in non-agricultural sectors is gaining importance in rural Peru, allowing households to improve incomes through this diversifying process. Elbers and Lanjouw (2001), Escobal (2001), Lanjouw (2001) suggest that engaging in high productivity, non-agricultural activities can be very conducive to income growth and poverty reduction. Despite the gaining importance of non-farm activities, the majority of the rural work force is still employed in agriculture. Of the economically active population, more than one third was engaged in farming activities over the period of investigation, spanning 2004 to 2012 (INEI, 2014). Since many poor people depend on agriculture, improving income growth in this sector remains crucial for poverty and inequality reduction. This can be achieved by various means: First, real agricultural price increases could be an explanation for income growth in this sector. Higher global and domestic food demand due to structural changes in world markets has led to higher agricultural commodity prices. Due to policy shifts towards more liberalized agricultural markets in Peru, high international prices have transmitted into domestic prices and thus very likely affected farmers' income (Robles and Torero, 2010, Anderson et al., 2011). Secondly, as a reaction to more open markets, Peru has shifted agricultural production to some high value export products for which it has comparative advantages and increasingly imported lower value staple food (Niemeyer and Garrido, 2011, Velazco and Velazco, 2012). So, the question is whether poor farmer were able to benefit from these new market opportunities. Thirdly, longer-term factors associated with the dynamics of rural income growth could be relevant. In the literature, it is acknowledged that higher agricultural productivity is crucial to raise income, especially for the poorest of rural households (Ravallion and Datt, 1996, Timmer, 1997, Datt and Ravallion, 1998, Fan et al., 2004, Klasen et al., 2013).

In light of the current global and domestic rural market transformations, the study's overarching objective is to examine the drivers of rural poverty dynamics and changes in income inequality in Peru between 2004 and 2012. More specifically, we will focus on the following research questions: (1) To what extend has income diversification into non-agricultural sectors contributed to changes in poverty and income inequality? (2) What were the main dynamics outside of farming that had distributional impacts? (3) In the agricultural sector, was a shift towards higher value crops responsible for the reduction in poverty and changing income inequality? (4) What were the main forces behind poverty and inequality changes of poor staple food producers?

The remainder of this study is organized as follows. Section 4.2 outlines the methodology used for the empirical analysis and describes the data. Section 4.3 presents selected results from the descriptive and multivariate analysis, while the discussion in light of the research questions follows in section 4.4. Section 4.5 summarizes and concludes.

4.2 Data and methodology

4.2.1 Methodology

Income generation process

To disentangle the underlying causes of poverty and inequality reduction, we use decomposition techniques following Bourguignon et al. (2005) and Lay (2010). First, we need to estimate the household income generation process. The model uses individual-level employment information. This implies that individuals make occupational choices and earn wages or profits accordingly. These labor market incomes plus other exogenous incomes comprise household income. The components of the income generation model are thus an earnings model and an occupational choice model. Eq. 3.1 describes the household's earnings (all variables are referred to a year, but do not index to ease the presentation).

$$Y_{hh} = \frac{1}{p}\left[\sum_{i=1}^{n}\sum_{s}\omega_i^s DW_i^s + \sum_{i=1}^{n}\pi_i^{nonag}DP_i^{nonag} + \sum_{i=1}^{n}\sum_{sag}\pi_i^{sag}DP_i^{sag} + \bar{y}_{hh}\right] \quad \text{(Eq. 3.1)}$$

Rural Peruvian household's income Y_{hh} is earned by n members who are active in different sectors. Individual i's wage income ω_i^s is either earned in the agricultural or the non-agricultural sector $s = \{\text{ag, nonag}\}$. π_i^{nonag} or π_i^{sag} refer to profits in self-employment. In the case of agricultural self-employment there are sub-sectors $sag = \{$maize farmer, potato farmer, coffee farmer, "other" farmer$\}$. DW_i^s and DP_i^{nonag} or DP_i^{sag} are dummy variables indicating whether individual i is wage or self-employed in one of the sectors (or sub-sectors). Wages and profits include monetary income as well as wage payments in kind or production for auto-consumption. Note that we only consider first employment activities, but add incomes from any second activity. In addition, the household receives an exogenous nominal income $\bar{y}_{hh}$, like remittances and transfers from social programs . All these components are expressed in real monetary values, i.e. deflated with the general price level p of the year 2009. Per capita income is obtained by dividing total household income by household size. Eq. 3.1 is not estimated econometrically, it aggregates information from Eq. 3.2, Eq. 3.3, Eq. 3.4, Eq. 3.8, Eq. 3.9, Eq. 3.10 (shown below) and exogenous income ($\bar{y}_{hh}$) directly from the household dataset.

In the wage equation Eq. 3.2, consideration must be given to the human capital theory which calls for the inclusion of skill variables such as education and experience. For ease of notation, we refrain from indexing time periods in the equations.

$$ln(\omega_i^s) = \alpha_w^s + \Pi_w^s \mathbf{X}_i^w + u_{w_i}^s \quad \forall\ s \tag{Eq. 3.2}$$

Eq. 3.2 for both sectors are Mincer-type equations with log wage income of individual i as a function of personal characteristics. $ln(\omega_i^s)$ is the log of real individual monthly wage income from either agriculture or non-agriculture, α_w^s is a constant term, $\mathbf{X}_i^w$ is a vector of individual characteristics and controls, Π_w^s is a set of parameters that reflect the returns to those characteristics and $u_{w_i}^s$ is a random error term that captures the effect of unobservable characteristics. $\mathbf{X}_i^s$ includes two skill dummies, one for medium skills (1 if the individual has completed primary education), and a second dummy for higher education. Further, experience is included, defined as age minus years of education. Other covariates include gender, ethnicity, working hours and location. The non-agricultural wage equation further controls for different sectors.

Estimating profits of self-employment in the two distinct sectors (Eq. 3.3 and Eq. 3.4), besides the human capital theory, consideration is given to production theory. This is because entrepreneurs and farmers, unlike wage earners, must use physical capital and farmers also land in addition to labor in deriving their income. Thus, standard production inputs of land, labor and capital[1] should be included besides personal characteristics. The following set of equations describe the profit equations in the agricultural and non-agricultural sector, respectively.

$$ln(\pi_i^{nonag}) = \alpha_p^{nonag} + \Pi_p^{nonag}\mathbf{X}_i^p + \Phi_p^{nonag}\mathbf{W}_i^p + u_{p_i}^{nonag} \qquad \text{(Eq. 3.3)}$$

$$ln(\pi_i^{sag}) = \alpha_p^{sag} + \Pi_p^{sag}\mathbf{X}_i^p + \Phi_p^{sag}\mathbf{W}_i^p + \Psi_p^{sag}\mathbf{V}_i^p + u_{p_i}^{sag} \quad \forall\ sag \qquad \text{(Eq. 3.4)}$$

The dependent variable are log profits from either being self-employed in non-agriculture (Eq. 3.3) or in agriculture (Eq. 3.4). $\mathbf{X}_i^p$ is the same vector than in the wage equation Eq. 3.2. The vector $\mathbf{W}_i^p$ includes the variables number of paid labor and the number of non-remunerated family members[2] that work in the business. $\mathbf{V}_i^p$ includes the covariate hectares of land in logarithm and a dummy variable that takes on the value one if the farm is equipped for modernized irrigation systems. In total we estimate seven earnings functions for two time periods separately (2004 and 2012) using an Ordinary Least Squares (OLS)[3] estimator.

[1] Due to lacking data we unfortunately cannot include capital as an explanatory variable in estimating self-employment income.

[2] The number of nun-remunerated workers is likely to be endogenous. We therefore instrumented them by using the total number of household members, but since regression results did not deviate severely we concluded that the bias in the OLS estimation is not severe. Therfore, we abstain from reporting the instrumental variable results, but they can be obtained from the authors upon request.

[3] The errors terms are unlikely to be independent from the exogenous variables. Hence, a sample selection bias correction procedure should be used. However, the standard Heckman procedure for

We now turn to the occupational choice model. The parameters that describe the utilities associated with the respective occupational choices are estimated from a multinominal choice model that allows individuals to choose from being non-remunerated, or employed in wage or self-employment in one of the seven sectors. Household heads (h), spouses (s) and other household members (o) are treated differently, meaning that we assume a sequential choice with the household head deciding first. The utility of being unemployed or not-economically active ut_i^{nact} is arbitrarily set to zero, whereas the utilities of the other employment options $ut_i^{w_s}$ (wage employment in agriculture or non-agriculture), $ut_i^{p_{nonag}}$ (self-employment in non-agriculture) and $ut_i^{p_{sag}}$ (self-employment in one of the agricultural sub-sectors) for household heads depend on education, age, gender, and the number of household members in different age groups. For spouses and other household members the labor choice utility depends on education, age, gender, number of children under 14, the number of household members in different age groups, employment choice dummy of the household head. The described characteristics are included in Z_i. Unobserved occupational choices are represented by the residual terms. Eq. 3.5 give the utility of each occupational choice of household heads (h), while Eq. 3.6 and Eq. 3.7 describe the utilities of spouses (s) and other household members (o).

$$\begin{aligned} ut_{i,h}^{nact} &= 0 \\ ut_{i,h}^{w_s} &= c_h^{w_s} + \Theta_{i,h}^{w_s}\mathbf{Z}_{i,h}^{w} + \varepsilon_{i,h}^{w_s} \quad \forall\ s \\ ut_{i,h}^{p_{nonag}} &= c_h^{p_{nonag}} + \Theta_{i,h}^{p_{nonag}}\mathbf{Z}_{i,h}^{p} + \varepsilon_{i,h}^{p_{nonag}} \\ ut_{i,h}^{p_{sag}} &= c_h^{p_{sag}} + \Theta_{i,h}^{p_{sag}}\mathbf{Z}_{i,h}^{p} + \varepsilon_{i,h}^{p_{sag}} \quad \forall\ sag \end{aligned} \qquad \text{(Eq. 3.5)}$$

sample selection bias correction requires equally strong assumptions about the orthogonality between the error terms of the earnings equations and the error term from the occupational-choice multinominal logit equations below. The assumptions required to validate OLS estimation of equations are not more demanding than those required to validate the results of the Heckman procedure (Ferreira and de Barros, 2005). We assume, therefore, that all errors are independently distributed and do not correct for sample selection bias in the earnings regressions.

$$
\begin{aligned}
ut_{i,s}^{nact} &= 0 \\
ut_{i,s}^{w_s} &= c_s^{w_s} + \Theta_{i,s}^{w_s}\mathbf{Z}_{i,s}^{w} + \varepsilon_{i,s}^{w_s} \quad \forall\ s \\
ut_{i,s}^{p_{nonag}} &= c_s^{p_{nonag}} + \Theta_{i,s}^{p_{nonag}}\mathbf{Z}_{i,s}^{p} + \varepsilon_{i,s}^{p_{nonag}} \\
ut_{i,s}^{p_{sag}} &= c_s^{p_{sag}} + \Theta_{i,s}^{p_{sag}}\mathbf{Z}_{i,s}^{p} + \varepsilon_{i,s}^{p_{sag}} \quad \forall\ sag
\end{aligned}
\tag{Eq. 3.6}
$$

$$
\begin{aligned}
ut_{i,o}^{nact} &= 0 \\
ut_{i,o}^{w_s} &= c_o^{w_s} + \Theta_{i,o}^{w_s}\mathbf{Z}_{i,o}^{w} + \varepsilon_{i,o}^{w_s} \quad \forall\ s \\
ut_{i,o}^{p_{nonag}} &= c_o^{p_{nonag}} + \Theta_{i,o}^{p_{nonag}}\mathbf{Z}_{i,o}^{p} + \varepsilon_{i,o}^{p_{nonag}} \\
ut_{i,o}^{p_{sag}} &= c_o^{p_{sag}} + \Theta_{i,o}^{p_{sag}}\mathbf{Z}_{i,o}^{p} + \varepsilon_{i,o}^{p_{sag}} \quad \forall\ sag
\end{aligned}
\tag{Eq. 3.7}
$$

Eq. 3.5, Eq. 3.6 and Eq. 3.7 link the estimated utilities to the individual i's occupational choices. Individuals will choose the activity that leads to the highest utility. The following equations give the number of wage and self-employed individuals in each sector. For ease of notation, we suppress an index for household heads, spouses and other household members as well as the year index.

$$
\begin{aligned}
DW_i^s = I[ut^{w_s} = max(&ut^{nact}, ut^{w,ag}, ut^{w,nonag}, \\
&ut^{p,nonag}, ut^{p,maize}, ut^{p,potato}, ut^{p,coffee}, ut^{p,other}, ut^{nonrem})] \quad \forall\ s
\end{aligned}
\tag{Eq. 3.8}
$$

$$
\begin{aligned}
DP_i^{nonag} = I[ut^{p_{nonag}} = max(&ut^{nact}, ut^{w,ag}, ut^{w,nonag}, \\
&ut^{p,nonag}, ut^{p,maize}, ut^{p,potato}, ut^{p,coffee}, ut^{p,other}, ut^{nonrem})]
\end{aligned}
\tag{Eq. 3.9}
$$

$$DP_i^{sag} = I[ut^{p_{sag}} = max(ut^{nact}, ut^{w,ag}, ut^{w,nonag}, ut^{p,nonag}, ut^{p,maize}, ut^{p,potato}, ut^{p,coffee}, ut^{p,other}, ut^{nonrem})] \quad \forall\, sag \qquad \text{(Eq. 3.10)}$$

Before we can use the estimated model for our poverty and income inequality decomposition, we have to simulate certain components of the income generation model. First, there are residuals of the occupational choice model that cannot be obtained from this type of econometric model. Yet, they can be randomly drawn to be consistent with the observed choice. Secondly, residuals need to be simulated for incomes that cannot be observed initially. For example, if an individual is induced to switch from agricultural self-employment into non-agricultural wage-employment, the person will then earn a wage that will be determined by the estimated parameters of the wage equation and the wage residual. As this (log) residual cannot be observed, it will be randomly drawn from a normal distribution (with the variance of this distribution estimated from the observed residuals). The same holds for the residual of earnings from self-employment if they cannot be observed initially (for details see Lay, 2010).

Decomposition method

$D(y, P)$ measures the income distribution, using the three Foster-Greer-Thorbecke poverty measures ($P(\alpha)$, $\alpha = 0, 1, 2$), computed with respect to region-specific poverty extreme and moderate poverty lines), and four inequality indices (the GINI coefficient, the Theil-indices $E(\alpha)$, $\alpha = 0, 1, 2$). The larger α is, the greater is the degree of "poverty aversion" (sensitivity to large poverty gaps); or the more sensitive react inequality indices to income differences at the top of the distribution (Foster et al., 1984, Shorrocks, 1984). The earnings are represented by y and P is the probability of the occupational choice decisions as defined in the occupational choice model described above. Let β be all estimated parameters in the wage and profit equations Eq. 3.2, Eq. 3.3 and Eq. 3.4;

let $\mathbf{X}$ be all independent variables used in these equations and let $\mathbf{u}$ be the error terms in the earnings equations. Let λ be the estimated parameters in the occupational choice equations Eq. 3.5, Eq. 3.6 and Eq. 3.7. We can then rewrite $D(y, P)$ as $D(\beta, \mathbf{X}, \mathbf{u}, \lambda)$. This decomposition exercise consists of estimating the effects on the joint distribution of income and occupational choice by changing one or more arguments of $D(.)$. The occupational choice effect is estimated by modifying λ_t, where t indicates two different points in time. The price effect (also called returns effect) is estimated by changing β_t which are the estimated returns to different household and individual characteristics in two points in time; the population effect is estimated by modifying the distribution of $\mathbf{X}_t$; and the effect of unobservable factors is estimated by simulating the distribution of residuals (Bouillon et al., 2005).

Thus, Eq. 3.11 gives the change in the income distribution between time t and $t^{'}$:

$$\Delta D = D(\beta^{'}, \mathbf{X}^{'}, \mathbf{u}^{'}, \lambda^{'}) - D(\beta, \mathbf{X}, \mathbf{u}, \lambda) \qquad \text{(Eq. 3.11)}$$

Since we are interested in finding those factors that contributed to changes in the income distribution, we decompose changes in D[.] between two periods in time (comparing 2004 and 2012) into its components. The principal idea is to disaggregate the observed changes in labor incomes into a “price effect”, an “endowment effect”, an “occupational choice effect” and a “residual effect”. The price effect isolates the impact of changes in the returns to individual or household characteristics, such as the level of education or returns to agricultural land, if the endowments and occupational choices of the Peruvian population would have been constant over time. Analogously, the “endowment effect” captures the contribution of changes in the level and distribution of the characteristics of the rural population, keeping returns constant. This can be done for all returns (population characteristics) or selected parameters (covariates) at a time. While the price effect of only specific variables is straight-forward by simply changing only a subset of the coefficients obtained in the regressions, a further decomposition of the endowment effect is more complex. We follow Bouillon et al. (2005) and apply a reweighting methodology. Survey weights in time t' are adjusted in order to reflect the population distribution observed in time t, and vice versa. The adjusted survey weights are then used to simulate the counterfactual class shares. Changes in the distribution and returns of the error term capture the impacts of "unobservable" characteristics to changes in income distribution. Further, the occupational choice effect captures changes in income due to shifts in the participation in different sectors, holding returns and endowments constant. Moreover, there is a remainder that reflects real poverty changes between two time periods, minus all mentioned effects. The remainder term captures the interaction between the price effect, the endowment effect, the occupational choice effect and the effect of unobservables. With those counterfactual vectors at hand, we can simulate poverty and income inequality changes due to different effects. Note that we can either hold conditions of the initial year or the final year constant. Since the results show path dependency, results from the decompositions, of first holding initial and second final conditions constant, represent the upper and lower bounds for the estimates (Bouillon et al., 2005). Hence, we take the mean of both decompositions.

4.2.2 Data

Data description

We use data from the nationally and regionally representative Peruvian household survey *Encuesta Nacional de Hogares* (ENAHO for its acronym in Spanish) collected by the National Institute of Statistics and Informatics (INEI) between 2004 and 2012. The ENAHO data are collected annually from a sample of about 80,000 people corresponding to 20,000 households in urban and rural areas of all regions. However, we restrict our analysis to only rural areas defined as those areas with a population of less than 2,000 inhabitants (see Table 4.1). The survey provides detailed information on demographics, employment, education, housing, income and consumption of households and their members. With respect to employment, sector-specific information can be obtained. Households in which at least one individual is identified as an independent worker or as an employer, and who is working in agriculture, livestock or forestry are interviewed in agricultural production modules. These modules capture information on specific production quantities and values, total land endowments, and irrigation technologies. Unfortunately, information of land allocation to different crops is missing. We categorize farmers either as maize, potato, coffee or "other" farmers depending on which product makes up the highest share of total production value per farm.

For our analysis, we use the Peruvian official national poverty lines constructed by INEI (2014) to measure absolute poverty. There are different poverty lines based on consumption baskets for different geographic domains and median prices in major cities in the country. The value of each moderate poverty line is equal to the household's per capita cost of a basic basket of food and non-food consumption. The value of each extreme poverty line represents the expenditure necessary to purchase a basic basket of food items only. For details on how poverty lines were constructed see INEI (2013). Consumption-based poverty measures have proven to be the better long-term welfare measure compared to income, because households tend to smooth their consumption over time while income shows more volatility. However, our analysis focuses on the labor market, so we need to construct income based poverty lines. To do so, we scale up the consumption-based poverty lines in such a way that they reflect the difference between the household's total expenditures and total income. Since we are interested in the dynamics of poverty, it would be useful to have panel data information. ENAHO provides repeated cross-sectional data between 2004 and 2012. We intended to match individuals within households, but unfortunately there are only few individuals that repeat in the years 2004 and 2012. Therefore we use cross-sectional data of all years for the descriptive analysis and the two cross-sections of 2004 and 2012 for the microsimulation described above. Table 4.1 gives an overview of the rural sample size in each year.

Table 4.1: ENAHO rural sample size

	Individuals		Households	
year	**survey observation**	**represented population**	**survey observation**	**represented population**
2004	31,333	7,300,923	6,826	1,600,215
2005	33,319	7,226,282	7,322	1,619,520
2006	33,687	7,194,305	7,484	1,615,803
2007	32,525	7,172,525	7,388	1,628,283
2008	32,070	7,224,382	7,275	1,636,717
2009	32,686	7,221,078	7,543	1,675,714
2010	32,175	7,139,683	7,506	1,668,468
2011	35,475	7,057,748	8,538	1,706,195
2012	34,223	6,988,413	8,447	1,727,869

4.3 Results

4.3.1 Descriptive analysis

Before we turn to the estimation results and the decomposition of poverty and income inequality changes between 2004 and 2012, it is useful to gain some inside about changes in the Peruvian labor force participation and wages and profits earned in different sectors between 2004 and 2012. Furthermore, it is helpful to gather some evidence on key variables, such as the evolution of demographic trends, educational attainment and land and labor endowments of the Peruvian rural society. Finally, developments within the agricultural sector give an idea about important changes in rural areas that might explain the observed poverty and income inequality dynamics between 2004 and 2012.

Labor market profile

Table 4.2 and Table 4.3 illustrate the occupational structure and the evolution of average monthly[4] income in different sectors in rural Peru. Between 2004 and 2012, more than 6% of the rural population at working age moved from non-remunerated to paid employment. These changes occurred likewise for males and for females, however there were more males than females receiving income. Female labor market participation slightly

[4] Since individuals work different hours per month, hourly income would be more accurate. However, information on hours worked are not always reliable, and moreover we expect structural biases between different sectors and between wage and self-employment. Therefore, we stick to monthly income.

dropped from 74% in 2004 to 71% in 2012 in rural areas. In the active labor force, non-agricultural wage-employment gained importance. About 15% of rural non-agricultural wage earners worked in private or public services with an upward trend over the years of investigation. Other important sectors within agricultural wage work with gaining importance were construction work, working at wholesale or retail shops and mining companies. Average real income was highest in non-agricultural wage-employment compared to any other sector and wages increased dynamically between 2004 and 2012. Especially wages in mining increased from average 620PEN (Peruvian Nuevo Sol) in 2004 to 1338PEN in 2012. Less people moved into agricultural self-employment. On average, real profits doubled between 2004 and 2012, but income remained at lower levels than non-agricultural wages. The majority of rural businesses were wholesale and retail shops, followed by manufacturers. Also running hotels and restaurants and the transportation sector gained importance. Despite the growing relevance of non-agricultural sectors, agricultural self-employment remained being most important in rural areas, with an even increasing trend among women. Average income from agricultural activities (wage or self-employment) was about as high as average non-agricultural profits in 2004, but increased less by 2012. “Other” farmers started of wealthier than maize or potato farmers in 2004, but by 2012 maize, potato and “other” farmers showed similar profits around PEN 435. Since “other” farmers aggregate a large number of different products, the variance of income is very high within this sector. This probably also explains why average female profits were only about one third of their male counterparts, indicating that males had access to profitable fruits and vegetables markets, while females were largely left out. Coffee is Peru’s most important export crop (FAOSTAT, 2014). Unsurprisingly, coffee growers were more profitable than maize or potato farmers in Peru. By 2012, coffee growers earned almost 50% more than other farmers.

Endowments

Table 4.4 shows how the rural population was endowed with different assets in 2004 and 2012. The Peruvian population grew older; households became smaller and had fewer

Table 4.2: Rural labor market choices (first occupation)

	year	Non-agr. wage empl	Agr. wage empl.	Non-agr. self-empl.	Agr. self-empl.	Non-remun.	Unempl.	Not econ. Active
Rural average	**2004**	5.74%	6.25%	7.30%	30.99%	38.93%	1.92%	8.87%
	2012	10.89%	7.75%	7.77%	31.12%	32.34%	1.75%	8.37%
Rural males	**2004**	7.61%	9.22%	4.71%	49.38%	22.40%	1.49%	5.19%
	2012	13.87%	10.29%	4.80%	46.52%	16.84%	1.37%	6.31%
Rural females	**2004**	3.70%	3.00%	10.13%	10.92%	56.98%	2.39%	12.89%
	2012	7.55%	4.92%	11.09%	13.91%	49.67%	2.18%	10.68%

Note: Statistic includes rural population that are in working age, so all individuals fourteen years or older.
(Source: own elaboration based on ENAHO data)

Table 4.3: Monthly wages and profits in the agricultural and non-agricultural sectors

		Non-agr. wage income		Agr. wage income		Profits from non-agr. self-empl.		Profits from agr. self-empl.	
	year	**PEN**	**%-change**	**PEN**	**%-change**	**PEN**	**%-change**	**PEN**	**%-change**
rural average	**2004**	528		249		241		251	
	2012	843	+4.20	467	+8.35	483	+11.81	476	-0.42
	Δ 2004/2012		+59.66		+87.55		+100.41		+89.64
rural males	**2004**	580		278		423		269	
	2012	955	+3.02	547	+13.02	888	+14.43	543	+2.45
	Δ 2004/2012		+64.66		+96.76		+109.93		+101.86
rural females	**2004**	424		155		152		170	
	2012	625	+6.84	298	+3.83	315	+7.14	273	-12.50
	Δ 2004/2012		+47.41		+92.26		+107.24		+60.59

Note: Monthly gross wages are given at individual level and include monetary payments as well as payments in natural goods. Monthly profits from self-employment are reported at household level and contain monetary profits and the value produced for auto-consumption. Income from any second occupation is added. PEN stands for the Peruvian official currency "Nuevo Sol" and is given in real terms with a base year of 2009. The official exchange rate to US dollars were 3.4PEN/US$ in 2004 and 2.6PEN/US$ in 2012.
(Source: own elaboration based on ENAHO data)

children. The average age of individuals living in extreme poor households increased from 24 to 27 years, in moderate poor households from 28 to 29, and in non-poor households the average age dropped from 34.3 to 33.7 years. Accordingly, the average number of children per household dropped the most in extreme poor households and slightly increased in non-poor households. In 2012, 32.7% of the rural population aged 13 years or younger lived in non-poor households, while in 2004 the share of non-poor children was only 7.6%. In other words, approximately one third of all children in rural Peru were growing up in households that were above the poverty line in 2012. Table 4.4 also shows that the average years of schooling and unskilled population share did not change much over the eight years of investigation. There is some variation between groups though. Unsurprisingly, the group of extreme poor had the lowest educational status while the non-poor had higher years of schooling. However, even in the group of non-poor a large fraction did not complete secondary education. Primary education was completed by most individuals, regardless of the social class.

The lower half of Table 4.4 shows the evolution of average labor and land endowments of the self-employed rural population, expressed as number of paid or non-remunerated staff and hectares of cultivated land. Both in non-agricultural businesses and in agricultural self-employment the average number of family members that worked non-remunerated were almost unchanged over time. This holds for all social classes and all farm types. As expected, the number of non-remunerated family members was highest among extreme poor farmer families. With respect to paid staff in non-agricultural self-employment, it is noteworthy that the average number of paid staff was on the decrease between 2004 and 2012 if the business owner was poor. But the number of paid labor staff was on the rise in businesses owned by non-poor people. This trend could have widened income inequality. Also, extreme poor farmers hired less paid staff in 2012 than in 2004, while moderate poor farmers and non-poor farmers were endowed with more labor in 2012 than 2004. Among farmers, the majority of paid staff was occupied in potato farming, followed by coffee farming. Peruvian farmers on average had less cultivated land in 2012 compared to 2004. Surprisingly, especially the non-poor farms were smaller in 2012 than in 2004. However, on average potato and coffee farms grew larger between 2004 and 2012. In contrast, maize and “other” farms cultivated less hectares of land in 2012 than in 2004.

Table 4.4: Demographic characteristics in rural areas by social class

Indicator	year	Extreme poor	Moderate poor	Non-poor	Rural average
Mean age (years)	2004	23.7	27.8	34.3	26.8
	2012	26.6	29.0	33.7	30.6
Mean household size	2004	5.3	4.5	3.2	4.6
	2012	5.0	4.4	3.5	4.0
Mean number of children per household (aged < 14 years)	2004	2.3	1.5	0.7	1.7
	2012	2.0	1.5	0.8	1.2
Population aged < 14 years (in %)	2004	53.6	38.8	7.6	12.3
	2012	28.3	38.9	32.7	9.5
Mean years of schooling	2004	6.1	7.1	8.3	6.9
	2012	6.2	6.9	8.3	7.5
Population share without completed secondary education (in %)	2004	94.3	87	68.8	85.9
	2012	93.7	89.4	75.3	82.8
Mean number of paid labor in non-agriculture	2004	5.2	9.1	4.6	6.7
	2012	4.4	5.0	6.0	5.5
Mean number of non-remunerated labor in non-agriculture	2004	0.9	0.9	0.9	0.9
	2012	0.7	1.0	0.9	0.9
Mean number of paid labor in agriculture	2004	6.9	7.2	10.5	7.7
	2012	5.8	10.8	27.0	17.9
Mean number of non-remunerated labor in agriculture	2004	1.9	1.8	1.4	1.8
	2012	1.9	1.8	1.6	1.7
Mean hectares of land	2004	6.2	5.2	12.4	6.5
	2012	4.9	5.0	6.8	5.8

Note: Education statistics include only population that have already completed their education.
(Source: own elaboration based on ENAHO data)

Agricultural sector

Due to the continuous importance of the agricultural sector in rural areas, this section examines the sector in more detail. Profits in agriculture more than doubled in real terms between 2004 and 2012 (see Table 4.3). This increase could be ascribed to various factors: First, rising producer prices, second, a shift towards more profitable products, and third, increasing productivity. The data allows us to explore the evolution of producer prices and production shifts. However, since information on land allocation to different crops is missing, we cannot examine shifts in productivities.

Agricultural producer prices

Table 4.5 reveals that average farm gate prices increased most for coffee which is Peru's most important export product. But also import-competing maize showed real price increases between 2004 and 2012. Unsurprisingly, maize producer prices increased most in 2007 and 2008. Maize was one of the products that experienced the largest spike in international markets in those years (Headey and Fan, 2008, Abbott and Borot de Battisti, 2011). Only real potato prices, the most important staple crop, slightly decreased between 2004 and 2012. Since profits increased despite stable potato farm gate prices, potato growers must have experienced large productivity growth.

Table 4.5: Farm gate prices (yearly averages)

year	Maize		Potatoes		Coffee	
	PEN /ton	%-change	PEN /ton	%-change	PEN /ton	%-change
2004	1,089		759		3,615	
2005	1,019	-6.45	634	-16.47	4,805	+32.90
2006	1,025	+0.55	736	+16.08	5,283	+9.95
2007	1,148	+12.05	723	-1.72	5,301	+0.34
2008	1,334	+16.17	777	+7.45	4,606	-13.10
2009	1,452	+8.85	849	+9.17	4,786	+3.90
2010	1,450	-0.14	791	-6.75	5,241	+9.50
2011	1,453	+0.22	766	-3.21	6,770	+29.18
2012	1,494	+2.78	755	-1.44	6,121	-9.58
Δ 2004-2012		+37.10		-0.56		+69.31

Note: Farm gate prices are calculated by dividing total production values per product by the quantity produced per year and are given in local currency unit per metric tons. PEN stands for the Peruvian official currency "Nuevo Sol" and is given in real terms with a base year of 2009. The official exchange rate to US dollars were 3.4PEN/US$ in 2004 and 2.6PEN/US$ in 2012.
(Source: own elaboration based on ENAHO data)

Shifts in agricultural production

As shown above, more than 30% of the rural Peruvian population was occupied in agricultural self-employment. The majority of farmers were either maize growers (36% in 2004 and 32.5% in 2012) or potato growers (42% in 2004 and 39% in 2012) with a much larger share of women in potato farming than maize farming. The average share of coffee growers increased from 11% in 2004 to almost 14% in 2012 with many more men working in this sector. The share of farmers that produce other products increased by 5% to 15% in 2012 and even by 11% to 27% in 2012 among female farmers. Note, that “other farmers” subsume a large variety of products; among them high value export products, but also low-productivity crops for domestic markets. Yet, we see that some farmers shifted their production away from maize or potato farming towards cash crops like coffee, or they diversified their portfolio moving into “other” farming.

Looking at the descriptive statistics can already give some hints about the underlying forces of rural poverty reduction in Peru. Nevertheless, casual glances at the data can be misleading, because there can be countervailing changes in different realms: the returns in the labor markets, the distribution of important endowments over the population, and the pattern of occupational choices. Thus, we turn to the income generation model and decomposition method to disentangle these effects.

4.3.2 Determinants of rural incomes

The results of the OLS estimations of Eq. 3.2, Eq. 3.3 and Eq. 3.4 are shown in Table 4.6 and Table 4.7. The static results show unsurprising outcomes, with all variables being significant and showing the expected signs. One exception is the control variable “ethnic decent” being only significant in both years in the earnings regression of maize and potato farmers. Also, the irrigation dummy is never significant in both years. Another exception are the regional control variables indicating that some regions are insignificant in one year or even both years. Most relevant are regional differences in agricultural wage-employment, maize and potato farming as well as “other” farming activities. The coefficients on the levels of education, with low skilled workers (four or less years of schooling) being the reference category, are significant, positive and larger at higher educational levels. Experience (defined as age minus years of education) impacts wages and profits positively, but it is concave with a turning point at 40 to 48 years. The female dummy is negative and large, particularly in non-agricultural self-employment, followed by “other” farmers in the agricultural self-employment sector. In agricultural and non-agricultural self-employment, occupying more paid or non-remunerated labor leads to higher profits. The same holds for cultivating more land on farms. Also the constant term is statistically significant. The constant baseline income generally captures effects of the macroeconomic market environment. Although we are more interested in the dynamics than the static results of the estimations, we focus on the research questions and move the discussion about changing coefficients between 2004 and 2012 to Appendix C2.

The results of the multinominal logit equations indicate some changes in the choice of occupation between 2004 and 2012. Some variables that describe individual characteristics, like education, age or gender, and some variables that describe the composition of a household, like number of children or the age structure of the household, lead to different probabilities of choosing one of the seven sectors (non-agricultural wage-employment, agricultural wage-employment, non-agricultural self-employment, maize farming, potato farming, coffee farming or “other” farming). Generally, higher skills led to a higher probability of entering the non-agricultural wage sector in both years. Opposed to this, higher levels of education became insignificant for entering the farming sector. Furthermore, more experienced people were more likely to leave inactivity and participate in the work force. This holds also for most farming sectors. Due to space limitations, a more detailed discussion of the driving forces behind occupational choices are presented in Appendix C3.

4.3.3 Simulation results

After discussing the key variables of the income generation process, we now turn to the decomposition results. As a starting point, we observe changes in poverty and income inequality indices between 2004 and 2012. As already mentioned, headcount extreme poverty dropped by 23%, moderate poverty decreased by 7%, while the GINI increased by 1.4% in rural Peru. The following decomposition results reveal the underlying forces behind these trends by measuring the proportional contribution to changes in poverty and income inequality of (1) changes in occupational choices (occupational choice effect), (2) changes in returns to different assets in each sector (price effect), (3) changes in

Table 4.6: Labor income regressions of wage employment and non-agricultural self-employment with wages and profits in logarithms as dependent variables

	Non-agricultural wage employment		**Agricultural wage employment**		**Non-agricultural self-employment**	
Variable	**2004**	**2012**	**2004**	**2012**	**2004**	**2012**
Medium skilled	**0.273*****	**0.124*****	**0.126*****	**0.210*****	**0.167*****	**0.337*****
	(0.055)	(0.044)	(0.046)	(0.048)	(0.058)	(0.061)
High skilled	**0.601*****	**0.431*****	**0.364*****	**0.457*****	**0.603*****	**0.634*****
	(0.060)	(0.046)	-0.06	(0.060)	(0.078)	(0.080)
Experience	**0.051*****	**0.042*****	**0.041*****	**0.033*****	**0.072*****	**0.059*****
	(0.005)	(0.003)	(0.004)	(0.004)	(0.007)	(0.006)
Experience squ.	**-0.0006*****	**-0.0005*****	**-0.0005*****	**-0.0004*****	**-0.0009*****	**-0.0007*****
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Female	**-0.244*****	**-0.274*****	**-0.513*****	**-0.476*****	**-1.001*****	**-1.114*****
	(0.049)	(0.031)	(0.053)	(0.044)	(0.057)	(0.067)
Paid labor					**0.197*****	**0.294*****
					(0.031)	(0.028)
Non-remunerated labor					**0.122*****	**0.146*****
					(0.023)	(0.022)
d2 (Mining)	**0.181****	**0.325*****			**0.338****	0.228
	(0.080)	(0.049)			(0.138)	(0.143)
d3 (Manufacturing)	**-0.299*****	**-0.205*****			**-0.560*****	**-0.377*****
	(0.074)	(0.049)			(0.064)	(0.068)
d4 (Construction)	**-0.276*****	**-0.143*****			**0.195***	0.108
	(0.069)	(0.045)			(0.114)	(0.105)
d5 (Wholesale/retail shops)	**-0.456*****	**-0.293*****			base sector	
	(0.076)	(0.049)				
d6 (Hotels & restaurants)	**-0.417*****	**-0.233*****			**0.311*****	**0.399*****
	(0.100)	(0.052)			(0.088)	(0.080)
d7 (Transport & Communic.)	**-0.294*****	**-0.364*****			0.0932	**0.148***
	(0.081)	(0.063)			(0.081)	(0.084)
d8 (Public administration)	base sector					
d9 (Domestic workers)	-0.0847	**-0.0946***				
	(0.070)	(0.053)				
d10 (Other activities)	**0.286*****	**0.0822****				
	(0.056)	(0.041)				
Constant	**4.621*****	**5.157*****	**3.546*****	**3.788*****	**3.431*****	**3.804*****
	(0.116)	(0.085)	(0.092)	(0.093)	(0.143)	(0.144)
Observations	1,015	2,046	1,058	1,463	1,134	1,545
R^2	0.539	0.465	0.510	0.535	0.530	0.498

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Regional control variables and control variable for ethnic decent and working hours are included, but not reportet due to limited space. They can be obtained from the authors upon request. Labor is measured as number of employed people including business owner.
(Source: own elaboration)

Table 4.7: Labor income regressions of agricultural self-employment with profits in logarithms as dependent variables

	Maize farmers		Potato farmers		Coffee farmers		"Other" farmers	
Variable	**2004**	**2012**	**2004**	**2012**	**2004**	**2012**	**2004**	**2012**
Medium skilled	0.186***	0.097***	0.173***	0.084**	0.131**	0.119**	0.172**	0.180***
	(0.038)	(0.035)	(0.037)	(0.034)	(0.054)	(0.060)	(0.079)	(0.057)
High skilled	0.450***	0.205***	0.281***	0.223***	0.290***	0.243**	0.254**	0.322***
	(0.059)	(0.051)	(0.061)	(0.052)	(0.086)	(0.097)	(0.104)	(0.084)
Experience	0.024***	0.030***	0.027***	0.037***	0.046***	0.054***	0.022**	0.046***
	(0.005)	(0.005)	(0.005)	(0.004)	(0.008)	(0.008)	(0.009)	(0.006)
Experience squ.	-0.0003***	-0.0003***	-0.0003***	-0.0005***	-0.0006***	-0.0007***	-0.0002***	-0.0005***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Female	-0.301***	-0.304***	-0.125**	-0.296***	-0.420***	-0.387***	-0.727***	-0.606***
	(0.056)	(0.046)	(0.050)	(0.041)	(0.094)	(0.094)	(0.097)	-0.058
Paid labor	0.056***	0.065***	0.039***	0.068***	0.055***	0.057***	0.112***	0.134***
	(0.008)	(0.008)	(0.009)	(0.010)	(0.013)	(0.012)	(0.018)	(0.013)
Non-remunerated labor	0.064***	0.046***	0.060***	0.068***	0.093***	0.096***	0.105***	0.073***
	(0.013)	(0.014)	(0.014)	(0.014)	(0.021)	(0.025)	(0.030)	(0.025)
Land (log)	0.131***	0.149***	0.117***	0.096***	0.107***	0.194***	0.091***	0.054***
	(0.015)	(0.012)	(0.019)	(0.010)	(0.027)	(0.021)	(0.023)	(0.013)
Improved irrgation system	0.355***	0.153**	0.136*	0.124**	0.976***	-0.311***	0.0634	-0.193
	(0.094)	(0.077)	(0.071)	(0.057)	(0.143)	(0.120)	(0.194)	(0.139)
region1 (Costa north)	0.363***	0.0814			0.508***	0.0387	0.535***	0.299***
	(0.066)	(0.071)			(0.156)	(0.166)	(0.146)	(0.088)
region2 (Costa center)	0.639***	-0.0562	0.730***	1.597***			0.633***	0.392***
	(0.091)	(0.099)	(0.128)	(0.054)			(0.154)	(0.100)
region3 (Costa south)	1.129***	0.223**	0.261***	-0.181			1.038***	0.572***
	(0.109)	(0.091)	(0.074)	(0.113)			(0.180)	(0.103)
region4 (Sierra north)	-0.165***	-0.234***	0.0508	-0.317***	-0.121	-0.210*	0.173	-0.105
	(0.057)	(0.057)	(0.050)	(0.050)	(0.138)	(0.111)	(0.201)	(0.110)
region5 (Sierra center)	base region		base region		base region		base region	
region6 (Sierra south)	-0.0631	0.291***	0.0764**	-0.0380	0.143	0.202	0.144	0.211**
	(0.055)	(0.045)	(0.035)	(0.035)	(0.148)	(0.125)	(0.153)	(0.092)
region7 (Selva)	0.0704	0.0578	0.367***	-0.177	0.0750	0.267***	0.242*	0.314***
	(0.045)	(0.049)	(0.104)	(0.128)	(0.117)	(0.089)	(0.133)	(0.074)
Constant	3.894***	4.531***	4.001***	4.708***	3.834***	4.180***	3.667***	3.485***
	(0.118)	(0.118)	(0.120)	(0.113)	(0.175)	(0.195)	(0.257)	(0.165)
Observations	1,926	2,251	1,692	2,181	603	752	722	1,105
R^2	0.261	0.326	0.180	0.284	0.286	0.356	0.369	0.516

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Control variable for ethnic decent, working hours and improved irrigation system are included. Labor is measured as number of employed people including owner of the farm.
(Source: own elaboration)

observed and unobserved population characteristics in each sector (endowment effect and unobserved effect), (4) changes in exogenous non-labor income sources, and (5) the the remainder, representing interaction effects. In the following, we only present the decomposition results for the poverty headcount indices (P(0)) of extreme and moderate poverty and for the GINI index. A higher attention to detail is given in the appendices where all three Foster-Greer-Thorbecke poverty measures, the GINI coefficient, and the Generalized Entropy class of inequality indices are reported. Note that sometimes results indicate that moderate poverty decreased due to a specific effect. This, however, does not necessarily mean that poverty decreased. If a decrease in moderate poverty came along with an increase in extreme poverty, this would indicate that some moderate poor fell back into extreme poverty.

To get a first impression about which effects were most dominant in explaining changes in poverty and inequality, Table 4.8 shows the aggregate occupational choice effect, the aggregated price and endowment effects as well as the effect of changing non-labor income sources. For ease of understanding, Figure 4.1 illustrates these aggregate effects for poverty headcount changes ($P(0)$). At first glance, we find that the price effect caused a large drop in extreme poverty, followed by an increase in non-labor income sources. Non-labor income sources had a poverty reducing effect due primarily to increasing non-monetary income in poor households. In Peru, the recent expansion in social expenditures and transfer programs had only a small impact on poverty, because coverage of conditional cash transfers were still low in 2012. The effect from changing occupations between 2004 and 2012 also reduced poverty, however the effect was not as pronounced as the price effect. These poverty decreasing effects were in part counterbalanced by the endowment effect. This means that the rural population was placed in a worse position in 2012 than in 2004 as a result of inferior endowments of important assets. However, a further decomposition of the endowment effect into its components reveals that the majority of the impoverishing total endowment effect cannot be attributed to any observed endowment, but is captured by the remainder term (see Table C5.1 in Appendix C5). The large remainder results from a problem that arises when computing the endowment effect. The actual and the simulated household income vectors necessarily use non-labor income of two different time periods. Thus, although holding occupations, prices and the distribution of unobservables constant, the difference between the simulated and the actual income distribution is not only attributed to changes in the level and distribution of individual characteristics, but also results from changes in non-labor income. Therefore, we subtract the poverty (or inequality) changing effect resulting from a change in non-labor income from the total endowment effect. From Table 4.8 we also see that poverty reduction did not always go hand in hand with a reduction in income inequality. While the aggregate occupational choice effect reduced income inequality, the aggregate price effect and aggregate endowment effect increased income inequality. The effect of unobserved factors on poverty and income inequality played a minor role.

Table 4.8: Aggregate decomposition results of changes in poverty incidences and income inequality

	Extreme poverty (P(0))	**Moderate poverty (P(0))**	**Income inequality (GINI)**
2004 observed	44.7	42.0	38.8
2012 observed	20.9	34.6	40.2
Δ 2004-2012	-23.8	-7.4	+1.3
Total occupational choice effect	-3.8	-0.5	-1.1
Total price effect	-24.1	-0.7	+2.7
Total non-labor income effect	-15.5	+3.3	-2.8
Total endowment effect	+19.0	-9.7	+1.0
Unobserved effect	-0.4	-1.3	+0.8
Remainder	+1.0	+1.5	+0.7

Note: The table reports the observed poverty headcount index (P(0)) in 2004 and 2012, computed with respect to region-specific extreme and moderate poverty lines, and the observed GINI coefficient in 2004 and 2012. P(0) and the GINI can take on values between 0% and 100%. Higher values indicate higher poverty incidences or higher income inequality, respectively. Each effect shows the proportionate contribution to observed total changes in P(0) and the GINI presented in (Δ 2004-2012). Thus, the decomposition results (contribution of each effect) is given in %-points, which means that the sum of all effects amount to the observed total changes of P(0) and the GINI between 2004 and 2012.
(Source: own elaboration)

These aggregate effects are summary measures, capturing a variety of different and partly counteracting influences. In order to frame specific policy recommendations it will be interesting to learn about the driving forces behind these aggregate results. Each effect can be further decomposed into its components, either aggregated over all occupations or within each of the seven labor market sectors. Appendix C5 reports

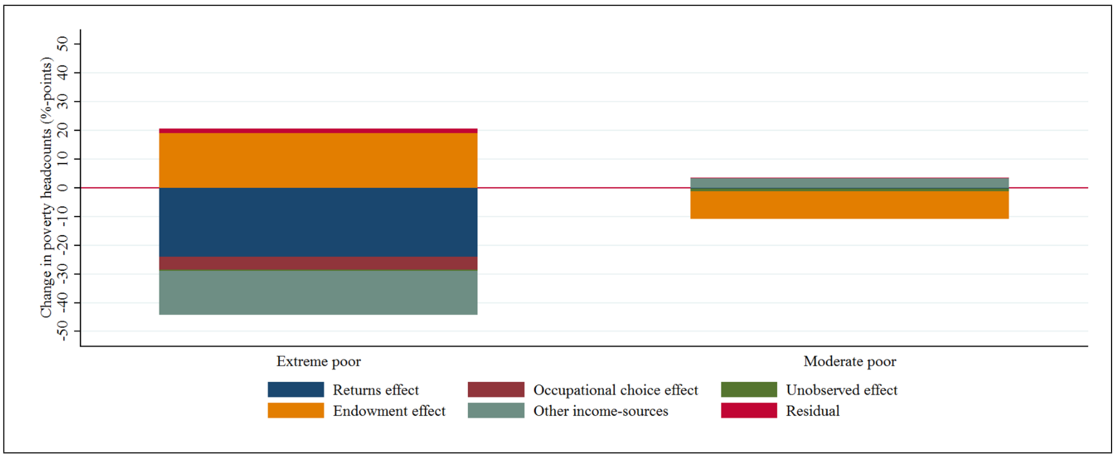

Figure 4.1: **Aggregate decomposition results of poverty incidences (%-points)**
Note: Each effect shows the proportionate contribution to observed total changes in P(0). Extreme poverty dropped by 23%, moderate poverty dropped by 7%. Thus, the decomposition results (contribution of each effect) are given in %-points, which means that the sum of all effects amount to the observed total changes of P(0) 2004 and 2012.
(Source: own elaboration)

a further decomposition of the price effect and endowment effect aggregated over all occupations which gives a good overview of the main structural changes that drove poverty and inequality in the total rural society (see Table C5.1 and Figure C5.1 in Appendix C5). But since our study wants to identify the main forces within each sectors and those attributed to occupational shifts, in the following we only report the key decomposition results that are related to the research questions stated above.

Impacts of income diversification

Going back to Table 4.2, we saw that there was a strong shift towards non-agricultural wage-employment accompanied by a significant drop in non-remunerated work. We want to know the distributional impacts of these occupational shifts between 2004 and 2012. Due to missing panel data, we simulated occupational shifts between 2004 and 2012 for each individual of the rural population in in both years using the results of the multinominal logit model (see Appendix C3 and Appendix C4). Table 4.9 shows how shifts between different sectors impacted poverty and income inequality between 2004 and 2012 (for more poverty and inequality indices see Appendix C6).

Since the total occupational choice effect is very small, the second-order effects are also very small. We find that the largest impact on poverty, especially extreme poverty, were associated to movements into non-agricultural wage-employment. Especially the transition from working as a non-remunerated family worker in 2004 to working in one of the non-agricultural wage sectors in 2012 helped people escape extreme poverty (-0.6%). Another 0.6% decrease in extreme poverty was caused by leaving any other paid sector and entering non-agricultural wage-employment. Of these 0.6% in poverty reduction, 0.2%-points were attributed to movements out of agricultural self-employment. These poverty reducing effects of movements into non-agricultural wage-employment can be explained by the fact that non-agricultural wage-work was better paid compared to any other sector. Simultaneously, income inequality fell slightly due to shifts into non-agricultural wage-employment. Apart from occupational shifts into non-agricultural wage-employment, 3.2% of non-remunerated family workers were simulated to move into paid agricultural wage-employment by 2012 (see Appendix C4). These movements lifted 0.5% out of extreme poverty, of which 0.3%-points remained in moderate poverty, though. Note that we do not present the decomposition results reflecting changes within agricultural wage-employment, but they are shown in Appendix C7. Occupational shifts between other sectors played in minor role in poverty reduction. Also, moving out of agricultural self-employment into other rural sectors hardly had distributional impacts.

Main drivers of change within non-agricultural wage-employment

Above, we showed that shifts towards receiving income from non-agricultural wage-work reduced poverty and income inequality to a certain extent (see Table 4.9). Hence, we analyzed whether dynamics within the non-agricultural wage-sector had distributional impacts, holding the structure of the rural labor market constant at the state of 2004 (and vice versa). In other words, Table 4.10 sheds light on the price and endowment effects within this sector. Although real average monthly wages increased by almost 60%

Table 4.9: Decomposition of the occupational choice effect

	Extreme poverty (P(0))	**Moderate poverty (P(0))**	**Income inequality (GINI)**
Observed total changes (2004 - 2012)	-23.8	-7.4	+1.3
Move out of non-remunerated work into the paid labor force			
Move to non-agricultural wage-employment	-0.6	+0.1	-0.1
Move to agricultural wage-employment	-0.5	+0.3	-0.1
Move to non-agricultural self-employment	n.e.	-0.1	n.e.
Move to maize farming	n.e.	n.e.	n.e.
Move to potato farming	-0.1	+0.1	n.e.
Move to coffee farming	n.e.	n.e.	n.e.
Move to “other” farming	n.e.	+0.1	n.e.
Occupational shifts from any sector, excluding movements out of non-remunerated work			
Move to non-agricultural wage-employment	-0.6	n.e.	-0.1
Move to agricultural wage-employment	-0.1	-0.1	n.e.
Move to non-agricultural self-employment	-0.1	+0.1	-0.6
Move to maize farming	n.e.	n.e.	n.e.
Move to potato farming	-0.2	+0.1	-0.3
Move to coffee farming	-0.2	n.e.	n.e.
Move to “other” farming	-0.1	-0.1	-0.1
Occupational shifts away from agricultural self-employment into other paid sectors			
Move to non-agricultural wage-employment	-0.2	+0.1	-0.1
Move to agricultural wage-employment	n.e.	+0.1	n.e.
Move to non-agricultural self-employment	n.e.	n.e.	n.e.

Note: The table reports changes in poverty headcount index (P(0)), computed with respect to region-specific extreme and moderate poverty lines, and changes in the GINI coefficient due to occupational shifts in the rural labor force. P(0) and the GINI can take on values between 0% and 100%. Higher values indicate higher poverty incidences or higher income inequality, respectively. The changes, in %-points, measure the contribution of each effect to the total observed changes of poverty and income inequality between 2004 and 2012. Observed changes in poverty and income inequality between 2004 and 2012 are given in the upper rows of this table. (Source: own elaboration) in this sector between 2004 and 2012, we find that the distributional impacts were rather moderate in this sector. While the endowment effect was literally non-existent, the total price effect in this sector caused not more than 2.5% of extreme poverty reduction. Keeping in mind that the total rural price effect amounted to a reduction of 20% in extreme poverty, the relevance of this sector for lifting people out of extreme poverty seems rather low. Nevertheless, more than one third of the fall in moderate poverty between 2004 and 2012 was attributable to changing returns in the non-agricultural wage sector. Particularly outstanding was the increase in the constant baseline income. This increase reflects an improved macroeconomic market environment in Peru which obviously also benefited rural areas. Also, higher returns to working hours in non-agricultural wage-employment in 2012 than in 2004 impacted real rural incomes positively. However, both higher constant base income and higher returns to working hours increased the rural GINI coefficient by more than 1%. In contrast, the price effect of decreasing returns to education and experience led to higher extreme and moderate poverty headcounts, but decreased income inequality.

Although the total change in returns within non-agricultural wage-employment led to a reduction in poverty between 2004 and 2012, it aggravated income inequality in rural areas. If only returns to different assets in this sector had changed, holding all other factors constant at 2004-levels, the GINI coefficient would have increased by 2.2%. The reason behind these distributional effects is illustrated in Figure 4.2. We find that the positive effects from changing returns manifest themselves much more in the upper ends of the income distribution, while the lower ends of the income distribution benefit much less by changing returns. Note that due to path dependency the estimation results vary, for either holding 2004-conditions constant or for holding 2012-conditions constant. This is the reason why we report the mean of these two effects in all tables. Driving forces behind changes in the rural income distribution resulting from dynamics within non-agricultural self-employment are presented in the Appendix C7.

Table 4.10: Decomposition of the price and endowment effect within non-agricultural wage-employment

	Extreme poverty (P(0))	**Moderate poverty (P(0))**	**Income inequality (GINI)**
Observed total changes (2004 - 2012)	-23.8	-7.4	+1.3
Price effect			
Total price effect within non-agricultural wage-employment	-2.5	-2.7	+2.2
Education	+0.4	+0.6	-0.8
Experience	+0.5	+0.4	-0.8
Female income gap	-0.1	+0.3	-0.3
Ethnic income gap	n.e.	+0.2	-0.2
Working hours	-0.9	-1.3	+1.0
Regional income gap	-1.6	-1.1	+0.5
Sectoral income gap	-0.1	n.e.	-0.4
Baseline income	-2.2	-1.9	+1.9
Remainder	+1.5	+0.2	+1.2
Endowment effect			
Education	n.e.	n.e.	+0.1
Experience	-0.2	+0.3	-0.2
Female labor force participation	n.e.	n.e.	n.e.
Working hours	+0.2	+0.3	-0.4
Sector mobility	n.e.	n.e.	-0.2

Note: The table reports changes in poverty headcount index (P(0)), computed with respect to region-specific extreme and moderate poverty lines, and changes in the GINI coefficient due to different price and endowment effects within non-agricultural wage-employment. The total endowment effect, separate for non-agricultural wage-employment, is not reported, because it cannot be simulated due to missing information of other household members being occupied in other sectors in the simulated year. P(0) and the GINI can take on values between 0% and 100%. Higher values indicate higher poverty incidences or higher income inequality, respectively. The changes, in %-points, measure the contribution of each effect to the total observed changes of poverty and income inequality between 2004 and 2012. Observed changes in poverty and income inequality between 2004 and 2012 are given in the upper rows of this table.
(Source: own elaboration)

Shift towards higher value crops

Since agricultural self-employment remained being the major source of income for most (poor) households in rural Peru, we also analyzed how structural changes within farming affected the distribution of income. More precisely, we investigated the distributional impacts of possible shifts away from staple crops, like maize or potatoes, to the production of a cash crop, such as coffee. Note that we did not simulate production quantities of different crops per farm, but we estimated the probabilities of mainly producing maize, potatoes, coffee or other agricultural products (see Appendix C3 for estimation results).

According to our occupational choice simulations (see Appendix C4), some shifts

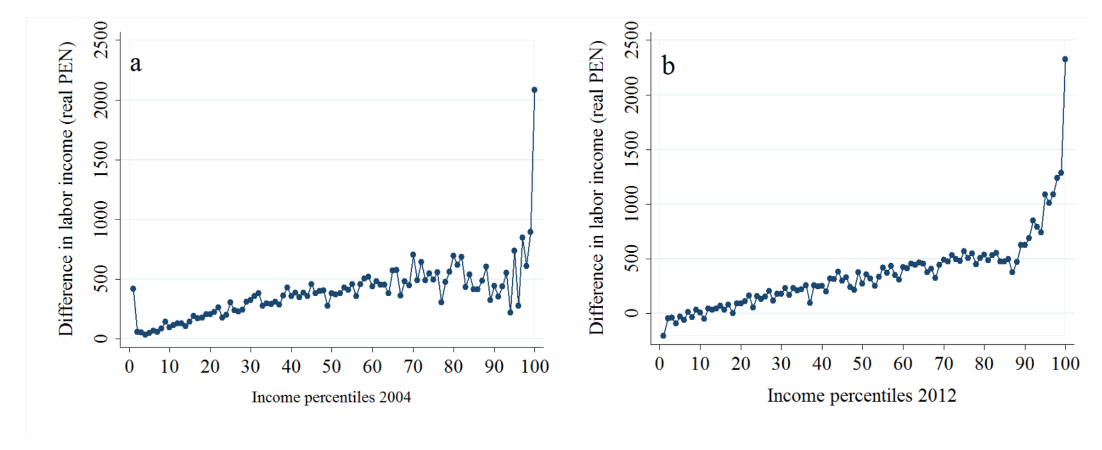

Figure 4.2: **Price effect within non-agricultural wage-employment (Δ2004-2012)**
Note: The dots show how average per capita household income changes within each income percentile due to changing returns in non-agricultural wage-employment between 2004 and 2012. Panel a) Estimates the price effect using returns of the year 2012 within agricultural-wage-employment holding everything else at 2004-conditions. Panel b) Estimates the price effect using returns of the year 2004 within agricultural-wage-employment holding everything else at 2012-conditions. PEN stands for the Peruvian official currency "Nuevo Sol" and is given in real terms with a base year of 2009. The official exchange rate to US dollars were 3.4PEN/US$ in 2004 and 2.6PEN/US$ in 2012.
(Source: own elaboration)

between maize and potato production occurred, but more farmers shifted away from the increasingly import-competing maize production into potato farming. An even larger number of maize and potato farmers shifted to coffee production for export markets, and to a lesser extend into "other" farming activities by 2012. Very few left the coffee sector between 2004 and 2012. Thus, there were less maize and potato farmers in 2012 than in 2004, but an increased number of coffee and "other" farmers. However, these production trends had hardly any distributional effects in rural areas (for details see Appendix C8). Moving into maize farming had no effect. Movements into potato farming lifted 0.1% out of extreme poverty, without allowing to escape moderate poverty. Shifts into the export sector of coffee production (and "other" farming activities) lifted 0.1% above the extreme poverty line and another 0.1% above the moderate poverty line. It seems that the shift towards the production of higher value crops like coffee failed to produce large poverty effects, because poor farmers were not able to take advantage of these market opportunities and remained in producing lower value staple crops. Despite these trends rural income inequality did not aggravate.

Main drivers of change within maize and potato farming

The majority of farmers, especially those living in poverty, did not shift towards high value export crops, but rather proceeded with the production of staple crops like maize or potatoes. Thus, we investigated the driving forces behind poverty reduction and changes in income inequality within maize and potato farming. Table 4.11 reveals that the price effect was the driving force behind extreme poverty reduction. The endowment effects were very low, in the main being poverty enhancing, especially for maize growers. There are only two endowment factors worth mentioning: First, some vulnerable farmers held less agricultural land in 2012 than in 2004 which pushed them below the extreme poverty line, and second some maize farmers at the lower end of the income distribution worked less hours in 2012 than 2004 with an impoverishing result. On average maize farmers worked 41 hours per week in 2004 which was reduced to 36 hours in 2004. Among extreme poor maize farmers, weekly working hours even decreased to 34 hours. These two effects also caused a more unequal income distribution in 2012 than in 2004.

Since the aggregate price effect in maize and potato farming together lifted 11% out of poverty, it is instructive to look at this aspect more closely. From the decomposition of the price effect, presented in Table 4.11 and Figure 4.3, we learn that the main driving force behind poverty reduction was an increase in the constant baseline income in both maize farming and potato farming. As mentioned above, this increase reflects improving macroeconomic conditions between 2004 and 2012. In the agricultural sector this change may have been caused by different factors, such as an improvement rural infrastructure granting better access to markets. Another important factor probably influencing farmers income was the general increase in food price levels due to international market forces during that time period. Especially maize was an increasingly import-competing product, and should thus have benefited from higher global price levels (Niemeyer and Garrido, 2011, Baquedano and Liefert, 2014). The higher baseline income in potato farming even reduced rural income inequality, but higher baseline incomes in maize farming slightly increased inequality. Another poverty reducing effect among maize and potato farmers were higher returns to working hours. This means that the negative endowment effect from working less hours were more than compensated by the positive price effect. This holds for both maize and potato farmers. However, in maize farming higher returns to working hours led to higher income inequality. And yet, the benefits from a higher baseline income and higher returns to working hours are in turn offset by other factors. Most notably, lower returns to education could be observed, pushing some people into extreme poverty and aggravating income inequality. Decomposition results of coffee and "other" farmers are presented in Appendix C9.

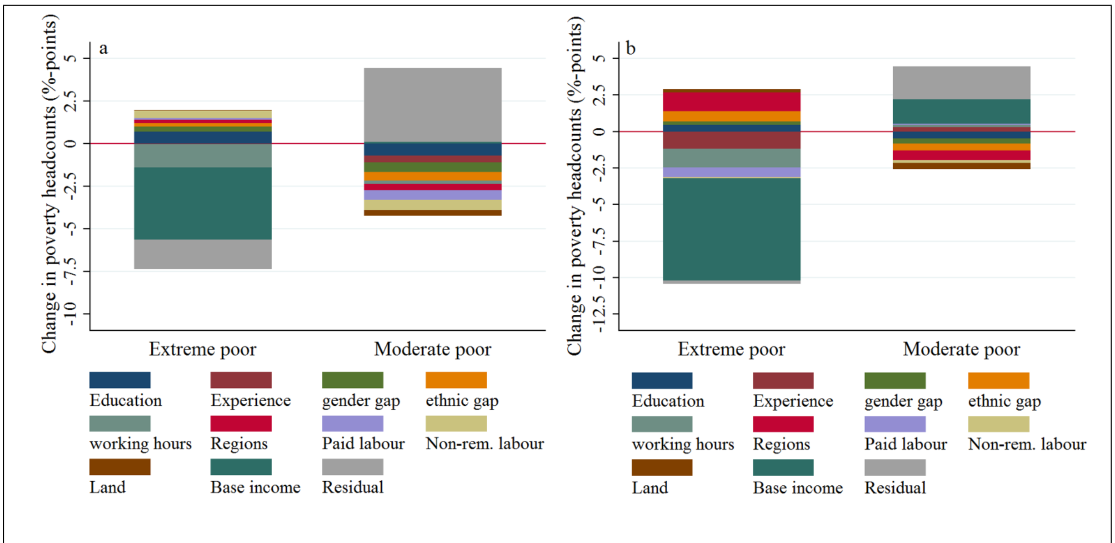

Figure 4.3: **a) Decomposition of the price effect in maize farming (Δ2004-2012); b) Decomposition of the price effect in potato farming (Δ2004-2012)**
Note: Each effect shows the proportionate contribution to observed total changes in P(0). Extreme poverty dropped by 23%, moderate poverty dropped by 7%.
(Source: own elaboration)

Table 4.11: Decomposition of the price and endowment effect within maize and potato farming

	Maize farmer			Potato farmer		
	Extreme poverty (P(0))	**Moderate poverty (P(0))**	**Income inequality (GINI)**	**Extreme poverty (P(0))**	**Moderate poverty (P(0))**	**Income inequality (GINI)**
Price effect						
Total price effect within farming	-5.4	+0.2	n.e.	-6.8	+1.0	-0.1
Education	+0.7	-0.7	+0.1	+0.4	-0.2	+0.3
Experience	n.e.	-0.4	+0.2	-1.2	+0.4	n.e.
Female income gap	+0.1	-0.4	+0.3	+0.1	-0.2	+0.2
Ethnic income gap	+0.3	-0.6	+0.5	+0.7	-0.3	+0.3
Working hours	-1.2	-0.2	+0.6	-1.5	+0.3	n.e.
Regional income gap	+0.1	-0.4	+0.6	+1.2	-0.5	+0.4
Paid labor	+0.1	-0.5	+0.4	-0.7	+0.3	+0.1
Non-remunerated labor	+0.4	-0.5	+0.3	-0.2	n.e.	+0.2
Land	n.e.	-0.4	+0.1	n.e.	n.e.	+0.2
Baseline income	-4.2	+0.2	+0.3	-7.2	+1.7	-0.6
Remainder	-1.7	+4.1	-3.5	+1.7	-0.5	-1.1
Endowment effect						
Education	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Experience	+0.2	-0.5	+0.2	-0.1	-0.1	+0.2
Female labor force participation	n.e.	-0.1	n.e.	-0.1	+0.1	n.e.
Working hours	+0.6	-0.6	+0.3	n.e.	-0.1	+0.2
Paid labor	+0.2	-0.4	-0.1	n.e.	-0.2	+0.2
Non-remunerated labor	+0.3	-0.6	+0.5	-0.1	n.e.	+0.2
Land	+0.6	-0.3	+0.4	+0.5	-0.2	+0.3

Note: The table reports changes in poverty headcount index (P(0)), computed with respect to region-specific extreme and moderate poverty lines, and changes in the GINI coefficient due to different price and endowment effects within maize and potato farming. The total endowment effect, separate for maize and potato farming, is not reported, because it cannot be simulated due to missing information of other household members being occupied in other sectors in the simulated year. P(0) and the GINI can take on values between 0% and 100%. Higher values indicate higher poverty incidences or higher income inequality, respectively. The changes, in %-points, measure the contribution of each effect to the total observed changes of poverty and income inequality between 2004 and 2012. Observed changes in poverty and income inequality between 2004 and 2012 are given in table 4.8.
(Source: own elaboration)

4.4 Discussion

In this paper, we analyzed the driving forces behind rural poverty and income inequality dynamics in Peru between 2004 and 2012 by using microeconometric decompositions methodology following Bourguignon et al. (2005). Our study moves beyond the examined outcomes of the existing literature by providing a more holistic view of rural income changes and the corresponding poverty and inequality impacts. Results of other works devoted to Peru range from studies of rural non-farm income diversification (Escobal, 2001, Jonasson, 2009) or the effects of a growing mining industry on rural development (Hinojosa, 2011, PWC, 2013), to the effect of modern infrastructure on household income in rural areas (Escobal and Torero, 2005, Chong et al., 2009). Others studies focus on microenterprises in urban areas (Dodlova et al., 2015).

We found that dynamics in the labor market were primarily responsible for moving the majority of people out of poverty. Higher productivity and growth in real wages, as well as the creation of paid work at the bottom of the distribution were the main mechanisms to achieve poverty reduction. On the other hand, a growing share of non-market earnings in total household income, such as benefits in kind like free transportation or meals, revealed certain relevance for lifting people out of extreme poverty and reducing income inequality. Our study focused on the labor market story behind poverty reduction. We found that structural changes in the labor market and the corresponding occupational choice change towards more non-agricultural wage-employment triggered income gains among the richer rural population, but had very moderate effects for the poor. Moving into non-agricultural wage employment only lifted about half a percent out of poverty between 2004 and 2012. This can be explained by two factors: First, non-agricultural wage-employment primarily gained importance at the "Costa", where poverty was already lower in 2004 than in other rural areas. The Peruvian coastal regions are the most densely populated in the country with high urbanization rates. This proximity to markets likely facilitated the development of businesses creating new employment opportunities. Further, it is possible to commute to urban areas as cities generally show higher employment opportunities outside of agriculture than more remote areas. However, some wage-employment was also generated in the "Selva' mainly due to a rising mining industry in this area (Escobal and Ponce, 2008). Wages paid in mining increased dramatically maybe due to an increasing demand for labor leading to lower extreme and moderate poverty incidences in the "Selva". Second, the probability of being employed in non-agricultural wage-sectors was much higher if educational attainments were higher. Hence, lower levels of education, typical for the poor population, constituted an entry barrier into profitable non-agricultural wage-sectors. Other authors come to similar conclusions. de Janvry and Sadoulet (2001), Reardon et al. (2001) and Jonasson (2009) emphasize the role of rural non-farm income as a potential pathway out of rural poverty. On the other hand, Escobal (2001) and Jonasson (2009) state that usually the relatively well educated benefit from higher returns to education in this sector compared to the agricultural sector. Although we find decreasing returns to education over time, higher skills still led to higher wages or profits in any sector. Thus, raising the capacity of the poor (e.g through better public educational institutions, employment skills trainings, or improvements in infrastructure to facilitate market access) is crucial for poverty reduction. In particular, if emerging non-agricultural markets in rural areas should operate in favor of the rural poor. Special attention is required to include women which were increasingly left behind in rural areas.

Another structural change affecting rural markets was the rise in agricultural wage work. However, poverty and inequality effects were rather low. Extreme poverty was reduced by a little more than half a percent, mainly due to movements out of non-remunerated work. Generally the landless low-skilled rural population engages in agricultural wage-employment, which are typically among the poorest of the rural population (Lanjouw, 2001). Thus, it is not surprising that new opportunities in this sector have the potential to reduce extreme poverty. The new demand for agricultural labor was in parts driven by an increasing engagement in international agricultural trade in Peru. While coffee remains Peru's most important agricultural export crop, more than 60% of all agricultural exports are now fruits and vegetables. The production of these products continues to be labor intensive, as many tasks, such as the harvest of asparagus, are not mechanized. Due to climatic conditions, a more favorable topography and proximity to markets, the Peruvian fruit and vegetable export industry developed at the "Costa" (Meade et al., 2010, Niemeyer and Garrido, 2011). The fact that development would be most needed in the "Sierra", and not at the coastal regions, explains why the poverty effects of these new employment opportunities were so low. However, some reason for hope offer recent private and foreign investments in infrastructure projects that connect remote areas to the coast (The Economist, 2013). Although the potential for progress in agricultural productivity in these areas is somewhat limited due to less favorable growing conditions (INIA, 2008), better market access could foster the establishment of new non-agricultural businesses, stimulating new employment opportunities in remote areas.

In line with other authors (Dixon et al., 2001, Ravallion and Chen, 2003, Christiaensen et al., 2011), our results provide evidence that the farming sector was crucial for poverty reduction. This is unsurprising, because a bulk of the rural (poor) population worked as self-employed farmers. Over the last decade, Peru has liberalized its agricultural markets (FAO, 2010, Velazco and Velazco, 2012) causing the discussed surge in agricultural trading activity. Due to comparative advantages, especially exports of coffee as well as fruits and vegetables rose, while maize became more and more import-competing (Tulet, 2010, FAOSTAT, 2014). These trends led to production shifts away from maize farming, and to some extent also from potato farming, into coffee and "other" farming. Some authors stress the relevance of cash crop production for poverty alleviation in developing countries under the premise that small and poor farmers are not excluded from the opportunities in these market sectors (Lipton, 2005, Weinberger and Lumpkin, 2007). Our results show that the distributional impacts of crop production shifts were very small. Income inequality went down slightly, but poverty was almost unchanged due to production shifts. This indicates that poor farmers were not able to take advantage of these new global market opportunities. Also women were largely left out of the production of cash crops. Our findings are in line with Fort (2008), Meade et al. (2010) who state that there was an increased concentration of acreage by just a handful of farmers that produce crops predominantly for export markets, not least due to complicated rules of land tenure. Subject to the land Titling Act from 1997, uncultivated land was declared as "abandoned" and taken over by the State. This law strongly disadvantaged smallholders who left some of their coastal lands fallow due to a lack of water resources and not as the result of land abandonment. Thus, improvements in land tenure rules and access to irrigation could already help poor farmers to participate in more profitable agricultural production. The limited ability to move from staple crop production to cash crop production was in part attributed to geographic growing conditions, though. Coffee, for example is primarily grown in the northern "Sierra" and "Selva" while the southern "Sierra" has only limited agricultural development opportunities due to its harsh climate and geophysical conditions (Escobal and Ponce, 2008, Velazco and Velazco, 2012).

Although the majority of poorer farmers stayed in maize and potato farming, changing conditions in agriculture lifted a remarkable fraction of farmer families out of poverty. We did not find evidence, though, that agricultural development equalized incomes. The main driving force behind poverty reduction were improving macroeconomic conditions between 2004 and 2012 leading to higher profits in agriculture. Despite the fact that the decomposition method cannot identify the reason behind increasing returns and higher baseline incomes in agriculture, one possible conjecture is that improvements in the road network reduced transaction costs and allowed for greater returns due to better market access (Inchauste et al., 2012). Furthermore, the real value of agricultural production probably increased due to relative price changes in favor of agriculture. Note that the decomposition results of the agricultural price effect do not reveal what part of agricultural profit changes was attributed to an increase in real productivity and what part was associated with an increase in relative prices. However, given that the period of investigation was characterized by an increase in the relative domestic prices of agricultural products, this factor might have been an important driver of agricultural returns especially since 2007/08 (Abbott and Borot de Battisti, 2011, FAOSTAT, 2014). Some potato farmers were also lifted out of poverty due to increasing returns to labor. By contrast, rising female profit gaps and profit gaps related to ethnic descent were a source of some concern. Also, some vulnerable farmers were pushed into poverty due to decreasing farm sizes over time. Hence, not only adequate land tenure rules, but also reducing gender and ethnic discrimination would help to combat rural poverty. Furthermore, access to capital might help to increase farm size and to hire more labor.

Applying microsimulation models based on household income generation models yields some important advantages in poverty and inequality analysis. They are not only effective in assessing the welfare implications of changing returns to rural assets, but they also embrace the impacts of discrete changes in individual behavior, such as labor market choices, sectoral movements or educational attainments. However, this is not without limitations. Due to a lack of theoretical foundation and the reduced-form representation of labor market behavior, these decompositions do not allow for the identification of causal effects and the related transmission channels of distributional changes. Yet, they are useful to focus attention on the elements that are quantitatively important in describing changes in poverty. Furthermore, estimating earnings equations that correspond to different occupational choices implicate selection problems, causing biases in the OLS estimation results. Although Heckman correction models are very common in approaching this issue, it is not trivial to correct for selection biases due to missing valid instruments that need to explain the sectoral choice, but not earnings. For a more complete description of the limitations of this microeconometric method see Bourguignon et al. (2005), Lay (2010).

4.5 Conclusions

This study identifies key drivers of rural poverty and income inequality changes in Peru between 2004 and 2012; a time characterized by fast economic growth and changing domestic and global market forces. We use a microsimulation model based on rural household income generation models to decompose the observed decline in poverty and the simultaneous increase in income inequality between 2004 and 2012 into different components. We find that structural changes and the corresponding shift away from non-remunerated work into non-agricultural and agricultural wage-employment improved poverty and income inequality indices to some extent. Income diversification away from agriculture into rural non-farm activities hardly showed distributional impacts. Unsurprisingly, the bulk of extreme rural poverty reduction occurred within the agricultural sector, especially in maize and potato farming. Changing returns to rural assets in only these two sectors contributed to more than 50% of the total decline in extreme poverty between 2004 and 2012, but had weaker implications for moderate poverty reduction and almost no effect on income inequality. A large fraction of the decline in moderate rural poverty can be explained by improving returns to assets in non-agricultural wage-employment. However, in non-agricultural sectors the richer rural population benefited more than the poor. Thus, the poverty alleviating price effect in non-agricultural activities were also responsible for the more unequal income distribution in 2012 than 2004 in rural Peruvian areas. The main poverty reducing effect in all sectors can be attributed to favorable changing macroeconomic conditions. The country was enjoying a splendid economic growth, with foreign investments flowing into mining and infrastructure projects. These developments created new jobs inside and outside of agriculture and improved market access in rural areas. Furthermore, the commodity boom's export income did not only generate wage-employment in agriculture or mining, but also provided tax revenues and led to a currency appreciation, allowing for large growth of public investments (The Economist, 2013). For example, conditional cash transfers were expanding, but coverage of these programs was still too small in 2012 to have made a significant impact on poverty. In summary we can state that new opportunities in non-farm as well as farm activities arose. In order to give the poor a stake in the development of the non-agricultural wage-employment sectors, capacity raising through better public educational institutions, employment skills trainings (especially for women), or further improvements in infrastructure will be needed. Given the fact that agriculture remains being the most important income source for rural households, supporting agricultural research, training and financial services to poor farmers should be targeted. The participation of the poor in Peru's continued success in the agricultural export sector will require overcoming further challenges, such as poor transportation infrastructure and marketing systems, especially in the "Sierra", and a complicated land tenure situation.

Chapter 5

Synthesis and future research

5.1 Contribution of this thesis

The research goals of this thesis were motivated by the recent transition of agricultural and rural markets driven primarily by ongoing globalization of the food sector and a rapidly growing world population. These transformations pose major risks for the environment and affect prospects for economic development in different regions. The demand for holistic solutions required to address these challenges inspired me to conduct multi-scale research on the various impacts of globalizing agricultural markets. A special focus of the analyses lies on the effects of increasing agricultural trade. This thesis contributes to four different strands of literature: first, the literature on the trade-environment nexus; second, the literature on interlinkages between globalization, trade and food security; third, the food price transmission literature; and fourth the literature on poverty and distributional implications of trade. Seeking to fill knowledge gaps within each of these literature strands, I formulated several research questions in the introductory chapter. This section presents the main conclusions drawn from answering these research questions.

Chapter 2 contributes to the literature about the role of trade and different agricultural production practices for feeding the expected nine billion people living on this planet in 2050 and the related impacts on the environment (see e.g. Fischer et al., 2008, FAO, 2009a, Godfray et al., 2010a, Phalan et al., 2011, Schmitz et al., 2012). In particular, the chapter sought to answer the following questions:

1.1. *What are the trade-offs between improving global food security via*

> *further trade liberalization and environmental outcomes in large agricultural exporting regions like LA?*

To answer this question, the dynamic partial equilibrium model of the agricultural sector “IMPACT” is used to model global agricultural trade flows up to year 2050, comparing a BAU scenario with a scenario that assumes liberalized trade regimes. Major socio-economic trends, like population growth, income growth in emerging countries and urbanization trends with the associated dietary shifts are taken into account. Also the effects of progressing climate change on crop yields and water resources are considered in the modeling exercise. IMPACT results on future food supplies of both scenarios are linked to various food security and environmental indicators to discuss trade-offs between both goals.

I found that trade liberalization leads to lower global prices for most crops and livestock products compared to a world with less trade. Production, especially for export markets, shifts to those regions that hold comparative advantages in food production. Especially LAC’s livestock production would benefit from more open agricultural markets. This implies that trade liberalization is one way to improve global food security via higher global food supplies and lower prices, because these parameters affect people’s ability to access food across the world, particularly in developing countries. Chapter 2 shows that the number of malnourished children will be somewhat lower in 2050 under open agricultural trade regimes compared to a world with a higher degree of border protection.

However, I also found that more open trade, with its effect of increasing agricultural production in exporting regions, entails environmental risks. Due to LA’s abundant natural resources, the region holds strong comparative advantages in the production of food for world markets, which will be stimulated even further by future trade liberalization. Comparing the BAU scenario with the scenario that considers more open trade shows that trade will put additional pressure on the use of natural resources in many regions in LA. Increasing the production for domestic and export markets will result in a substantially higher rainfed crop production (adding to the already large green water footprint), and to a lesser extent, an increase in freshwater use for agricultural purposes (blue water footprint). Since, the true impacts of increasing rainfed production are associated with the environmental costs of land conversion, rather than the use of water, Chapter 2 analyzed carbon-stock losses and risks for biodiversity. The results suggest worrisome rates of conversion for both scenarios, but impacts on C-stocks and biodiversity are even higher if trade will be liberalized. The same holds with N-emissions to water bodies in LA that could severely degrade the quality of water in many river basins in the future. In conclusion, the results of Chapter 2 suggest that increasing agricultural trade can help to achieve the goal of global food security, but without adequately adjusting agricultural management practices, this ongoing trend of globalization can have harmful effects on freshwater stocks and water quality as well as for biodiversity and the C-storing capacity of the region. Therefore, unless LA national governments implement stricter land conversion policies, coupled with higher investments in R&D in the agricultural sector, the current path of gradual expansion of agricultural land, and intensification of agricultural production in most LAC countries, stimulated by increasing world's food demand, will lead to serious and potentially irreversible environmental effects.

1.2. *How do different agricultural production pathways change future outcomes of open trade for food production, global food security, and environmental sustainability and natural resource use in LA?*

The literature suggests that food production has to increase substantially by 2050 (FAO, 2009a). My results show that trade is one mean to enhance global food production, but bears the risk of environmental degradation in leading exporting regions. Thus, question 1.2 investigates whether different future production pathways allow to further increase agricultural production for global markets without causing further environmental damage. Chapter 2 analyses different production scenarios, contrasting land expansion versus more intensified agriculture, and versus one scenario that considers sustainable intensification as a possible solution to produce more food with less inputs.

The alternative scenario of increased extensification in the LA region achieves increased food production through low-input agriculture combined with increased agricultural land expansion. The results show that this production pathway can reduce water consumption and pollution levels in some Latin American countries and areas within countries, but leads to very high rates of land conversion with adverse impacts on carbon stock and biodiversity levels. In total, C-stock losses will be almost five times higher than under intensive agricultural crop production, and the risk of biodiversity losses will be substantially higher than under any other possible future. Moreover, extensification will curtail agricultural supply and thereby threaten regional and global food security. Thus, accelerated land expansion cannot offset the slowdown in yield growth.

Contrarily, the scenario of agricultural intensification reduces land use change, but places additional pressure on some regions in LA that already suffer from water scarcity. Also, more conventional intensification entails higher risks of water pollution with N-emissions being more than 25% above the emission rates that extensive agriculture would cause. On the food security side, important reductions in global food prices and thus in the number of undernourished children can be achieved under intensification.

The most favorable scenario is the sustainable intensification scenario, which achieves the same productivity and food security impacts as the intensification scenario but also uses natural resources more efficiently. Hence, increasing agricultural trade cannot only lead to global efficiency gains in the use of natural resources, but also be more environmentally sustainable for exporting regions if agricultural management practices are adjusted adequately. For the sustainable intensification scenario to become a reality in Latin America, higher investments in research and development in agriculture and better management of natural resources will be needed. Examples include breeding for more nutrient-efficient and salt- and drought-tolerant crop varieties, targeting further expansion of no-till agriculture, and more rapid development of affordable precision agricultural tools adapted to the region, as well as improved monitoring and enforcement of regulations concerning water pollution. Furthermore, sub-surface drip irrigation technologies, coupled with modernized irrigation systems, have the potential to significantly increase water productivity. Furthermore, Brazilian and Argentinian governments should enforce the predominant use of feedlot systems to limit extensive livestock farming, which would lower pasture land expansion and associated adverse environmental consequences.

1.3. *Where are future agricultural trade-induced environmental hotspots in LA and at what scale do environmental changes show their impacts?*

I found that future trade-offs between economic benefits and environmental drawbacks vary significantly across LA regions and depending on the production path chosen. Especially under the extensification scenario, land-use change will be highly concentrated in a few important production regions. C-stock losses and an increase in the risk of biodiversity loss resulting from crop land expansion will be most pronounced in Brazil and northern Argentina. This points to the outstanding role of these two countries as global food -especially of soybeans and its derivatives- providers. I also found that liberalizing trade regimes will boost livestock production, concentrated in some LA regions. Since pasture land often crowds into C-rich and biodiversity-rich forest areas, environmental impacts can be severe. Associated C-stock losses of enhanced livestock production will be highest in the Orinoco river basin in Northern-South-America, North-East Brazil, and the Amazon in Central-South America and Peru. Biodiversity risks will increase most in Tocantins in Brazil and the Orinoco river basin in Northern South America. The large increase in carbon emissions in these few LA regions will have impacts at the global scale through accelerated climate change. On the other hand, the environmental consequences of biodiversity losses can show their impacts at multiple scales. The species shaping an ecosystem determine its productivity by affecting nutrient cycles and soil contents, as well as water cycles, weather patterns, climate and other no-biotic aspects. The loss of so called “keystone species” could be related with a reduced functioning or destruction of entire ecosystems which could take place at the local scale, but also at broader regional scales.

Contrarily to the consequences of the extensive agriculture, the scenario of conventional agricultural intensification reduces land use change, but places additional pressure on some water-scarce regions, like the state of Tocantins in Brazil and coastal Peru. Water scarcity issues are mostly local or regional issues, not only affecting agriculture, but also municipal water uses, especially in times of increasing urbanization. Furthermore, more conventional intensification entails higher risks of water pollution, particularly for northeastern Brazil and parts of Mexico. Furthermore, vast amounts of N-fertilizers are used to grow farm animal feed, primarily composed of maize and soybeans. So, if further global demand pressure led to a continuation of past trends in maize, soybean and livestock production, these countries will likely hit environmental limits with regional and global environmental consequences.

Chapter 3 mainly contributes to the literature on the processes surrounding food price transmission rates from global to domestic markets that evolved after the so called food price crisis of 2007/08. In particular, the content of the chapter is devoted to gain deeper understanding of the effects of agricultural market integration on the price path-through from global to domestic food markets. From a policy perspective it is also relevant to identify other price-determining factors that are able to buffer price shocks. In this context, Chapter 3 addressed the following research questions:

> 2.1. *How do different degrees of agricultural market integration affect horizontal food price transmission rates in LA?*

In order to analyze the relationship between global food price shocks, trade openness and domestic food price movements, Chapter 3 applies an error correction modeling framework to estimate how different degrees of agricultural market integration influenced world price transmission rates in six LA countries (Argentina, Brazil, Colombia, Chile, Mexico and Peru). This is particularly important in light of the recent global price spikes and the presumption that food prices might be subject to a certain degree of volatility over the next decade due to changing global market forces. As a reaction to global food price volatility, policy makers tend to apply border protection policies which could curtail global supply and aggravate global, and even domestic, food price volatility.

Results suggest that international trade and market integration has led to different degrees of price transmission rates in the studied countries. I found that increasing levels of trade openness elevate food price transmission rates after price shocks, especially in the short-run. Short-run price transmission elasticities vary between 33 and 89% in the six countries of investigation, depending on the degree of market integration. Long-run transmission elasticities are less dependent of trade openness, being at rates between 71 and 81%. Hence, more trade openness brings with it more price instability in the short-term under world price shocks and the resulting persistence in the long-term. In the absence of effective safety nets, the drastic short-run price transmission rates can be harmful for poor consumers in countries that are deeply integrated into global food markets. Although the results confirm higher world price transmission rates with increasing degrees of trade openness, this does not necessarily verify the usefulness of trade policies to buffer price shocks. First, because there is a considerable risk of price volatility due to domestic supply shocks if self-sufficiency is promoted. Second, protectionism might exclude the country from participating in beneficial high-value agricultural supply chains and thereby hamper economic development.

2.2. *How did these different food price transmission rates affect large LA agricultural trading nations after the 2008-price shock?*

To get a better understanding of the consequences of the global food crisis of 2007/08, the estimated short-run and long-run food price transmission rates of each country are applied to the global price situation in those years. According to the IMF and FAO, the general food price index jumped up by one quarter between 2007 and 2008. As a result, the estimated domestic food price reaction in Chile was in total 41% (short-run plus long-run) and in Argentina 31%, both being countries that are very dependent on food imports and exports. Chile's level of trade openness in 2008 was 220%, while Argentina's import and export values still made up 107% of the country's total agricultural GDP at the time. In contrast, countries that produced a large fraction of their total food production for domestic markets showed more moderate domestic price increases in 2008 induced by the global price shock. In Brazil and Colombia, the global-price-shock-induced increase in domestic food prices were at rates around 25%.

On the one hand, my results show that trade-dependent countries were affected more severely by the global food price shock of 2008. On the other hand, the domestic food price reaction in a very trade-dependent country like Chile was only 10%-age points higher than in Argentina which trade openness indicator was more than 100%-age points below Chile's degree of trade openness. This finding challenges the rationale of Argentina's trade policy as a reaction to the price shock. It appears that imposing export bans and export taxes might not be as effective for price stabilization as wanted by many policymakers and generally expected by the civil society. However, to reduce households' vulnerability to sudden and large increase of food prices, some degree of price management for basic staples may be warranted, coupled with income support or cash transfers. Besides price interventions by establishing maximum food prices for certain commodities temporarily, policies for redistributing food as well as providing food in elementary schools can be appropriate, but must be carefully planned with the required budget readily available.

2.3. *Did other macroeconomic factors moderate or reinforce price transmission rates?*

Chapter 3 also considers other macroeconomic variables that can potentially influence domestic food prices. Specifically, I investigate movements in exchange rates and money supply in the six LA countries. My results illustrate that currency appreciations can in part buffer the path-through of global to domestic prices. For example the Brazilian, Colombian and Peruvian currencies appreciated between five and six percent between 2007 and 2008 which made food imports less expensive and exports less competitive and thereby decreased the domestic food CPI. Results also suggest that a country can regulate food price (inflation) by managing its money supply through effective monetary policies. According to Gonçalves and Salles (2008), developing countries with effective inflation targeting regime did not only experience greater drops in inflation, but also in volatility of CPIs. Inflation targeting regimes have been adopted in Brazil, Chile, Mexico and Peru. Thus, promoting macroeconomic stability and well-functioning institutions seem to be a crucial factor in stabilizing food prices, and thereby safeguarding sufficient food access to the poor. However, the potential of macroeconomic policies to cushion rapid and unexpected food price increases depends very much of the fiscal capacity of the country and soundness of the basic underlying parameters of the economy. So this conclusion does not warrant clear recommendations for all countries in all circumstances.

Chapter 4 contributes to the literature on the role of agriculture as well as diversification into non-agricultural sectors for rural poverty reduction. Changing global megatrends and more liberal agricultural markets have affected rural areas across the world, also and especially in developing countries. Narratives of changes related to globalization range from being very optimistic to pessimistic. On the one hand, it is argued that these changes imply opportunities for growth and income improvements. In rural areas, these changes give rise to opportunities within the agricultural sector as well as outside of agriculture. Also, people might be able to switch occupations to higher income sectors. On the other hand, globalization might increase income inequality and vulnerability to poverty due to lacking capabilities of integrating the poor into globalization processes. Taking the example of Peru, a country increasingly integrated into global food markets, that showed remarkable reductions in rural poverty, but also persistently high rates of rural income inequality, I approached the research questions 3.1-3.4. To answer them, I apply a microsimulation model based on rural household income generation models to decompose the observed changes in poverty and income inequality in Peru between 2004 and 2012 into different components, like occupational shifts, price changes within and outside of agriculture, or changes in important characteristics of the rural population.

3.1. *To what extend has income diversification into non-agricultural sectors contributed to changes in poverty and income inequality?*

Non-farm employment can be an important source of income for the poor and an effective way out of poverty for rural households, as well as a means to cope with missing credit and insurance markets (Dethier and Effenberger, 2012). Although, wages paid outside of agriculture are well above agricultural or non-agricultural profits or wages paid in the agricultural sector, results for Peru show very limited poverty and inequality effects from diversifying household income sources via participating in non-agricultural wage-employment. Instead, I found that structural changes in the labor market and the corresponding occupational shift towards more non-agricultural wage-employment triggered income gains among the richer rural population. My findings provide evidence that the probability of being employed in non-agricultural wage-sectors was much higher if educational attainments were higher. Thus, in order to extent new employment opportunities outside of agriculture to the poor, proper education is necessary to guarantee access to non-farm jobs. Consequently, rural development programs and other regional policies should incorporate such needs into their strategies. Despite the described entry barriers into rural non-farm wage-employment, I found that important dynamics led to income gains for the rural population already employed in non-agricultural wage sectors. While these dynamics had some poverty reducing effect, the same forces simultaneously increased income inequality, indicating that the richer population benefited more, in relative terms, than the poor. These changes led me to my next research question:

> 3.2. *What were the main dynamics outside of farming having distributional impacts?*

I identified that the rural non-farm sector mainly benefited from favorable changing macroeconomic conditions. Peru was enjoying a time of splendid economic growth, with foreign investments flowing into mining and infrastructure projects. These developments created new jobs in non-farm sectors and improved market access of firms in rural areas. Furthermore, the commodity boom's export generated wage-employment in agriculture or mining, and provided tax revenues and led to a currency appreciation, allowing for large growth of public investments. As a result of these market transformations, non-agricultural wages (but also wages within agriculture) rose over the last decade. My results suggest that these favorable conditions were responsible for a large fraction of the decline in moderate rural poverty, and to a lesser extent for the decline in extreme poverty. However, the population at the upper end of the income distribution benefited more than the poorer population groups, which entailed an increase in income inequality.

The relevance of agricultural growth in reducing rural poverty is well established (Irz et al., 2001), a finding that my thesis could confirm. However, important discussions remain about the drivers of growth within agriculture. This brought the thesis to the next two research questions:

> 3.3. *In the agricultural sector, was a shift towards higher value export crops responsible for the reduction in poverty and changes in income inequality?*

Globalization trends in the agricultural sector have led to production shifts away from maize farming, and to some extent also from potato farming, into lucrative export sectors like coffee farming or the production of fruits and vegetables. The coastal regions specialized in the production of non-traditional vegetables to satisfy global demand, while the “Selva” region increasingly produced traditional export crops, like coffee, cacao or oil palm. The “Sierra” region was largely characterized by the production for domestic markets and smallscale farming (Velazco and Velazco, 2012). While some authors stress the relevance of cash crop production for poverty alleviation in developing countries, I found the poverty effects of crop production shifts to be very small in Peru. Income inequality went down slightly, but poverty was almost unchanged, indicating that poor farmers were excluded from opportunities that new global markets can bring about. In particular, most regions in the “Sierra” were left out these processes of change, which is where rural poverty remains to be most severe in Peru. Chapter 4 concludes that this exclusion of poor farmers can be explained by inappropriate land tenure rights, insufficient education and limited access to capital. In the coastal regions, missing access to irrigation can also explain the exclusion of smallholders. In part, the poorer regions, especially located in the “Sierra”, were excluded from crop production for export markets due to unfavorable climatic and geophysical conditions (Velazco and Velazco, 2012). Here, it would be most crucial to foster employment opportunities outside of agriculture. However, high altitudes and remoteness of many rural areas in Peru constitute obstacles for economic growth across sectors.

Although results indicate that the population group belonging to the poor agricultural self-employed were largely excluded from the production of high-value crops, these new markets generated wage-employment opportunities within the agricultural sector. Especially women were increasingly hired as workers on large farms that produced for export markets (Velazco and Velazco, 2012). My results show that rising opportunities in the agricultural wage-sector lifted some households out of poverty, especially because these women worked non-remunerated before.

3.4. *Did the changing global agricultural market environment contribute to welfare changes of poor staple food producers?*

Findings in Chapter 4 show that the majority of poverty reduction occurred due to changing conditions in maize and potato farming, which is unsurprising since most of the rural poor were occupied in these sectors in Peru. Although the analysis does not allow for identifying direct causal effects of globalization and trade on changes in the distribution of income, there are a few developments suggesting that global agricultural market forces influenced poor staple crop producers. According to the decomposition results in Chapter 4, the major part of poverty reduction resulted from an increase in the baseline income in maize and potato farming, which points to more favorable macroeconomic market conditions that facilitated growth in these sectors. Despite the fact that the decomposition method applied in Chapter 4 cannot identify the reason behind increasing returns and higher baseline incomes in agriculture, one possible conjecture is that improvements in the road network reduced transaction costs and allowed for greater returns due to better (global) market access. Furthermore, the period of investigation was characterized by an increase in the relative prices of agricultural products, in part likely driven by higher global food price levels. This factor might have been an important driver of returns in maize and potato production, and thereby lifted a large fraction out of extreme poverty. Apart from the general growth effect on poverty, some potato farmers were also lifted out of poverty due to increasing returns to labor which might be explained by improving labor productivity. On the other hand, rising female profit gaps as well as profit gaps related to ethnicity were a source of some concern. Also, some vulnerable farmers were pushed into poverty due to decreasing farm sizes over time. These decreasing farm sizes of poor farmers within traditional agriculture might be explained by the trend of expanding agriculture for export markets at the expense of traditional agriculture; as well as poorly defined property rights. In general the Peruvian farming system is very fragmented with farm sizes being below 10 or even below three hectares, leading to low productivity rates. Hence, adequate land tenure rules, as well as reducing gender and ethnic discrimination would help to combat rural poverty.

In summary, Chapter 4 provides evidence that the overall economic growth that Peru experienced during the last decade lifted a substantial fraction of the rural population out of poverty. In part, the economy as a whole probably benefited from policy changes towards more open trade regimes and the agricultural sector by the transmission of higher global food prices to domestic producer prices. However, the results also suggest that the rural population's endowments with important assets, especially of the poor, did not improve much between 2004 and 2012. For example, poor people's educational attainment was hardly better in 2012 than in 2004. Also land and labor endowments, especially in the "poverty-relevant" agricultural sector, rather decreased than increased over time. Given the fact that these variables are statistically significant and positive in the labor income regressions, my results indicate that there is still scope for policy action to improve access to these assets.

5.2 Limitations and future areas of research

Although this thesis intents to provide a holistic view of the implications of changing agricultural markets in light of globalization, there are still many related aspects that could not be addressed and some shortcomings that result from the data, the methods and analyses. A complete discussion of the methodological shortfalls is already presented at the end of each chapter. To name the most important ones: In Chapter 2, uncertainties of environmental impacts related to land-use change could be reduced if a proper land-use model could be linked to the IMPACT model, instead of applying the rough approximation of future cultivated areas derived from estimates of area harvested. Chapter 3 likely suffers from selection bias due to the non-random selection of countries analyzed in a panel framework. The most noteworthy methodological limitation of Chapter 4 is related to the missing theoretical foundation of the modeling framework applied, making causal inference impossible.

Besides these methodological aspects, here I want to name a few general limitations of the thesis. The most relevant one is related to the fact that the thesis has the ambitious goal to provide insights of impacts of globalization and agricultural trade from many different angles, covering many different topics. This involves the trade-off between providing holistic solutions to a complex dynamic system and the sometimes insufficient depth and precision of the analysis of each of the aspects covered. The thesis covers topics ranging from environmental issues, over issues related to food security, to macroeconomic aspects of food price movements to a microeconomic poverty analysis. Each of these topics would merit a deeper discussion. But, this, in the modest view of the author, could also be considered a strength because it provides many insights and a holistic discussion on some of the most important global and regional aspects surrounding the future of LAC's rural development and food prices, agriculture, water and land resources, as well as C-stock and biodiversity levels.

Chapter 2 considers environmental impacts, ranging from water related issues to consequences for carbon stocks and biodiversity impacts for the entire LAC region. Although, the analysis provides results at the subnational level for each of the indicators, solutions that prevent environmental degradation are typically context-specific and require more detailed research at lower scale. Chapter 2 also discusses the implications of trade and different future food production paths for global food security. Although the approach applied takes into account a variety of socio-economic variables, besides varying levels of food supply in each world region, this is a rather simplistic approach to assess changes in food security. Food security is, in a great measure, related to poverty which requires research at the micro-level in order to truly form an opinion about the effects of trade openness and changing agricultural management practices. Policy changes will generate winners and losers, a fact completely ignored in chapter 2. However, the combination of agricultural trade analysis with the quantification of various economic and environmental impacts, although at the aggregate level, is still useful to raise concerns about future developments and environmental hotspots, which can call attention to global environmental and development communities.

Chapter 3 looks at food price movements after global price shocks in the context of increasing agricultural market integration. This chapter of the thesis provides useful knowledge about whether trade policy can be an effective means to stabilize domestic food prices and whether macroeconomic policies can mitigate food price inflation at the aggregate level. However, a major limitation is associated with the fact that I only looked at the aggregate food price index. A lack of data on sub-product-categories or single food items over a sufficient number of years did not allow me to go into deeper detail which prevented me from obtaining product-specific results. Especially if price changes should be discussed with respect to food security issues, exclusively considering the food CPI in the analysis might obscure important insights. The CPIs are usually constructed in such a way that the food items presented reflect the average consumption patterns of a ‘middle-class’ target population, usually living in urban areas. To better serve food security analyses, CPIs for the poor should be constructed that better represent consumption patterns of the rural and urban population living around the poverty line. Furthermore, the analysis of Chapter 3 is limited to a set of six countries and analyzed in a panel framework. A broader set of countries, clustering them into groups of net food importing and net food exporting nations, could avoid a possible selection bias of the results and allow for more detailed inferences on adequate trade policies.

Chapter 4 provides a holistic analysis about the drivers of rural poverty reduction and possible backgrounds of persisting income inequality in Peru. While the analysis manages to direct the attention to those factors that were quantitatively important in describing changes in the distribution of income between 2004 and 2012, it does not allow for the identification of causal effects and the related transmission channels of poverty and inequality changes. Furthermore, the counterfactual scenarios that I constructed in chapter 4 are based on historical observations over time rather than stylized trade scenarios. As a consequence, this permitted drawing some conclusions about the drivers behind observed poverty and income inequality changes. However, it also narrowed the scope to isolate trade-related effects. In order to put the focus more on trade-related changes in the distribution of rural income, one would have to apply sequential macro-micro-simulations that would prefix a macroeconomic CGE model to a behavioral microsimulation model, like the one presented in Chapter 4 (for details see (Lay, 2010)).

Despite the indicated limitations, the thesis provides an integrated framework for the assessment of a broad array of possible impacts related to transforming agricultural and rural markets in light of globalization. Based on insights derived from the research discussed in this thesis, I want to emphasize a reasoning that deserves closer academic attention: the upcoming challenges of the next decades, related to changing global mega-trends, will require large increases in global agricultural production and more food trade.

To fully exploit the world's potential in producing enough food for all, smallholders in developing countries cannot be longer excluded from global agricultural supply chains. In this context, the goal of achieving global food security and poverty eradication are closely interrelated. Hence, the world must promote improvements in agricultural productivity bearing in mind environmental limits and integrating the rural poor. This, however, requires finding viable solutions to a number of complex technical, institutional, and policy issues: including agricultural extension via enhanced R&D on seeds and inputs, the adoption of existing sustainable technologies, and good natural resource management inside and outside of agriculture. Furthermore, improving land markets, facilitating access to credit and irrigation systems, and connecting remote poor rural areas to markets by improving rural infrastructure should be incorporated into rural development strategies. And last but not least, trade policy and the reduction of agricultural price uncertainties are crucial for functioning agricultural markets necessary to enhance food production. Beyond the need to enhance total food production, policies targeting higher agricultural productivity can protect small farmers in developing countries from income shocks, related to global and domestic market forces. The question of how to achieve this goal, however, seems to be scientifically and institutionally challenging, to say the least. In this regard, there are still several literature gaps to fill which is where future research priorities may lie. The bottom line is that agricultural productivity improvements should consider environmental limits and be socially inclusive. Therefore, more research is needed to further develop technological solutions that guarantee resource-sparing agricultural production practices in the future. On the other hand, rural poverty in developing countries is one of the main obstacles to the adoption of existing agricultural technologies. Hence, future research should target a deeper understanding of the causes of rural poverty, and not least importantly, finding tailored solutions out of poverty. In this regard, more research about entry barriers to export markets and possible technological spill-over effects from high-value global agricultural supply chains to small poor farmers is needed. In order to address the above mentioned issues in future research attempts, more agricultural and rural data sources down to the household level are needed for several countries, providing the basis for effective planning and policymaking.

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Appendices

Appendix A1. Sensitivity analysis to global climate models

In the sensitivity analysis we analyze the same scenario specifications, but under different global climate models (GCM), namely CSIRO and MIROC. We focus on the outcomes of different climate change models, because different impacts of climate change reflect quite well existing uncertainties due to different future agricultural growing conditions. With identical GHG-emissions, the GCM climate outputs differ substantially. The CSIRO A1B scenario represents a dry and relatively cool future, while the MIROC A1B scenario represents a wet and warmer future at global scale. Such differences have yield effects and implications for irrigation water needs and in turn on land use patterns. In the main text all results presented stem from model runs using MIROC, because comparing reported FAO data between 2000 and 2010, MIROC seems to be closer to true values than model runs with CSIRO. On request the authors can provide all results presented in the paper also for the CSIRO CGM.

The results of the sensitivity analysis are summarized below. All numbers refer to the %-difference between the MIROC and CSIRO CGM in the year 2050, with MIROC being the reference model. The differences between the two climate change models in 2050 are relatively moderate, especially with respect to the aggregated land and water related variables. Deviations in aggregated area harvested and water footprints never exceed nine percent. The biggest deviations in area harvested appear in rice and maize production, but still being below 20 percent. Yield differences between the two GCMs are highest for maize, but do not pass 27 percent. The economic market effects are more pronounced, though. The largest deviation is observed for world prices of rice in 2050.

Variable	Product	**(1)**	**(1a)**	**(2)**	**(3a/3b)**	**(4)**	**(5)**
Green water footprint	All crops	-3%	-3%	-3%	-3%	-3%	-3%
Blue water footprint	All crops and livestock	-7%	-7%	-7%	-8%	-7%	-8%
Area harvested	All crops	-8%	-8%	-8%	-8%	-8%	-8%
Area harvested	Maize	-14%	-14%	-14%	-14%	-14%	-14%
Area harvested	Potatoes	-4%	-3%	-3%	-3%	-3%	-4%
Area harvested	Rice	-18%	-18%	-16%	-16%	-16%	-18%
Area harvested	Sorghum	0%	0%	0%	0%	1%	1%
Area harvested	Soybeans	-8%	-8%	-8%	-8%	-9%	-8%
Area harvested	Sugarcane	-3%	-3%	-3%	-3%	-3%	-3%
Area harvested	Wheat	-19%	-19%	-19%	-19%	-19%	-19%
Yield	Maize	24%	24%	27%	27%	24%	21%
Yield	Potatoes	14%	14%	16%	16%	13%	12%
Yield	Rice	-4%	-4%	-3%	-3%	-4%	-4%
Yield	Sorghum	4%	4%	5%	5%	4%	4%
Yield	Soybeans	3%	3%	4%	4%	2%	1%
Yield	Sugarcane	4%	4%	4%	4%	4%	3%
Yield	Wheat	13%	13%	12%	12%	13%	14%
World prices	Maize	-25%	-25%	-25%	-25%	-25%	-25%
World prices	Potatoes	-14%	-13%	-14%	-14%	-13%	-13%
World prices	Rice	-36%	-36%	-36%	-36%	-36%	-36%
World prices	Sorghum	-7%	-7%	-7%	-7%	-6%	-6%
World prices	Soybeans	-19%	-19%	-20%	-20%	-21%	-20%
World prices	Sugar	-12%	-12%	-12%	-12%	-11%	-11%
World prices	Wheat	-30%	-30%	-30%	-30%	-30%	-30%

Note: Numbers in the headline row refer to scenarios: (1) BAU, (1a) BAU liberal, (2) Intensification, (3a) Sustainable intensification (Improved nutrient use efficiency), (3b) Sustainable intensification (Precision agriculture), (4) Yield gaps closed, (5) Extensification.
(Source: own elaboration)

Appendix A2. Projections of cropland and pasture land

We make a projection of the annual expansion of cropland and pasture areas between the year 2010 and 2050 under each agricultural production scenario to assess the carbon and biodiversity trade-offs over time. Furthermore, pasture land projections are also required for our water quality assessment which takes into account emissions from livestock production.

Cropland area

Model runs from the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) provide the projected annual area harvested per crop, Food Producing Unit (FPU) and scenario. Since the area harvested per crop might contain multiple harvests per year, annual cultivated area per FPU is calculated as:

$$Acrop_t = \sum_{i=1}^{7} \sum_{k=1}^{2} \frac{AH_{i,t,k}}{CI_{i,t,k}} \qquad \text{(Eq. A2.1)}$$

where $Acrop$ refers to the cultivated area of all seven crops (maize, rice, wheat, soybeans, sugarcane, potatoes, sorghum) in year t. CI is the cropping intensity of crop i and k accounts for rainfed and irrigated land. AH refers to annual area harvested of crop i under both, rainfed ($k = 1$) and irrigated conditions ($k = 2$). CI values are derived from You et al. (2013).

Pasture area for livestock production

Projected pasture area here refers to the estimated land footprint required to sustain the expected increase in livestock production under the different scenarios. IMPACT does not directly provide results on annual pasture land requirements. Hence, we used the data on pasture land area by FPU provided by Ramankutty et al. (2010) for the year 2000 as a reference point to make future pasture projections. Likewise, we converted the IMPACT outputs of projected head numbers of cows, sheep and goats (for pigs and chickens we assume that they are raised in landless/urban systems) by FPU into livestock units (LU), applying region-specific conversion factors provided by FAO (2011a). Accordingly, projected annual pasture land by FPU is calculated as:

$$Apasture_t = \sum_{l=1}^{3} Apasture_{l,2000} * \frac{LU_{l,t}}{LU_{l,2000}} \qquad \text{(Eq. A2.2)}$$

where $Apasture_{2000}$ refers to the projected pasture area in year t and $Apasture_{l,2000}$ is the projected pasture area in the base year 2000 per livestock type l. $LU_{l,t}$ are the expected livestock units (heads per hectare) of type l in each future year t and $LU_{l,2000}$ refers to the livestock units of type l in the base year (2000).

Livestock densities may vary across different production systems. We assume the share of different livestock production systems (agro-pastoral, mixed extensive, mixed intensive) per FPU to remain constant at year 2000 levels. Hence, only changes in livestock numbers and livestock yields affect changes in the pasture land expansion, ignoring possible shifts towards more intensified livestock production systems, due to data limitations.

Appendix A3. Water scarce Food Producing Units

Water scarcity is given where irrigation water supply reliability is smaller one or where total renewable water resources over total water withdrawals is larger than 20% at some point in time between 2010 and 2050. Food Producing Units (FPU) that suffer from water scarcity are:

- The Caribbean, Central-America (CAR_CCA)
- Cuba, Central-America (CUB_CCA)
- North-East Brazil (NEB_BRA)
- Parana, Brazil (PAR_BRA)
- Coastal Peru (PEC_PER)
- Salada-Tierra, Argentina (SAL_ARG)
- Tocantins, Brazil (TOC_BRA)
- Uruguay, Brazil (URU_BRA)
- Uruguay, Uruguay (URU_URU)
- Yucatan, Central-America (YUC_CCA)

A list of all FPUs can be found in Appendix A4 with the corresponding map in Appendix A6.

Appendix A4. Definition of Food Producing Unit codes

FPU code	FPU in LAC
AMA_BRA	Amazon, Brazil
AMA_CSA	Amazon, Central-South-America
AMA_COL	Amazon, Colombia
AMA_ECU	Amazon, Ecuador
AMA_PER	Amazon, Peru
CAR_CCA	Caribbean, Caribbean-Central-America
CAM_CCA	Central-America, Caribbean-Central-America
CHC_CHL	Chile-Coast, Chile
CUB_CCA	Cuba, Caribbean-Central-America
MIM_MEX	Middle-Mexico, Mexico
NSA_NSA	North-South-America-Coast, Northern-South-America
NEB_BRA	Northeast-Brazil, Brazil
NWS_COL	Northwest-South-America, Colombia
NWS_ECU	Northwest-South-America, Ecuador
ORI_COL	Orinoco, Colombia
ORI_NSA	Orinoco, Northern-South-America
PAR_ARG	Parana, Argentina
PAR_BRA	Parana, Brazil
PAR_CSA	Parana, Central-South-America
PEC_PER	Peru-Coastal, Peru
RIC_ARG	Rio-Colorado, Argentina
RIG_MEX	Rio-Grande, Mexico
SAL_ARG	Salada-Tierra, Argentina
SAN_BRA	San-Francisco, Brazil
TIE_ARG	Tierra, Argentina
TOC_BRA	Toc, Brazil
UME_MEX	Upper Mexico, Mexico
URU_BRA	Uruguay, Brazil
URU_URU	Uruguay, Uruguay
YUC_CCA	Yucatan, Caribbean-Central-America
YUC_MEX	Yucatan, Mexico

Note: FPU = Food Producing Unit. To locate specific Food Producing Unit see Appendix A6. CCA = Belize, Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Nicaragua, Panama; CSA = Bolivia, Paraguay; NSA = Guyana, Surinam, Venezuela.

Appendix A5. Food Producing Units with remaining yield gaps in 2050 in LAC (in tons/hectare)

FPU	Crop	Irrigated/ Rainfed	Observed yield, year 2000	Projected yield (BAU), year 2050	75% of attainable yield, year 2000	Yield gap, year 2000	Remaining yield gap, year 2050
AMA_COL	Wheat	rainfed	2.05	3.72	4.59	2.54	0.88
AMA_CSA	Potatoes	irrigated	11.62	18.87	26.30	14.68	7.43
AMA_CSA	Potatoes	rainfed	6.00	9.04	17.59	11.59	8.56
AMA_ECU	Maize	irrigated	2.03	5.59	6.09	4.06	0.50
AMA_ECU	Maize	rainfed	1.06	2.94	4.68	3.62	1.74
AMA_ECU	Potatoes	irrigated	9.01	13.92	26.08	17.06	12.16
AMA_ECU	Potatoes	rainfed	5.68	5.97	20.54	14.86	14.57
AMA_ECU	Wheat	irrigated	0.64	1.63	4.83	4.19	3.20
AMA_PER	Maize	rainfed	1.67	3.20	3.30	1.64	0.10
AMA_PER	Potatoes	irrigated	15.68	22.31	27.36	11.68	5.05
AMA_PER	Potatoes	rainfed	7.96	6.94	18.36	10.40	11.41
AMA_PER	Soybeans	rainfed	1.46	1.26	1.75	0.28	0.48
AMA_PER	Wheat	rainfed	1.28	2.02	4.09	2.81	2.07
CAM_CCA	Maize	rainfed	1.55	2.61	3.22	1.67	0.61
CAR_CCA	Maize	rainfed	1.54	2.17	2.81	1.27	0.64
CAR_CCA	Sorghum	rainfed	0.63	1.33	1.77	1.14	0.44
CHC_CHL	Potatoes	rainfed	14.36	14.17	22.79	8.42	8.61
CUB_CCA	Maize	rainfed	1.55	2.32	3.99	2.44	1.68
CUB_CCA	Sorghum	rainfed	0.64	1.18	1.95	1.32	0.77
MIM_MEX	Maize	rainfed	2.13	2.77	2.81	0.67	0.04
MIM_MEX	Potatoes	rainfed	13.89	14.40	16.90	3.01	2.51
NSA_NSA	Maize	rainfed	1.97	2.57	2.99	1.02	0.43
NWS_COL	Maize	rainfed	1.93	3.32	3.49	1.56	0.16
NWS_ECU	Potatoes	irrigated	9.03	13.95	21.67	12.64	7.72
NWS_ECU	Potatoes	rainfed	5.68	6.17	14.90	9.21	8.73
NWS_ECU	Soybeans	rainfed	1.80	1.31	1.89	0.09	0.58
NWS_ECU	Wheat	irrigated	0.65	1.67	3.34	2.69	1.67

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continued

FPU	Crop	Irrigated/ Rainfed	Observed yield, year 2000	Projected yield (BAU), year 2050	75% of attainable yield, year 2000	Yield gap, year 2000	Remaining yield gap, year 2050
ORI_COL	**Maize**	**rainfed**	1.93	3.33	3.75	1.82	0.42
ORI_NSA	**Wheat**	**rainfed**	0.39	1.50	1.60	1.22	0.11
PAR_ARG	**Potatoes**	**rainfed**	15.58	16.37	18.21	2.63	1.83
PAR_CSA	**Potatoes**	**irrigated**	11.58	18.71	27.19	15.61	8.48
PAR_CSA	**Potatoes**	**rainfed**	5.91	7.92	14.62	8.71	6.70
PEC_PER	**Maize**	**rainfed**	1.66	1.95	4.09	2.43	2.14
PEC_PER	**Potatoes**	**irrigated**	15.63	22.16	28.33	12.70	6.17
PEC_PER	**Potatoes**	**rainfed**	7.94	6.97	19.26	11.32	12.29
PEC_PER	**Wheat**	**rainfed**	1.27	1.41	2.31	1.04	0.90
RIC_ARG	**Potatoes**	**rainfed**	15.62	15.21	21.38	5.76	6.17
RIG_MEX	**Maize**	**rainfed**	2.14	2.62	4.33	2.19	1.71
RIG_MEX	**Potatoes**	**rainfed**	13.90	14.07	14.91	1.01	0.83
SAL_ARG	**Potatoes**	**rainfed**	15.66	16.19	17.97	2.30	1.77
TIE_ARG	**Potatoes**	**rainfed**	15.62	14.44	19.83	4.21	5.39
UME_MEX	**Maize**	**rainfed**	2.15	2.92	4.52	2.37	1.60
URU_URU	**Soybeans**	**rainfed**	1.79	1.64	2.15	0.36	0.51
YUC_CCA	**Maize**	**rainfed**	1.56	2.56	3.61	2.05	1.05
YUC_CCA	**Sorghum**	**rainfed**	0.64	1.55	2.21	1.57	0.66
YUC_MEX	**Wheat**	**rainfed**	3.17	3.02	3.40	0.23	0.39

Note: BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 1 in the main text. FPU = Food Producing Unit. To locate Food Producing Units see Appendix A6 and Appendix A4.
(Source: own elaboration)

Appendix A6. Map of Food Producing Units in Latin America and the Caribbean

Appendix A7. The IMPACT model

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) uses supply and demand elasticities incorporated into a system of linear and nonlinear equations to represent the underlying production and demand functions for each product. World agricultural commodity prices are determined annually at levels that clear international markets. Domestic prices are a function of world prices, adjusted by the effects of price policies and expressed in terms of producer support estimates (PSE), consumer support estimates (CSE) and marketing margins (MI). PSEs and CSEs measure the implicit level of taxation or subsidy borne by producers or consumers relative to world prices and account for the wedge between domestic and world prices. PSEs and CSEs are based on OECD estimates and are adjusted by expert judgment to reflect regional trade dynamics (OECD, 2000). MI reflect other factors such as transport and marketing costs of shipping goods to markets and are based on expert opinion on the quality and availability of transportation, communication, and market infrastructure. In our study, trade liberalization is implemented by adjusting these three parameters which affects producer and consumer prices. The following equations describe this relationship:

$$PS_{tni} = PW_i * (1 - MI_{tni}) * (1 + PSE_{tni}) \qquad \text{(Eq. A7.1)}$$

$$PD_{tni} = PW_i * (1 - MI_{tni}) * (1 - CSE_{tni}) \qquad \text{(Eq. A7.2)}$$

where PS = producer prices, PD = consumer prices, PW = world prices, MI = marketing margin, PSE = producer subsidy equivalent, CSE = producer subsidy equivalent, i = agricultural commodity, n = country and t = year. Since prices in turn affect food demand and supply, trade liberalization can be seen as one driver of changing global food security.

In addition to trade liberalization, we estimate the effects of different future production pathways on crop and livestock production in LAC. Growth in crop production in each Food producing Unit (FPU) is determined by adjusting the rates of area expansion and yield growth. We assume changes in the exogenous area growth rate to model higher or lower investments in irrigation. Also, land policies that either allow for or restrict accelerated arable land growth are modeled by altering exogenous area growth rates. Adjustments in the exogenous yield growth rate capture different levels of investments in agricultural R&D, as well as yield responses to altered fertilization. Climate change impacts on yield and area growth are also captured in the exogenous growth rates. The corresponding model equations are as follows:

$$AC_{tni} = \alpha_{tni} * (PS_{tni})^{\varepsilon iin} * \prod_{j \neq i} (PS_{tnj})^{\varepsilon ijn} * (1 + gA_{tni} + \tau^{A}_{clim}) \qquad \text{(Eq. A7.3)}$$

$$YC_{tni} = \beta_{tni} * (PS_{tni})^{\gamma iin} * \prod_{k} (PF_{tnk})^{\gamma ikn} * (1 + gCY_{tni} + \tau^{y}_{clim}) \qquad \text{(Eq. A7.4)}$$

$$QS_{tni} = AC_{tni} * YC_{tni} \qquad \text{(Eq. A7.5)}$$

where AC = crop area, YC = crop yield, QS = quantity produced, PS = effective producer price, PF = price of inputs k (e.g. labor and fertilizer), i, j = commodity indices specific for crops, k = inputs such as labor and capital, n = country index, t = year, gA = exogenous growth rate of crop area, gCY = exogenous yield growth rate, τ^{A}_{clim} = area growth rate due to climate change, τ^{y}_{clim} = yield growth rate due to climate change, ε = area price elasticity, γ = yield price elasticity, α = crop area intercept, and β = crop yield intercept.

We also account for higher or lower degrees of intensification in the LACs' livestock sector. IMPACT models livestock production similarly to crop production except that livestock yield reflects only the effects of expected developments in technology which is the parameter we adjust in each scenario of our analysis. To change the total number of animals slaughtered, depending on the scenario assumptions, we adjust an exogenous trend variable. Besides the trend variable, the number of livestock slaughtered is a function of the livestock's own price and the price of competing commodities, as well as the prices of intermediate (feed) inputs. The following equations describe the livestock sector in IMPACT:

$$AL_{tni} = \alpha_{tni} * (PS_{tni})^{\varepsilon iin} * \prod_{j \neq i} (PS_{tnj})^{\varepsilon ijn} * \prod_{b \neq i} (PI_{tnb})^{\gamma ibn} * (1 + gSL_{tni}) \quad \text{(Eq. A7.6)}$$

$$YL_{tni} = (1 + gLY_{tni}) * (YL_{t-1,ni}) \quad \text{(Eq. A7.7)}$$

$$QS_{tni} = AL_{tni} * YL_{tni} \quad \text{(Eq. A7.8)}$$

where AL = number of slaughtered livestock, YL = livestock product yield per head, PI = price of intermediate feed inputs, i, j = commodity indices specific for livstock, b = commodity index specific for feed crops, gSL = exogenous growth rate of number of slaughtered livestock, α = intercept of number of slaughtered livestock, ε = price elasticity of number of slaughtered livestock, and γ = feed price elasticity. The remaining variables are defined as for crop production.

Water is treated endogenously in IMPACT. Over time the water available for crop production varies due to changes in demographics, climate, and competing demand for water from other sectors of the economy. A certain share of available water in each river basin is first allocated to satisfy environmental flow requirements. Secondly, domestic water uses are satisfied which is highly influenced by the amount of people living in cities. An urban population usually uses more water than a rural population in absolute terms. In a third step, the IMPACT water model allocates water to industrial uses, in a fourth step to livestock and finally the remainder is allocated to crop production.

The effect of water stress on irrigated crop area comes from the DSSAT suite of crop models and analysis, using location specific information on climate, soils, and nitrogen application rates. Total irrigation water supply is allocated to crops according to crop water requirements incorporating changes in the hydrological cycle, including precipitation, runoff, and crop-specific potential evapotranspiration.

In IMPACT, the concept of basin efficiency is used to account for changes in irrigation efficiency within a river basin. It fully accounts for the portion of diverted irrigation water that returns to rivers or aquifer systems and can be reused repeatedly by downstream users. Basin efficiency is defined as the ratio of beneficial irrigation water consumption to total irrigation water consumption (TC) and effects beneficial consumption. In our sustainable intensification scenarios (5a) and (5b), we increase basin efficiencies by a certain factor which leads to higher beneficial water consumption. This is because irrigation water demand (see Eq. Eq. A7.9) is lower with higher basin efficiencies, and consequently a larger portion of demand is met compared to scenarios with lower efficiencies, therefore leading to higher beneficial water consumption.

$$IRWD = \frac{(NIRWD_i * AI_i) * (1 + LR)}{BE} \qquad \text{(Eq. A7.9)}$$

where $IRWD$ = total irrigation water demand, $NIRWD$ = net irrigation water demand (for details see Rosegrant (2012)), AI" = Irrigated area, LR = Salt leaching factor, BE = Basin efficiency and i = commodity specific crop index.

Appendix A8. Food security estimations

Food security in different world regions is proxied by the total number of malnourished preschool children (under five years old). The cross-country regression suggested by Smith and Haddad (2000) uses the following covariates: (1) the availability of calories, (2) clean water access, (4) female access to secondary education and female relative life-expectancy. By means of the estimated coefficients and base year and future values of each explanatory variable, we estimate the prevalence of malnourishment in different world regions. IMPACT simulations of each scenario used in our study provide base year data and future estimates on per capita calorie availability (covariate 1) by country. Base year data on the other covariates (2-4) are obtained from WDI (2010), while future projections of the covariates (2-4) are taken from United Nations Department of Economic and Social Affairs Population Devision (2007) and MEA (2005). Note that, differences in future food security across our different scenarios owed to different IMPACT estimates of calorie availability in each country (covariate 1). The other covariates (2-4) change over time, but remain the same across scenarios.

Appendix A9. Water footprint calculations

IMPACT's water module calculates the annual GWF for each crop per FPU (in m^3/FPU) as follows (for simplicity of notation we refrain from indexing the FPU, year and scenario):

$$GWF_i = min \begin{cases} \sum_{m=1}^{M} ETM_{i,m} * AH_i, & \text{if } ETM_{i,m} < PE_{i,m} \\ \sum_{m=1}^{M} PE_{i,m} * AH_i, & \text{if } ETM_{i,m} \geq PE_{i,m} \end{cases} \quad \text{(Eq. A9.1)}$$

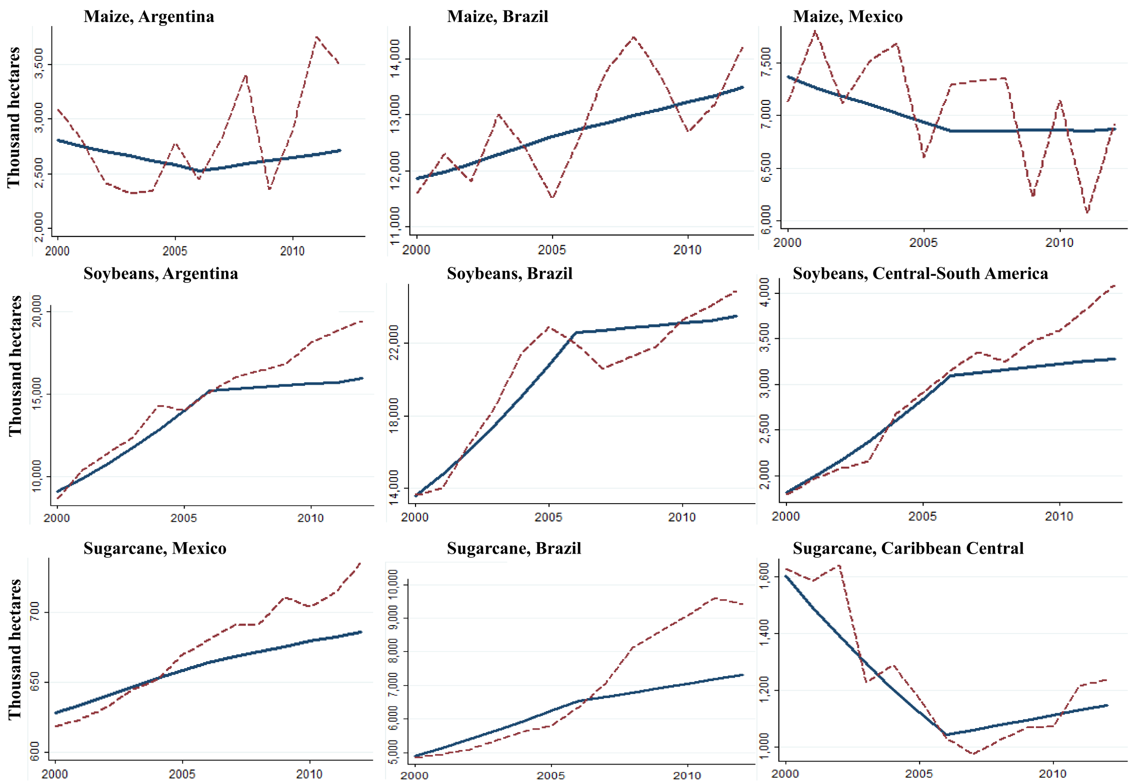
where $ETM_{i,m} = ET_{0_{i,m}} * K_{c_{i,m}}$. Furthermore, i = crop; m = month, with $M \leq 12$ (depending on cropping calendar); ETM = crop water depletion per unit crop; PE = effective precipitation per hectare; ET_0 = reference evapotranspiration; AH = area harvested and K_c = crop coefficient.

We define the annual blue water footprint of production (BWF) as total irrigation water (in m^3/FPU) applied per crop in each FPU which is calculated as follows:

$$BWF_i = min \begin{cases} \sum_{m=1}^{M} IRWD_{i,m}, & \text{if } IRWD_{i,m} \leq IRWS_{i,m} \\ \sum_{m=1}^{M} IRWS_{i,m}, & \text{if } IRWD_{i,m} > IRWS_{i,m} \end{cases} \quad \text{(Eq. A9.2)}$$

where $IRWD$ = total irrigation water demand and $IRWS$ = total irrigation water available for crop evapotranspiration. The model solves for total water that could be depleted in each month from surface and groundwater resources in each FPU, constrained by minimum environmental flow requirements and other water users' demand (domestic, industrial and livestock water uses). We can introduce future investments in new irrigation technologies and improved water management practices by improving the FPU's basin efficiency (for details see Text S1). A detailed methodology description on how the WSM calculates $IRWD$ and $IRWS$ can be found in Rosegrant (2012).

Appendix A10. Validation of IMPACT area harvested projections for selected crops and large production regions in LAC from 2000 to 2012.



IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade. The solid line (in blue) depicts IMPACT projections of area harvested under BAU and the dashed line (in red) represents data taken from FAOSTAT (2014). BAU refers to the Business-as-Usual scenario. MIROC climate change scenario assumptions were used which might differ slightly from other GCM results, because climate change is already assumed to show effects after year 2000. Although differences for this time span are rather low, MIROC's predictions yield closer to reality results. IMPACT predicts the trends correctly, but understates changes in area harvested, so all results that refer to increases in agricultural area should be interpreted as conservative predictions.

Appendix A11. Water quality assessment

The study assesses impacts of different production pathways on the water environement. In order to quantify the emissions of nitrogen-based pollutants related to each scenario, we apply the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) model and couple it to the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). For the base year SWAT simulation, grid-based estimates of farming area by crop, pasture land areas and livestock animal counts are obtained from Monfreda et al. (2008), Ramankutty et al. (2008) and Robinson et al. (2007). Data on crop and region specific fertilizer application rates for the year 2000 are taken from Mueller et al. (2012). Note that due to data limitations for year 2010, we had to take the base year 2000 for this analysis. In addition to fertilizer, manure also provides nitrogen input to agriculture land. Due to lacking data to track the fate of manure excreted from livestock production, we follow the approaches by Bouwman et al. (2009) and Liu et al. (2010), in which the total amounts of excreta accumulated in stables or on pasture land are calculated by multiplying the nitrogen excretion rates of livestock animals (Sheldrick et al., 2003) by the size of livestock species. It is assumed that 90% of manure produced in stables are recycled to cropland (Smil, 1999) after an adjustment to account for the loss of NH_3 vitalization, as proposed by Bouwman et al. (1997).

In order to analyze our future scenarios, we scale up gridded estimates of cropland areas, livestock animal counts and pasture land areas for the year 2000. Total future values of these variables aggregated to the Food Producing Unit (FPU) -level used in the SWAT simulation are matched to the values projected by IMPACT and the pasture land estimations at FPU-level (see Text S5) by assuming invariant spatial variability within each FPU. We also recalculate input rates of manure nitrogen to cropland and pasture land and estimate future fertilizer application rates for each of our future scenarios. We also estimate future fertilizer application rates and recalculate input rates of manure nitrogen to cropland and pasture land for each of our future scenarios. We project future fertilizer rates based on the increases in crop yields in each scenario, with a fertilizer yield response elasticity of 0.75. The elasticity is chosen following Valin et al. (2013) who calculated the world average trend observed over the last 30 years. Results from IMPACT model runs provide information on yield changes for each of the seven crops in each FPU in LAC in 2050 which serve as the basis for calculating fertilizer application rates. Note that this procedure is not optimal for estimating future fertilizer needs, because of nonlinearities in the fertilizer-yield response. Similarly, we recalculate input rates of manure nitrogen on cropland and pasture land by assuming that the values of those key parameters used in the calculation, such as livestock animal nitrogen excretion rates and manure recycle rates to cropland, are unchanged rates over time. However, due to data limitations and the large regional scale of the paper, we need to stick to these rough estimations.

Finally, extra care is taken in the simulations for sustainable intensification. Under the sustainable intensification scenario with NUE improvement (3a), input rates of fertilizer and manure nitrogen on crop land are further adjusted according to calculated nitrogen input rates for the intensification scenario (2) and specified NUE enhancement (+20%). In the simulation for sustainable intensification with precision agriculture (3b), an auto-fertilization function in the SWAT model (Neitsch et al., 2005) is invoked to mimic the "intelligence" in fertilization operation in precision agriculture. The auto-fertilization function allows the model to determine the quantity and timing of nitrogen fertilizer/manure applications, given nitrogen requirements of different crop plants.

Appendix A12. Assessment of carbon stock losses

Land use dynamics in LAC are highly complex. Since the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) is not a land use model, it cannot predict over which types of land uses crops and pastures are likely to expand over time. To assess the changes in carbon (C) stocks linked to cropland expansion under each scenario we assume two different land use pathways: (1) all new cropland area between 2010 and 2050 expands over existing pastures; and (2) new cropland area expansion takes place at the expense of former natural woody vegetation. Assessing the C trade-offs of both pathways, allows us to estimate a lower bound ($ClossLower$) and upper ($ClossUpper$) bound of C-losses associated with cropland expansion in Latin America and the Caribbean (LAC). For pastures, we assume that pasture area expansion related to livstock production between 2010 and 2050 occurs at the expense of former natural woody vegetation. Accordingly, annual losses in C stocks per Food Producing Unit (FPU) due to cropland or pasture land expansion are calculated as:

$$C_{lossUpper_t} = \sum_{i=1}^{7}(C_{biome} - C_{crop_i}) * \Delta Acrop_{i,t} \qquad \text{(Eq. A12.1)}$$

$$C_{lossLower_t} = \sum_{i=1}^{7}(C_{pasture} - C_{crop_i}) * \Delta Acrop_{i,t} \qquad \text{(Eq. A12.2)}$$

$$C_{lossPasture_t} = (C_{biome} - C_{pasture}) * \Delta Apasture_t \qquad \text{(Eq. A12.3)}$$

where C_{biome} is the average C content of natural woody vegetation, C_{crop} is the average content of C of crop i, and $C_{pasture}$ is the average content of carbon of pastures. ΔA_{crop} refers to the net area increase of crop i by FPU between the year 2010 and year t, and $\Delta A_{pasture}$ refers to the net area increase of pastures between 2010 and year t

by FPU. C_{biome}, C_{crop}, and $C_{pastures}$ calculations include above- and belowground stocks.

Positive values of $C_{lossUpper_t}$, $C_{lossLower_t}$ and $C_{lossPasture_t}$ will imply a net loss of C stocks over time per FPU. Negative values will imply a net gain of C stocks which might occur under two circumstances: first, because new crop and/or pasture area are able to store higher carbon stocks than original land use; and secondly, because $\Delta Acrop_{i,t}$ or $\Delta Apasture_t$ could show a negative trend, implying a net reduction of crop and/or pasture area over time. In this case, we have assumed that abandoned agricultural crops and/or pastures are able to recover their maximum C storage capacity (C_{biome}). This allows us to account for the potential long-term impacts of agricultural abandonment and forest re-growth.

Aboveground C_{biome} and $C_{pasture}$ by FPU are calculated by summarizing the aboveground C stocks of natural woody vegetation and pastures from the 5 *arc minute* resolution (~ 10 x 10 km) New IPCC Tier-1 Global Biomass Carbon Map (Ruesch and Gibbs, 2008). Aboveground C_{crop} is calculated following the approach of West et al. (2010) and is assumed to equal crop's net primary productivity (NPP_i), calculated as:

$$NPP_i = \frac{Y_i * DF_i * C}{HI_i * R_i} \qquad \text{(Eq. A12.4)}$$

where Y accounts for the average yield of a specific crop i and DF is the ratio of dry matter in crop i and was pre-defined to have a value of 0.85. C is a C content of 0.45 gr gr (C/gr) dry matter and considered to be equal for all crops. HI represents the harvested index (meaning the percent of biomass harvested that is used as food) and R is the proportion of belowground biomass with respect to total biomass. HI and R parameter values for each one of the seven crops were obtained from literature review (e.g. Larcher, 2003, Bradford et al., 2008)) and are as follows:

Crop i	HI	R
Maize	0.52	0.18
Potatoes	0.55	0.10
Rice	0.50	0.09
Sorghum	0.52	0.09
Soybeans	0.42	0.15
Wheat	0.39	0.19
Sugarcane	0.85	0.35

Belowground C_{biome} is calculated by summarizing the 5 *arc minute* resolution ($\sim$ 10 x 10 km) global soil organic carbon map in the top 1 m (Hiederer and Kochy, 2011) by FPU. We assume that conversion of natural vegetation and pastures to herbaceous croplands reduces soil carbon stocks by 50%. Likewise, the conversion of natural vegetation into pastures is assumed to reduce the soil carbon stock by 20%. These assumptions are consistent with Guo and Gifford (2002) meta-analysis on soil carbon stocks variations due to land use changes.

Appendix A13. Biodiversity risk index assessment

We use the species-area relationship (SAR) to account for potential biodiversity trade-offs associated with each scenario of agricultural production in LAC. SAR models have been widely applied to account for biodiversity impacts linked to land use changes and habitat loss, e.g (Brooks et al., 2002, Koh and Ghazoul, 2010b, Pimm and Askins, 1995, Proenca and Pereira, 2013). Specifically, we apply a countryside model (Pereira and Daily, 2006) to predict endemic bird's risk of extinction and endangerment (S_{risk}) attributable to agricultural expansion. We limit the study to birds since taxon's sensitivity to different forms of land-use change is well studied, and data on their conservation status and spatial range are most reliable, updated, and readily available from IUCN (2008) and CIESIN-Nature Server (2008). To avoid the scale dependency factor (Brooks et al., 2002) when assessing the extinction rate we limit our study to endemic birds i.e., species with breeding range limited to Latin America and the Caribbean (LAC).

Original SAR models, also called conventional power models, assume that variations in species number is mainly a function of changes in habitat size. These models have been questioned as they tend to overestimate extinction rates (He and Hubbell, 2011, Kinzig and Harte, 2000). Overestimation is due to a large extend to the oversimplification of species-habitat relationships which ignore critical factors like differential responses of species to matrix composition, permeability and the existence of different degrees of habitat suitability, (e.g. Ricketts, 2001, Revilla et al., 2004, Umetsu et al., 2008). Countryside models partially fill some of the main gaps of the more conventional power models as they take into account taxon's affinity and adaptability to changing conditions, and can be formulated as:

$$S_{risk,t} = \frac{S_{new,t}}{S_{org}} = c\left(\frac{\sum_{j=1}^{4} h_j * A_{new,t}}{A_{org}}\right)^z \qquad \text{(Eq. A13.1)}$$

where S_{new} is the number of bird species recorded in year t and S_{org} is the original number of bird species. A_{new} is the remaining habitat size in year t and $A_{org}$is the original habitat area. c is a constant and depends on the type of taxon and region, h_j represents the suitability of birds to habitat j, and z is also a constant indicating the rate of species change per unit of area (Koh and Ghazoul, 2010a). Positive values of S_{risk} imply an increase in the birds' risk of extinction and endangerment, while negative values will entail a risk reduction over time. Negative values might occur as a result of a reduction in the agricultural area (cropland/pasture land) in some FPUs. To account for the impacts that agricultural abandonment and forest re-growth might have on biodiversity, we assume that h_j for these new (regrown) habitats equal those of natural vegetation. Information on the different habitat types j and $Anew$ by FPU in 2010 is obtained from the 300 meter resolution 2009 Global Land Cover Map (ESA, 2010). Original land uses are grouped into four main classes (habitat types j): natural vegetation, cultivated area, cultivated pastures and urban/artificial. To determine the suitability of bird species to the different habitat types (h_j) we use the data provided by Koh and Ghazoul (2010b). To improve model performance, h_j values are calibrated, and finally set to: $h = 1$ for natural vegetation; $h = 0.45$ for pastures; $h = 0.32$ for croplands and $h = 0$ for urban/artificial.

Appendix A14. Irrigation water supply reliability in selected water stressed Food Producing Units in LAC in 2010 and 2050

FPU	Year	(1) BAU	(1a) BAU liberal	(2) Intensification	(3) Sustainable intensification	(4) Yield gaps closed	(5) Extensification
Central America and the Caribbean							
CUB_CCA	**2010**	0.75	0.75	0.75	0.75	0.75	0.75
	2050	0.45	0.45	0.40	0.55	0.40	0.50
YUC_CCA	**2010**	0.57	0.57	0.57	0.57	0.57	0.57
	2050	0.70	0.69	0.68	0.92	0.68	0.70
CAR_CCA	**2010**	0.65	0.65	0.65	0.65	0.65	0.65
	2050	0.73	0.73	0.71	0.87	0.71	0.75
South America							
TOC_BRA	**2010**	0.11	0.11	0.11	0.11	0.11	0.11
	2050	0.10	0.11	0.11	0.11	0.11	0.10
URU_BRA	**2010**	0.21	0.21	0.21	0.21	0.21	0.21
	2050	0.41	0.42	0.40	0.54	0.40	0.44
PEC_PER	**2010**	0.67	0.67	0.67	0.67	0.67	0.67
	2050	0.44	0.44	0.42	0.57	0.42	0.45
NEB_BRA	**2010**	0.81	0.81	0.81	0.81	0.81	0.81
	2050	0.56	0.56	0.50	0.68	0.49	0.61
SAL_ARG	**2010**	0.96	0.96	0.96	0.96	0.96	0.96
	2050	0.73	0.72	0.66	0.88	0.65	0.78
URU_URU	**2010**	0.60	0.60	0.60	0.60	0.60	0.60
	2050	0.77	0.76	0.73	0.73	0.73	0.79
PAR_BRA	**2010**	1.00	1.00	1.00	1.00	1.00	1.00
	2050	0.83	0.82	0.72	0.97	0.70	0.93

Note: The indicator irrigation water supply reliability takes on values between zero and one, with lower values indicating severe water scarcity and values closer to one low water scarcity. FPU = Food Producing Unit. To locate Food Producing Units see Appendix A6 and Appendix A4. BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 1 in the main text. Those FPUs are listed first that suffer the most from water stress under BAU (1) in 2050.
(Source: own elaboration)

Appendix A15. Changes in nitrogen-emission rates between the base year 2000 and 2050 across different Food Producing Units in LAC (in %)

FPU	(1)	(1a)	(2)	(3a)	(3b)	(4)	(5)
Central America and the Caribbean							
MIM_MEX	197	208	186	134	-59	238	197
YUC_MEX	97	104	99	75	-14	106	87
CAR_CCA	79	86	94	66	-6	91	82
CAM_CCA	41	45	41	31	-39	51	43
YUC_CCA	16	19	8	16	-20	33	35
UME_MEX	-34	-34	-38	-38	-53	-29	-32
CUB_CCA	-39	-37	-41	-45	-70	-39	-44
RIG_MEX	-53	-53	-55	-55	-62	-51	-52
South America							
NSA_NSA	1164	1239	1432	1202	1156	1211	1209
NEB_BRA	444	453	488	384	293	415	409
AMA_COL	381	399	434	392	365	398	393
PEC_PER	249	255	246	256	226	264	262
URU_URU	225	257	312	245	209	254	252
AMA_ECU	197	219	258	199	158	212	223
SAL_ARG	129	141	154	89	63	104	102
ORI_NSA	121	139	157	127	58	148	135
PAR_ARG	117	128	143	83	70	90	92
CHC_CHL	108	136	120	100	-44	163	138
NWS_ECU	99	108	107	75	-44	109	97
PAR_BRA	89	98	100	63	-11	82	73
PAR_CSA	83	91	107	84	74	87	88
AMA_CSA	76	92	117	83	70	86	87
AMA_PER	70	83	95	67	13	86	86
URU_BRA	63	68	72	46	37	49	50
NWS_COL	56	69	73	58	25	66	65
AMA_BRA	56	66	72	42	14	50	47
ORI_COL	55	55	55	53	42	55	54
SAN_BRA	51	59	63	32	-24	47	41
TOC_BRA	27	29	37	19	13	21	19
TIE_ARG	-6	-6	-6	-6	-6	-6	-6
RIC_ARG	-12	-11	-14	-13	-26	-9	-11

Note: Numbers in the first row refer to scenarios: (1) BAU, (1a) BAU liberal, (2) Intensification, (3a) Sustainable intensification (Improved nutrient use efficiency), (3b) Sustainable intensification (Precision agriculture), (4) Yield gaps closed, (5) Extensification. FPU = Food Producing Unit. To locate Food Producing Units see Appendix A6 and Appendix A4. Note: The table is organized in such a way that those Food Producing Units (FPU) where the increase in N-emissions are highest under (1) BAU, appear in the upper rows. BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 1 in the main text. To locate specific Food Producing Unit see Appendix A6 and Appendix A4.
(Source: own elaboration)

Appendix A16. Net changes in carbon stock losses due to crop production across Food Producing Units in LAC between 2010 to 2050 (in million tons)

	(1) BAU		(1a) BAU liberal		(2) Intensification / (3) Sust.-intens.		(4) Yield gaps closed		(5) Extensification	
FPU	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**
Central America and the Caribbean										
CAM_CCA	22	58	28	67	5	22	12	33	40	86
MIM_MEX	7	20	9	24	-20	-31	-16	-22	20	42
YUC_CCA	8	18	9	20	4	8	5	10	12	25
CUB_CCA	-25	7	-26	12	-32	11	-22	12	-14	12
CAR_CCA	-1	4	-1	4	-4	-2	-2	1	2	7
YUC_MEX	1	2	3	6	-20	-40	-19	-36	10	19
RIG_MEX	-1	-1	-1	-1	-2	-3	-1	-2	0	-1
UME_MEX	-2	-3	-2	-2	-5	-9	-4	-7	-1	-1

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	(1) BAU		(1a) BAU liberal		(2) Intensification / (3) Sust.-intens.		(4) Yield gaps closed		(5) Extensification	
FPU	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**
South America										
PAR_ARG	336	691	375	773	151	328	183	385	452	912
PAR_BRA	25	394	58	476	-62	133	21	250	219	707
SAL_ARG	126	329	141	368	48	159	70	194	183	442
AMA_BRA	127	241	145	276	40	82	60	115	188	347
URU_BRA	132	214	149	242	67	114	87	141	183	291
SAN_BRA	24	207	51	267	4	115	35	161	107	356
TOC_BRA	57	132	65	149	14	42	27	64	92	194
NEB_BRA	47	121	75	167	9	46	29	73	116	225
PAR_CSA	31	56	43	75	22	42	32	56	54	93
ORI_NSA	8	45	9	49	2	31	6	39	13	53
AMA_CSA	13	31	19	44	8	19	11	25	24	53
AMA_PER	9	31	12	41	7	28	8	30	14	43
NWS_COL	4	10	8	18	-1	1	1	4	12	23
AMA_ECU	4	8	5	9	4	7	4	7	5	9
URU_URU	3	4	5	8	3	4	3	5	6	9
ORI_COL	0	2	1	4	-1	-3	-1	-2	1	6
NWS_ECU	2	1	4	4	-1	-3	-1	-3	4	5
NSA_NSA	0	1	1	2	-1	-2	-1	-2	1	3
AMA_COL	0	1	1	2	0	0	0	0	1	3
TIE_ARG	0	0	0	0	0	0	0	0	0	0
PEC_PER	-4	-4	-4	-3	-8	-7	-6	-5	-2	-1
RIC_ARG	-6	-4	-6	-4	-11	-8	-8	-6	-4	-2
CHC_CHL	3	-6	6	-6	4	-20	6	-10	6	7

Note: The values represent carbon stock losses from additional land conversion between 2010 and 2050. Positive values should be interpreted as a loss in carbon stock, and thus higher carbon emissions. The lower bound reflects carbon storage losses if 100% of crop land expands over existing pasture land, while the upper bound reflects carbon storage losses if 100% of crop land expands over natural vegetation. Considered crops in the analysis are maize, rice, wheat, soybeans, sugarcane, potatoes, sorghum. FPU = Food Producing Unit. To locate Food Producing Units see Appendix A6 and Appendix A4. BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 1 in the main text. Those FPUs are listed first that show the highest total losses of carbon stocks according to the upper bound land expansion pathway under the BAU scenario.
(Source: own elaboration)

Appendix A17. Net changes in carbon stock losses due to livestock production across Food Producing Units in LAC between 2010 to 2050 (in million tons)

FPU	(1) BAU	(1a) BAU liberal	(2) Intensification / (3) Sust.-intens.	(4) Yield gaps closed	(5) Extensification
Central America and the Caribbean					
CAR_CCA	39	65	61	61	94
CUB_CCA	20	63	57	57	111
YUC_MEX	43	59	54	53	94
MIM_MEX	18	25	23	23	40
CAM_CCA	0	0	0	0	0
RIG_MEX	0	0	0	0	0
UME_MEX	0	0	0	0	0
YUC_CCA	0	0	0	0	0
South America					
ORI_NSA	803	1081	1032	1033	1534
NEB_BRA	627	629	625	626	852
TOC_BRA	603	606	601	602	820
AMA_CSA	344	468	448	448	663
AMA_PER	254	340	327	326	480
URU_URU	254	330	316	316	475
PAR_CSA	220	259	255	253	361
PAR_ARG	132	223	188	186	332
SAL_ARG	69	128	105	103	193
AMA_ECU	78	100	95	95	142
AMA_BRA	-482	73	29	25	184
NSA_NSA	54	73	69	69	103
AMA_COL	59	60	58	58	82
NWS_ECU	43	50	49	49	69
CHC_CHL	0	0	0	0	0
ORI_COL	0	0	0	0	0
PEC_PER	0	0	0	0	0
RIC_ARG	0	0	0	0	0
TIE_ARG	0	0	0	0	0
URU_BRA	0	0	0	0	0
NWS_COL	-19	-3	-4	-5	22
SAN_BRA	-65	-19	-27	-28	68
PAR_BRA	-64	-21	-29	-30	15

Note: The values represent carbon stock losses from additional land conversion between 2010 and 2050. Positive values should be interpreted as a loss in carbon stock, and thus higher carbon emissions. It is assumed that pasture land due to increasing livestock production entirely expands over natural vegetation. FPU = Food Producing Unit. To locate Food Producing Units see Appendix A6 and Appendix A4. BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 1 in the main text. Those FPUs are listed first that show the highest total losses of carbon stocks under the BAU scenario.
(Source: own elaboration)

Appendix A18. Species risk of extinction and endangerment due to crop production across Food Producing Units in LAC in 2050 (index in %) and net changes between 2010 and 2050 (in %age points)

	(1) BAU				(1a) BAU liberal				(2) Intensification / (3) Sust.-intens.				(4) Yield gaps closed				(5) Extensification			
FPU	**lower bound**		**upper bound**		**lower bound**		**upper bound**		**lower bound**		**upper bound**		**lower bound**		**upper bound**		**lower bound**		**upper bound**	
Central America and the Caribbean																				
CAM_CCA	44.4	(+0.1)	44.9	(+0.6)	44.4	(+0.1)	45.0	(+0.7)	44.3	(+0.0)	44.5	(+0.2)	44.4	(+0.1)	44.6	(+0.3)	44.5	(+0.2)	45.2	(+0.9)
CAR_CCA	57.8	(+0.1)	58.2	(+0.6)	57.8	(+0.1)	58.3	(+0.6)	57.7	(+0.1)	58.0	(+0.3)	57.7	(+0.1)	58.0	(+0.4)	57.8	(+0.1)	58.3	(+0.6)
CUB_CCA	25.2	(+0.0)	25.3	(+0.1)	25.3	(+0.0)	25.4	(+0.2)	25.3	(+0.0)	25.4	(+0.2)	25.3	(+0.0)	25.4	(+0.2)	25.2	(+0.0)	25.4	(+0.2)
MIM_MEX	28.9	(+0.0)	28.9	(+0.0)	29.0	(+0.0)	29.0	(+0.1)	28.8	(-0.2)	28.1	(-0.8)	28.8	(-0.1)	28.3	(-0.6)	29.0	(+0.1)	29.2	(+0.3)
RIG_MEX	28.5	(+0.0)	28.5	(+0.0)	28.5	(+0.0)	28.5	(+0.0)	28.5	(+0.0)	28.4	(-0.1)	28.5	(+0.0)	28.4	(-0.1)	28.5	(+0.0)	28.5	(+0.0)
UME_MEX	28.6	(+0.0)	28.4	(-0.2)	28.6	(+0.0)	28.4	(-0.2)	28.6	(-0.1)	28.4	(-0.3)	28.6	(-0.1)	28.4	(-0.3)	28.6	(+0.0)	28.5	(-0.2)
YUC_MEX	33.5	(+0.0)	33.3	(-0.2)	33.5	(+0.0)	33.4	(-0.2)	33.4	(-0.2)	32.6	(-0.9)	33.4	(-0.2)	32.7	(-0.8)	33.6	(+0.0)	33.6	(+0.0)

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	(1) BAU		(1a) BAU liberal		(2) Intensification / (3) Sust.-intens.		(4) Yield gaps closed		(5) Extensification	
FPU	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**	**lower bound**	**upper bound**
South America										
PAR_ARG	47.0 (+0.7)	49.7 (+3.4)	47.1 (+0.8)	50.2 (+3.8)	46.7 (+0.3)	47.9 (+1.5)	46.7 (+0.3)	48.1 (+1.7)	47.3 (+0.9)	50.8 (+4.4)
PAR_BRA	58.1 (+0.6)	60.6 (+3.0)	58.2 (+0.7)	61.0 (+3.5)	57.8 (+0.3)	59.0 (+1.4)	57.9 (+0.3)	59.2 (+1.7)	58.3 (+0.8)	61.6 (+4.1)
SAL_ARG	49.1 (+0.5)	51.3 (+2.7)	49.1 (+0.6)	51.6 (+3.1)	48.8 (+0.3)	50.0 (+1.5)	48.8 (+0.3)	50.2 (+1.6)	49.2 (+0.7)	52.0 (+3.5)
CHC_CHL	41.9 (+0.5)	44.0 (+2.6)	42.0 (+0.5)	44.1 (+2.7)	41.7 (+0.3)	43.0 (+1.5)	41.7 (+0.3)	43.1 (+1.6)	42.0 (+0.5)	44.2 (+2.7)
URU_BRA	58.9 (+0.5)	60.8 (+2.4)	59.0 (+0.6)	61.3 (+2.8)	58.7 (+0.2)	59.6 (+1.2)	58.7 (+0.3)	59.8 (+1.4)	59.1 (+0.6)	61.7 (+3.3)
SAN_BRA	52.9 (+0.2)	53.9 (+1.3)	52.9 (+0.3)	54.1 (+1.5)	52.8 (+0.1)	53.3 (+0.7)	52.8 (+0.2)	53.4 (+0.8)	53.0 (+0.3)	54.4 (+1.8)
NEB_BRA	48.8 (+0.2)	49.5 (+0.9)	48.9 (+0.2)	49.8 (+1.2)	48.7 (+0.1)	49.0 (+0.4)	48.7 (+0.1)	49.1 (+0.5)	48.9 (+0.3)	50.0 (+1.4)
TOC_BRA	45.9 (+0.2)	46.6 (+0.8)	45.9 (+0.2)	46.7 (+0.9)	45.8 (+0.0)	45.9 (+0.2)	45.8 (+0.1)	46.0 (+0.3)	46.0 (+0.2)	46.9 (+1.2)
AMA_BRA	20.2 (+0.1)	20.5 (+0.5)	20.2 (+0.1)	20.6 (+0.5)	20.1 (+0.0)	20.2 (+0.1)	20.1 (+0.0)	20.2 (+0.2)	20.2 (+0.1)	20.7 (+0.7)
PAR_CSA	37.5 (+0.1)	37.8 (+0.4)	37.5 (+0.1)	38.1 (+0.6)	37.5 (+0.1)	37.7 (+0.3)	37.5 (+0.1)	37.8 (+0.4)	37.6 (+0.2)	38.2 (+0.8)
ORI_NSA	35.7 (+0.1)	36.0 (+0.3)	35.7 (+0.1)	36.0 (+0.4)	35.7 (+0.0)	35.9 (+0.3)	35.7 (+0.1)	36.0 (+0.3)	35.7 (+0.1)	36.0 (+0.3)
AMA_ECU	27.4 (+0.1)	27.7 (+0.3)	27.4 (+0.1)	27.7 (+0.3)	27.4 (+0.0)	27.6 (+0.3)	27.4 (+0.1)	27.6 (+0.3)	27.4 (+0.1)	27.7 (+0.4)
RIC_ARG	16.2 (+0.1)	16.4 (+0.3)	16.2 (+0.1)	16.4 (+0.3)	16.2 (+0.1)	16.4 (+0.3)	16.2 (+0.1)	16.5 (+0.3)	16.2 (+0.0)	16.4 (+0.3)
PEC_PER	20.5 (+0.0)	20.7 (+0.2)	20.6 (+0.1)	20.9 (+0.4)	20.6 (+0.1)	20.9 (+0.4)	20.6 (+0.1)	20.9 (+0.4)	20.5 (+0.1)	20.7 (+0.3)
AMA_PER	18.9 (+0.0)	19.0 (+0.2)	18.9 (+0.1)	19.1 (+0.3)	18.9 (+0.0)	19.0 (+0.2)	18.9 (+0.0)	19.0 (+0.2)	18.9 (+0.1)	19.1 (+0.3)
AMA_CSA	26.7 (+0.0)	26.9 (+0.2)	26.8 (+0.1)	27.0 (+0.3)	26.7 (+0.0)	26.8 (+0.1)	26.7 (+0.0)	26.8 (+0.1)	26.8 (+0.1)	27.0 (+0.3)
NWS_COL	41.7 (+0.0)	41.8 (+0.1)	41.7 (+0.0)	41.9 (+0.2)	41.7 (+0.0)	41.7 (+0.0)	41.7 (+0.0)	41.7 (+0.0)	41.8 (+0.0)	41.9 (+0.2)
AMA_COL	20.2 (+0.0)	20.2 (+0.0)	20.2 (+0.0)	20.3 (+0.0)	20.2 (+0.0)	20.2 (+0.0)	20.2 (+0.0)	20.2 (+0.0)	20.2 (+0.0)	20.3 (+0.1)
TIE_ARG	11.4 (+0.0)	11.4 (+0.0)	11.4 (+0.0)	11.4 (+0.0)	11.4 (+0.0)	11.4 (+0.0)	11.4 (+0.0)	11.4 (+0.0)	11.4 (+0.0)	11.4 (+0.0)
NSA_NSA	13.8 (+0.0)	13.8 (+0.0)	13.8 (+0.0)	13.8 (+0.0)	13.8 (+0.0)	13.7 (-0.1)	13.8 (+0.0)	13.7 (-0.1)	13.8 (+0.0)	13.9 (+0.0)
ORI_COL	29.9 (+0.0)	29.9 (+0.0)	29.9 (+0.0)	29.9 (+0.0)	29.9 (+0.0)	29.8 (-0.1)	29.9 (+0.0)	29.8 (-0.1)	29.9 (+0.0)	29.9 (+0.0)
NWS_ECU	44.1 (-0.1)	43.7 (-0.5)	44.1 (-0.1)	43.8 (-0.4)	44.1 (-0.1)	43.5 (-0.7)	44.1 (-0.1)	43.5 (-0.6)	44.1 (-0.1)	43.9 (-0.3)

Note: Values show the percentage of species being threatend or endangered of extinction in the year 2050 in each FPU under different scenarios. The value in parentheses give the percentage point change compared to 2010 given different crop production and cropland expansion pathways. The lower bound reflects a risk of biodiversity loss if 100% of crop land expands over existing pasture land, while the upper bound reflects a risk of biodiversity loss if 100% of crop land expands over natural vegetation. Considered crops in the analysis are maize, rice, wheat, soybeans, sugarcane, potatoes, sorghum. FPU = Food Producing Unit. To locate Food Producing Units see Appendix A6 and Appendix A4. BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 1 in the main text. Those FPUs are listed first that show the highest increase in risk of biodiversity loss according to the upper bound land expansion pathway under the BAU scenario.
(Source: own elaboration)

Appendix A19. Species risk of extinction and endangerment due to livestock production across Food Producing Units in LAC in 2050 (index in %) and net changes between 2010 and 2050 (in %age points)

FPU	(1) BAU		(1a) BAU liberal		(2) Intensification / (3) Sust.-intens.		(4) Yield gaps closed		(5) Extensification	
Central America and the Caribbean										
MIM_MEX	29.5	(+0.6)	29.7	(+0.8)	29.7	(+0.7)	29.7	(+0.7)	30.2	(+1.2)
CAM_CCA	44.3	(+0.0)	44.3	(+0.0)	44.3	(+0.0)	44.3	(+0.0)	44.3	(+0.0)
CAR_CCA	57.7	(+0.0)	57.7	(+0.0)	57.7	(+0.0)	57.7	(+0.0)	57.7	(+0.0)
CUB_CCA	41.4	(+0.0)	41.4	(+0.0)	41.4	(+0.0)	41.4	(+0.0)	41.4	(+0.0)
RIG_MEX	28.5	(+0.0)	28.5	(+0.0)	28.5	(+0.0)	28.5	(+0.0)	28.5	(+0.0)
UME_MEX	28.7	(+0.0)	28.7	(+0.0)	28.7	(+0.0)	28.7	(+0.0)	28.7	(+0.0)
YUC_MEX	33.6	(+0.0)	33.6	(+0.0)	33.6	(+0.0)	33.6	(+0.0)	36.3	(+2.8)
South America										
TOC_BRA	52.2	(+6.5)	52.2	(+6.5)	52.2	(+6.4)	52.2	(+6.5)	54.3	(+8.5)
ORI_NSA	41.6	(+5.9)	43.4	(+7.7)	43.1	(+7.4)	43.1	(+7.4)	46.2	(+10.5)
AMA_ECU	33.0	(+5.6)	34.4	(+7.0)	34.1	(+6.7)	34.1	(+6.7)	36.9	(+9.5)
PAR_CSA	42.3	(+4.9)	43.1	(+5.7)	43.0	(+5.6)	43.0	(+5.6)	45.1	(+7.7)
AMA_CSA	30.8	(+4.1)	32.1	(+5.4)	31.9	(+5.2)	31.9	(+5.2)	34.1	(+7.3)
AMA_PER	21.6	(+2.8)	22.5	(+3.6)	22.3	(+3.5)	22.3	(+3.5)	23.7	(+4.9)
AMA_COL	22.7	(+2.5)	22.8	(+2.6)	22.7	(+2.5)	22.7	(+2.5)	23.6	(+3.4)
NSA_NSA	16.0	(+2.2)	16.7	(+2.8)	16.5	(+2.7)	16.5	(+2.7)	17.7	(+3.9)
PAR_ARG	47.6	(+1.3)	48.5	(+2.1)	48.2	(+1.8)	48.2	(+1.8)	49.5	(+3.1)
CHC_CHL	25.8	(+0.5)	26.9	(+1.7)	26.8	(+1.5)	26.8	(+1.5)	28.1	(+2.9)
AMA_BRA	20.1	(+0.0)	20.4	(+0.3)	20.2	(+0.1)	20.2	(+0.1)	20.9	(+0.8)
NEB_BRA	48.6	(+0.0)	48.6	(+0.0)	48.6	(+0.0)	48.6	(+0.0)	48.6	(+0.0)
NWS_ECU	44.2	(+0.0)	44.2	(+0.0)	44.2	(+0.0)	44.2	(+0.0)	53.8	(+9.6)
ORI_COL	29.9	(+0.0)	29.9	(+0.0)	29.9	(+0.0)	29.9	(+0.0)	29.9	(+0.0)
PAR_BRA	57.5	(+0.0)	56.5	(-1.0)	56.1	(-1.4)	56.1	(-1.4)	57.7	(+0.1)
PEC_PER	20.5	(+0.0)	20.5	(+0.0)	20.5	(+0.0)	20.5	(+0.0)	20.5	(+0.0)
RIC_ARG	16.1	(+0.0)	16.1	(+0.0)	16.1	(+0.0)	16.1	(+0.0)	16.1	(+0.0)
SAL_ARG	48.5	(+0.0)	48.5	(+0.0)	48.5	(+0.0)	48.5	(+0.0)	48.5	(+0.0)
SAN_BRA	52.6	(+0.0)	52.6	(+0.0)	52.6	(+0.0)	52.6	(+0.0)	52.6	(+0.0)
TIE_ARG	11.4	(+0.0)	11.4	(+0.0)	11.4	(+0.0)	11.4	(+0.0)	11.4	(+0.0)
URU_BRA	58.4	(+0.0)	58.4	(+0.0)	58.4	(+0.0)	58.4	(+0.0)	58.4	(+0.0)
NWS_COL	40.1	(-1.7)	41.5	(-0.2)	41.4	(-0.4)	41.3	(-0.4)	42.2	(+0.5)

Note: Values show the percentage of species being threatend or endangered of extinction in the year 2050 in each FPU under different scenarios. The value in parentheses give the percentage point change compared to 2010. It is assumed that pasture land due to increasing livestock production entirely expands over natural vegetation. FPU = Food Producing Unit. To locate Food Producing Units see Appendix A6 and Appendix A4. BAU refers to the Business-as-Usual scenario. Scenarios are described in Table 1 in the main text. Those FPUs are listed first that show the highest increase in risk of biodiversity loss under the BAU scenario.
(Source: own elaboration)

Appendix B1. Data description

Variable	Source	Years	Description
General CPI, Food CPI	ECLAC[a]	1995-2013	General consumer price index and food consumer price indices with base year 2005. All indices are yearly averages of monthly price data.
Agricultural world price indices	FAO[b], International Monetary Fund (IMF)[c]	1995-2013	*IMF:* Weighted average of individual commodity price indices. Weights depend on their relative trade volumes of each commodity compared to total world trade. *FAO:* Consists of the average of five commodity group price indices, weighted with the average export shares of each group for 2002-2004. In total 73 products are included.
Trade openness indicator	Comtrade[d], World Development Indicators (WDI)[e], IMF[c]	1995-2013	Calculated as the sum of import and export values over agricultural GDP in current US dollar. Agricultural GDP is derived from agricultural value added. Trade values are the sum of all food and livestock products being traded. Export (import) values are fob (cif) prices. SITC Rev. 3 commodity codes.
Exchange rate	Inter-American Development Bank (IDB)[f]	1995-2013	Local currency per US dollar, monthly averages.
Money supply (M2)	IDB[f]	1995-2013	Sum of currency outside banks, demand deposits other than those of the central government, and the time, savings, and foreign currency deposits of resident sectors other than the central government. Given in constant local currency units and as shares of GDP.
Unemployment rate	IDB[f]	1995-2013	Unemployment rate, annual average, in %.
World crude oil prices	IMF[c]	1995-2013	Average international crude oil prices in current US dollar per barrel.

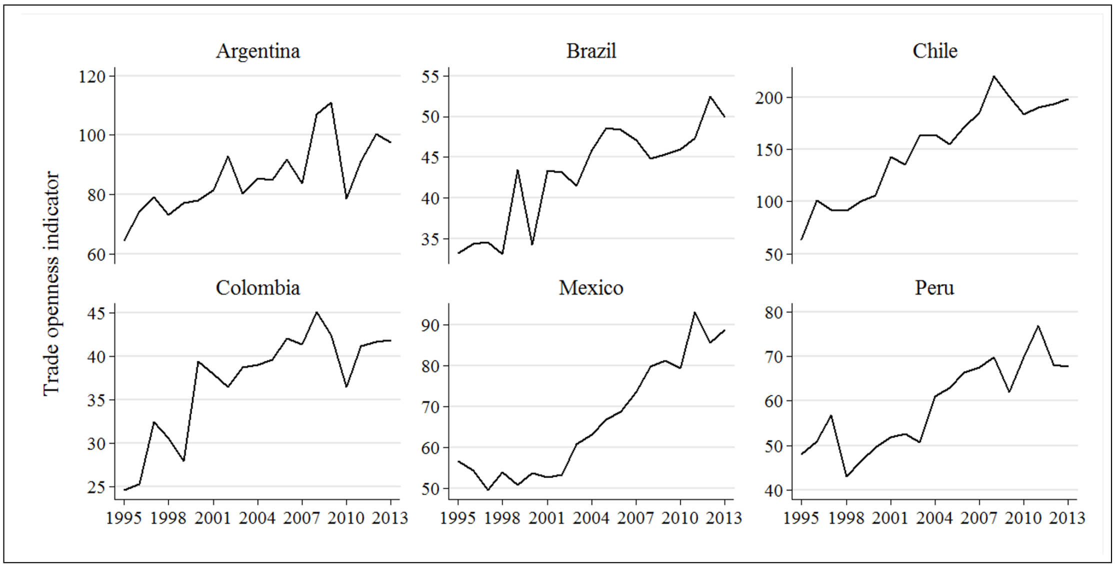
[a] www.eclac.org/
[b] http://www.fao.org/worldfoodsituation/foodpricesindex/en/
[c] http://www.imf.org/external/pubs/ft/weo/2014/01/weodata/index.aspx
[d] http://comtrade.un.org
[e] http://data.worldbank.org/datacatalog/
[f] http://www.iadb.org

Appendix B2. Descriptive statistics of the variables

Variable[a]		Mean	SD	Min	Max	Observations[b]	
	Overall	101.41	35.12	32.03	200.86	N	114
Food CPI	Between		5.49	95.43	110.45	n	6
	Within		34.76	36.36	198.84	T	19
	Overall	0.74	0.43	0.25	2.21	N	114
TOP	Between		0.41	0.37	1.51	n	6
	Within		0.20	-0.13	1.44	T	19
	Overall	152.45	198.80	3.30	878.93	N	114
Money supply (in local currency)	Between		159.46	14.08	359.66	n	6
	Within		134.70	-110.64	677.36	T	19
	Overall	31.42	13.66	6.67	57.77	N	114
Money supply (share of GDP)	Between		13.18	12.16	47.49	n	6
	Within		6.37	18.54	45.95	T	19
	Overall	8.88	3.90	2.20	22.45	N	114
Unemployment rate	Between		3.16	4.06	13.21	n	6
	Within		2.62	2.76	18.12	T	19
	Overall	415.29	745.13	0.92	2877.54	N	114
Exchange rate	Between		778.41	1.95	1945.64	n	6
	Within		214.05	-617.45	1347.20	T	19
World crude oil prices	No variation between countries	51.14	32.86	13.07	105.01	T	19
World food CPI (IMF)	No variation between countries	117.90	34.02	79.48	182.40	T	19
World food CPI (FAO)	No variation between countries	119.30	38.73	75.98	194.97	T	19

[a] "Overall" shows descriptive statistics over the whole sample, "Between" shows the between variation, "Within" shows the within country variation of each variable.
[b] N = Total number of observations over the sample, n = number of countries, T= number of time periods (1995-2013)

Appendix B3. Evolution of agricultural trade openness



Note: Agricultural trade openness is defined as the ratio of total trade values and agricultural GDP in current US dollar (expressed in %) (1995 - 2013).
(Source: Data obtained from Comtrade (2014), World Development Indicators (2014) and IMF (2014).)

Appendix C1. Income and poverty trends in rural Peru

Poverty reduction appears to be associated with income growth in rural Peru. Between 2004 and 2012 average household income per capita more than doubled in real terms (see Table C1.1[1]). Especially between 2007 and 2008, average income of the extreme poor and moderate poor rose substantially. This period of high income growth coincided with the international agricultural commodity price spike which could contribute to rising profits in the agricultural sector.

Table C1.1: Real household income per capita by social class in rural areas (2004-2012)

	Total population		**Extreme poor**		**Moderate poor**		**Non-poor**	
year	**PEN**	**percentage change**	**PEN**	**percentage change**	**PEN**	**percentage change**	**PEN**	**percentage change**
2004	144		80		151		337.41	
2005	142	-1.47	75	-5.71	145	-4.01	331.77	-1.67
2006	154	+8.73	80	+6.38	154	+6.29	324.99	-2.04
2007	180	+16.94	89	+11.42	161	+4.53	354.90	+9.20
2008	223	+23.86	109	+22.06	189	+17.36	406.79	+14.62
2009	251	+12.22	136	+25.16	211	+11.62	416.86	+2.48
2010	276	+9.95	136	-0.13	212	+0.80	439.16	+5.35
2011	298	+8.17	136	-0.12	220	+3.47	453.73	+3.32
2012	319	+6.79	141	+3.95	233	+6.10	468.33	+3.22
Δ 2004 - 2012		+121.19		+77.02		+54.62		+38.80

Note: Total household income per capita is obtained by adding up all monetary and non-monetary income sources of all household members and dividing it by the household size. PEN stands for the Peruvian official currency "Nuevo Sol" and is given in real terms with a base year of 2009. The official exchange rate to US dollars were 3.4PEN/US$ in 2004 and 2.6PEN/US$ in 2012.
(Source: own elaboration based on ENAHO data)

Table C1.2 illustrates how headcount poverty evolved in different rural Peruvian regions. The most dynamic rural regions with largest drops in extreme and moderate poverty were located in the central and northern "Costa". Also, in the southern "Costa", moderate poverty decreased substantially, so that more than 90% of the rural population had escaped poverty by 2012. Opposed to the coastal regions, the "Sierra" and "Selva"

[1] The disproportionately high income growth of the average rural population compared to the within group (extreme, moderate or non-poor) increase can be explained by the fact that between 2004 and 2012 a large fraction of the poor population escaped poverty, and thus appear in the group of the non-poor in later years.

showed less dynamic poverty reduction. Especially in the northern “Sierra”, three quarter of the population still lived with incomes below the poverty line in 2012. The “Selva”, although still being among the poorer regions, showed some poverty reduction between 2004 and 2012.

Table C1.2: Social class distribution per region (rural areas)

	Extreme poor			Moderate poor		
Region	**2004**	**2008**	**2012**	**2004**	**2008**	**2012**
Costa centro	5.92%	1.70%	0.81%	46.76%	22.69%	10.53%
Costa norte	26.34%	11.46%	6.78%	52.90%	46.74%	34.82%
Selva	33.14%	27.63%	14.18%	48.36%	34.92%	31.95%
Sierra sur	46.71%	35.24%	17.27%	39.51%	40.47%	33.77%
Costa sur	3.99%	0.00%	1.45%	38.65%	18.23%	7.45%
Sierra centro	46.77%	36.16%	19.77%	37.95%	34.03%	34.47%
Sierra norte	53.02%	44.59%	37.73%	36.90%	35.77%	36.52%
	Non-poor			**change percentage points**		
	2004	**2008**	**2012**	**extreme poor**	**moderate poor**	**non-poor**
Costa centro	47.32%	75.61%	88.66%	-5.11pp	-36.23pp	41.34pp
Costa norte	20.76%	41.80%	58.39%	-19.56pp	-18.08pp	37.63pp
Selva	18.50%	37.45%	53.87%	-18.96pp	-16.41pp	35.37pp
Sierra sur	13.79%	24.29%	48.97%	-29.44pp	-5.74pp	35.18pp
Costa sur	57.36%	81.77%	91.10%	-2.54pp	-31.20pp	33.74pp
Sierra centro	15.28%	29.81%	45.76%	-27.00pp	-3.48pp	30.48pp
Sierra norte	10.08%	19.64%	25.76%	-15.29pp	-0.38pp	15.68pp

Note: Regions are ordered according to largest increase of the non-poor class between 2004 and 2012 in percentage points (pp) (Last column).
(Source: own elaboration based on ENAHO data)

However, for poverty reduction not only average income, but also the distribution of income matters. The growth incidence curve of Figure C1.1(a) indicates that the incomes of the poorer and middle income parts of the population, up to the 45th to 55th percentiles, rose slower than average, while those of the richest showed the highest relative increase. Although also the incomes of the poorest households rose at average rates above 8%, the poorer population was left behind the richer population. Unsurprisingly, the illustrated income growth dynamics across different income percentiles led to an increase in income inequality which is evident from the Lorenz curve (Figure C1.1(b)).

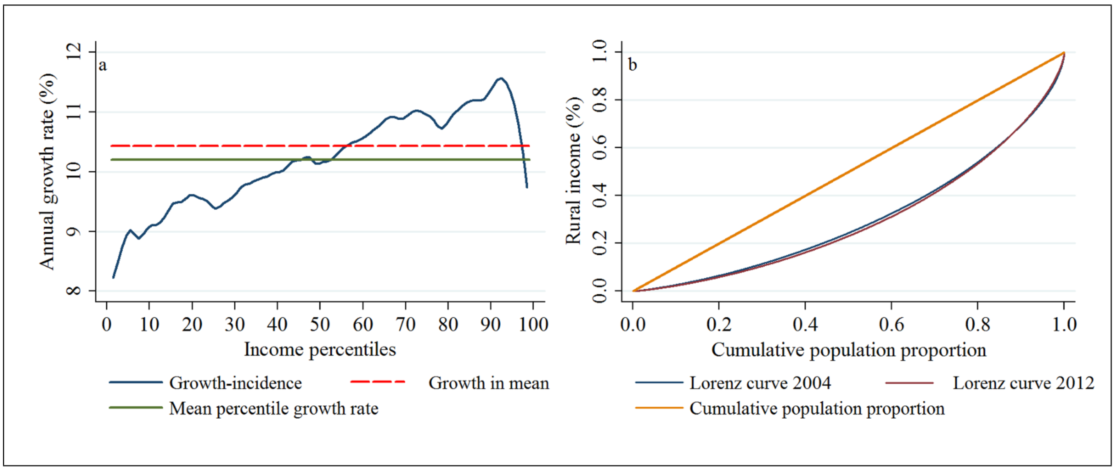


Figure C1.1: **a) Growth incidence curve 2004 -2012; b): Lorenz curve of rural areas**
Note: The calculation of the growth incidence curves is performed using the Poverty Analysis Toolkit written by Michael M. Lokshin and Martin Ravallion (2007), The World Bank to analyze poverty dynamics in STATA. The employed STATA command is 'gicurve'.
(Source: own elaboration based on ENAHO data)

Appendix C2. Dynamics of rural income regressions

While the static observations discussed in section 4.3.2 are little surprising, the dynamics are more interesting. Comparing the coefficients of 2004 and 2012 in Table 4.6 and Table 4.7 tells us that the driving forces behind income growth were distinct across different sectors. For example, the returns to education increased for agricultural wage-employment, non-agricultural self-employment and for “other” farmers, while they decreased substantially for non-agricultural wage-employment, maize, potato and coffee farmers. Experience decreased for all sectors, but agricultural self-employment. Also, opportunities for women improved in some sectors, while they worsened in others. The female wage gap diminished in agricultural wage-employment and in coffee and “other” farming activities. The sectoral dummies in the non-agricultural wage regression are all significant (except for domestic workers in 2004). Compared to the base sector “public administration”, people employed in mining were better paid with even increasing returns between 2004 and 2012. Furthermore, the wage gap of staff in manufacturing, construction and especially in hotels and restaurants attenuated between 2004 and 2012. Sectoral controls in the non-agricultural self-employment regression are significant in both years, only for manufacturing and hotels and restaurants. Compared to the base category (wholesale/retail shops), the income gap of manufacturing shrank, while hotels and restaurant owners had increasingly higher profits. Furthermore, in non-agricultural self-employment the returns to employing more paid staff increased by approximately 50%, and also occupying more non-remunerated family members became slightly more profitable in 2012. Within agricultural self-employment a similar trend could be observed with respect to hiring more staff. Especially for potato farmers, the returns to labor rose between 2004 and 2012. With respect to returns to land, the dynamics were ambiguous. For maize and most strikingly coffee farmers returns to land increased, while they decreased for potato and “other” farmers. Also, different sectors developed differently among regions. The central Sierra is chosen as a base region, because about one third of the rural population lived there of which more than 50% remained poor in 2012. Generally, incomes were highest in the coastal regions and the wage gap even increased in agricultural wage-employment. On the contrary, in most agricultural self-employment sectors the profit gap decreased between 2004 and 2012. Finally, the baseline income rose in all employment sectors, except for “other” farmers.

Appendix C3. Multinominal logit model estimations of occupational choices

Tables C3.1, C3.2, C3.3, C3.4, C3.5, C3.6 show the results of the multinominal logit regressions, separate for household heads, spouses and other household members, and for two different points in time. By comparing the coefficients of the year 2004 and 2012, we are able to grasp those factors that explain changing probabilities of being in one of the seven sectors. A head of household being high-skilled had a higher probability of being active in non-agricultural or agricultural wage-employment than heads with lower skills in both years. In 2004 high skills also increased the probability to participate in maize, potato or coffee farming, while skills where insignificant in 2012 for these sectors. For spouses, skills were only relevant for increasing the probability of participating in non-agricultural wage-employment, and surprisingly, for working non-remunerated in 2004. However, between 2004 and 2012 the probability of being high skilled and being a non-agricultural wage-earner dropped substantially. This could mean that also spouses with lower levels of education had access to this sector in 2012. In 2012, in addition to non-agricultural wage-employment, skilled spouses were also more likely to participate in agricultural wage-employment and non-agricultural self-employment compared to unskilled spouses. Also, skilled other household members were more likely to be in the active labor force than unskilled household members. It seems that being high skilled was most relevant for entering non-agricultural wage-employment, but higher levels of education lost relevance for being a farmer by 2012.

Another relevant variable that explained labor-force participation was age. Especially for spouses and other household members, the probability of participating in any sector increased as one got older. Age clearly proxies for experience, so there was an increasing demand for experienced staff over time.

Furthermore, with increasing numbers of household members at working age, the probability of participating in any sector increased compared to being economically inactive or unemployed.

In 2004, being a female household head increased the probability of leaving inactivity and working non-remunerated. However, in 2012 the gender variable became insignificant for household heads. Contrarily, if spouses were female (of which the majority generally are) the probability of working non-remunerated increased tremendously between 2004 and 2012. The same holds if the household counted an increasing number of children. This could mean that spouses were forced to participate in the labor force in 2004, while spouses were able to decide to take care of the children in 2012 instead.

Table C3.1: Occupational choice probabilities of household heads (2004)

Variable	Non-agricultural wage earner	Agricultural wage earner	Non-agricultural self-employed	Maize farmer	Potato farmer	Coffee farmer	"Other" farmer	Non-remunerated
Medium skilled	1.985	1.090	1.343	1.069	1.001	1.197	1.658	**4.544****
	(0.842)	(0.442)	(0.552)	(0.407)	(0.382)	(0.467)	(0.649)	(2.862)
High skilled	**5.015*****	**0.367***	0.867	**0.352****	**0.420***	**0.371***	0.817	**3.905***
	(2.591)	(0.194)	(0.458)	(0.173)	(0.206)	(0.190)	(0.412)	(3.063)
Age	**1.567*****	**1.322*****	**1.366*****	**1.301*****	**1.332*****	**1.297*****	**1.239*****	**1.273*****
	(0.121)	(0.089)	(0.092)	(0.072)	(0.074)	(0.078)	(0.070)	(0.119)
Age squ.	**0.995*****	**0.997*****	**0.996*****	**0.997*****	**0.997*****	**0.997*****	**0.998*****	**0.998****
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Female	**0.146*****	**0.184*****	**0.456**	**0.227*****	**0.329*****	**0.314****	**0.505**	**4.297****
	(0.087)	(0.101)	(0.226)	(0.098)	(0.140)	(0.146)	(0.224)	(2.595)
Number of members from 14 to 17	0.793	0.752	0.795	0.706	0.698	0.687	**0.615****	**0.409***
	(0.192)	(0.189)	(0.194)	(0.162)	(0.160)	(0.164)	(0.147)	(0.220)
Number of members from 18 to 24	**1.979****	1.486	**1.849****	**1.623***	1.585	**2.025****	**1.730***	**2.280****
	(0.583)	(0.446)	(0.551)	(0.465)	(0.455)	(0.586)	(0.503)	(0.861)
Number of members from 25 to 64	**0.651*****	**0.524*****	**0.748***	**0.611*****	**0.561*****	**0.613*****	**0.687*****	0.837
	(0.103)	(0.084)	(0.115)	(0.076)	(0.070)	(0.085)	(0.090)	(0.159)
Number of members older 64	0.842	**0.704****	0.842	**0.764****	**0.671*****	**0.695*****	**0.729****	**0.543***
	(0.114)	(0.101)	(0.116)	(0.085)	(0.079)	(0.090)	(0.090)	(0.172)
Constant	**0.001*****	0.231	**0.027****	0.599	0.494	0.241	0.277	**0.000*****
	(0.002)	(0.378)	(0.045)	(0.857)	(0.709)	(0.365)	(0.407)	(0.001)

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Observations: 5,680; Pseudo $R^2 = 0.043$.
(Source: own elaboration)

Table C3.2: Occupational choice probabilities of household heads (2012)

Variable	Non-agricultural wage earner	Agricultural wage earner	Non-agricultural self-employed	Maize farmer	Potato farmer	Coffee farmer	"Other" farmer	Non-remunerated
Medium skilled	**1.764***	0.963	**1.757***	0.893	0.836	0.928	1.099	1.213
	(0.562)	(0.299)	(0.564)	(0.252)	(0.236)	(0.271)	(0.318)	(0.468)
High skilled	**4.693*****	0.599	**2.482****	0.541	0.666	0.546	1.150	1.473
	(1.926)	(0.256)	(1.040)	(0.210)	(0.257)	(0.222)	(0.453)	(0.760)
Age	**1.243*****	**1.144***	**1.140***	**1.133***	**1.157****	1.095	1.105	1.016
	(0.097)	(0.094)	(0.090)	(0.079)	(0.081)	(0.079)	(0.078)	(0.081)
Age squ.	**0.997*****	**0.998*****	**0.998*****	**0.998*****	**0.998*****	**0.999****	**0.999****	1.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Female	**0.301*****	0.583	1.199	**0.384*****	**0.347*****	**0.279*****	0.859	1.924
	(0.112)	(0.217)	(0.419)	(0.122)	(0.111)	(0.100)	(0.277)	(0.807)
Number of members	1.225	1.184	1.288	1.098	1.181	1.089	0.957	1.124
from 14 to 17	(0.278)	(0.279)	(0.304)	(0.240)	(0.257)	(0.244)	(0.216)	(0.331)
Number of members	1.117	0.992	1.051	0.920	0.906	1.047	0.950	**1.581****
from 18 to 24	(0.178)	(0.166)	(0.175)	(0.140)	(0.138)	(0.164)	(0.150)	(0.314)
Number of members	**0.589*****	**0.575*****	**0.578*****	**0.517*****	**0.470*****	**0.613*****	**0.507*****	**0.726****
from 25 to 64	(0.067)	(0.077)	(0.070)	(0.049)	(0.044)	(0.065)	(0.053)	(0.109)
Number of members	0.759	**0.658***	**0.706***	0.762	**0.717***	0.769	**0.666****	**0.681***
older 64	(0.145)	(0.150)	(0.143)	(0.132)	(0.125)	(0.141)	(0.123)	(0.152)
Constant	0.675	6.573	2.604	**30.795***	29.544	25.349	14.738	1.877
	(1.490)	(14.769)	(5.748)	(63.360)	(60.909)	(53.300)	(30.707)	(4.356)

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Observations: 7,252; Pseudo $R^2 = 0.039$.
(Source: own elaboration)

Table C3.3: Occupational choice probabilities of spouses (2004)

Variable	**Non-agricultural wage earner**	**Agricul-tural wage earner**	**Non-agricultural self-employed**	**Maize farmer**	**Potato farmer**	**Coffee farmer**	**"Other" farmer**	**Non-remunerated**
Medium skilled	**2.191***	0.928	1.198	0.823	0.969	1.267	1.043	**0.695*****
	(0.925)	(0.247)	(0.198)	(0.268)	(0.334)	(0.827)	(0.455)	(0.094)
High skilled	**16.222*****	0.597	0.849	0.408	1.160	1.139	1.221	**0.356*****
	(7.240)	(0.298)	(0.246)	(0.287)	(0.524)	(1.155)	(0.690)	(0.092)
Age	**1.531*****	**1.225****	**1.376*****	1.096	1.104	3.045	**1.150***	**1.147*****
	(0.160)	(0.097)	(0.065)	(0.088)	(0.104)	(2.245)	(0.089)	(0.037)
Age squ.	**0.995*****	**0.998*****	**0.996*****	0.999	0.999	0.985	**0.998****	**0.998*****
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.011)	(0.001)	(0.000)
Female	**0.006*****	**0.008*****	**0.066****	**0.003*****	**0.008*****	**0.007*****	**0.007*****	**0.074*****
	(0.010)	(0.008)	(0.073)	(0.003)	(0.009)	(0.011)	(0.008)	(0.071)
Number of children	0.941	1.023	**0.816*****	1.023	0.953	0.734	0.944	1.018
	(0.116)	(0.100)	(0.048)	(0.128)	(0.109)	(0.171)	(0.121)	(0.050)
Number of members	0.914	1.045	0.912	0.671	**1.438***	0.988	0.740	0.920
from 14 to 17	(0.216)	(0.221)	(0.109)	(0.199)	(0.300)	(0.414)	(0.172)	(0.094)
Number of members	0.773	0.907	0.905	1.076	0.925	0.273	0.797	0.947
from 18 to 24	(0.164)	(0.157)	(0.084)	(0.242)	(0.176)	(0.225)	(0.155)	(0.074)
Number of members	**0.614***	0.726	0.961	1.095	1.193	1.095	0.854	0.882
from 25 to 64	(0.162)	(0.176)	(0.116)	(0.381)	(0.393)	(0.804)	(0.227)	(0.085)
Number of members	1.177	**0.700***	1.018	1.067	0.761	**0.000*****	1.023	0.964
older 64	(0.174)	(0.148)	(0.104)	(0.149)	(0.158)	(0.000)	(0.267)	(0.078)
Head in non-agric.	0.455	0.478	1.196	**0.323****	0.518	0.549	0.394	1.183
self-empl.	(0.360)	(0.314)	(0.469)	(0.180)	(0.263)	(0.420)	(0.225)	(0.433)
Head in agric.	**0.299*****	**0.392*****	**0.617****	**0.011*****	**0.012*****	**0.018*****	**0.014*****	1.079
self-empl.	(0.105)	(0.132)	(0.146)	(0.005)	(0.007)	(0.015)	(0.008)	(0.228)
Constant	0.017	3.542	0.151	**37.048****	18.926	0.000	18.628	**8.647***
	(0.044)	(5.913)	(0.209)	(65.213)	(37.088)	(0.000)	(35.959)	(9.592)

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Observations: 3,670; Pseudo $R^2 = 0.117$.
(Source: own elaboration)

Table C3.4: Occupational choice probabilities of spouses (2012)

Variable	**Non-agricultural wage earner**	**Agricultural wage earner**	**Non-agricultural self-employed**	**Maize farmer**	**Potato farmer**	**Coffee farmer**	**"Other" farmer**	**Non-remunerated**
Medium skilled	**1.722***	**0.669***	**1.391****	1.253	1.377	2.609	1.286	0.961
	(0.518)	(0.145)	(0.229)	(0.378)	(0.380)	(1.724)	(0.332)	(0.141)
High skilled	**6.545*****	**0.568***	0.855	0.675	0.638	1.814	0.721	**0.446*****
	(2.061)	(0.177)	(0.208)	(0.268)	(0.253)	(1.496)	(0.257)	(0.098)
Age	**1.418*****	**1.264*****	**1.259*****	**1.185****	**1.374*****	1.175	**1.140****	**1.150*****
	(0.104)	(0.070)	(0.048)	(0.086)	(0.093)	(0.149)	(0.062)	(0.037)
Age squ.	**0.996*****	**0.997*****	**0.997*****	**0.998****	**0.997*****	0.998	**0.999****	**0.998*****
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Female	**0.245*****	1.047	**2.882****	0.271**	**0.309****	**0.091*****	1.246	**7.016*****
	(0.122)	(0.562)	(1.353)	(0.155)	(0.170)	(0.064)	(0.801)	(3.130)
Number of children	0.953	0.985	0.999	0.851	0.890	0.787	1.016	**1.102***
	(0.097)	(0.078)	(0.062)	(0.099)	(0.099)	(0.154)	(0.093)	(0.063)
Number of members from 14 to 17	0.977	0.952	0.943	0.783	0.758	0.806	**0.734***	0.941
	(0.151)	(0.129)	(0.101)	(0.131)	(0.130)	(0.339)	(0.130)	(0.091)
Number of members from 18 to 24	0.981	**1.333****	1.149	**1.336***	1.094	1.306	1.024	1.147
	(0.165)	(0.162)	(0.122)	(0.222)	(0.169)	(0.488)	(0.180)	(0.113)
Number of members from 25 to 64	0.777	**0.714****	1.006	1.114	**0.542*****	1.694	0.772	0.916
	(0.162)	(0.120)	(0.102)	(0.220)	(0.119)	(0.631)	(0.143)	(0.082)
Number of members older 64	1.231	1.166	1.255	**1.657*****	1.339	**2.078***	1.109	**1.296****
	(0.294)	(0.198)	(0.173)	(0.314)	(0.279)	(0.782)	(0.227)	(0.159)
Head in non-agric. self-empl.	0.880	0.564	**1.967***	0.424	0.953	1.994	1.350	1.226
	(0.451)	(0.302)	(0.754)	(0.234)	(0.410)	(1.386)	(0.549)	(0.459)
Head in agric. self-empl.	**0.354*****	**0.499*****	1.029	**0.054*****	**0.002*****	**0.019*****	**0.023*****	**1.790*****
	(0.090)	(0.119)	(0.213)	(0.018)	(0.002)	(0.020)	(0.008)	(0.338)
Constant	**0.003*****	**0.035*****	**0.006*****	0.111	**0.029****	0.026	0.174	**0.043*****
	(0.004)	(0.042)	(0.006)	(0.165)	(0.043)	(0.080)	(0.216)	(0.036)

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Observations: 4,659; Pseudo $R^2 = 0.135$.
(Source: own elaboration)

Table C3.5: Occupational choice probabilities of other household members (2004)

Variable	**Non-agricultural wage earner**	**Agricul-tural wage earner**	**Non-agricultural self-employed**	**Maize farmer**	**Potato farmer**	**Coffee farmer**	**"Other" farmer**	**Non-remunerated**
Medium skilled	**3.220*** **	**2.019*** **	**1.702*** **	**2.904*** **	**2.097*** **	1.565	**2.531* **	**2.173*** **
	(0.564)	(0.267)	(0.314)	(0.708)	(0.586)	(0.539)	(1.293)	(0.164)
High skilled	**2.123*** **	**0.444*** **	0.791	**0.557** **	**0.232*** **	**0.458* **	0.989	**0.491*** **
	(0.440)	(0.087)	(0.173)	(0.164)	(0.085)	(0.193)	(0.514)	(0.064)
Age	**1.967*** **	**2.014*** **	**1.987*** **	**2.505*** **	**2.673*** **	**2.448*** **	**2.514*** **	**1.716*** **
	(0.067)	(0.073)	(0.087)	(0.136)	(0.161)	(0.190)	(0.196)	(0.036)
Age squ.	**0.992*** **	**0.992*** **	**0.992*** **	**0.990*** **	**0.989*** **	**0.990*** **	**0.990*** **	**0.994*** **
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Female	**0.589*** **	**0.154*** **	**0.814**	**0.137*** **	**0.118*** **	**0.063*** **	**0.325*** **	**0.729*** **
	(0.068)	(0.021)	(0.116)	(0.034)	(0.035)	(0.032)	(0.124)	(0.047)
Number of children	0.965	1.001	**0.916* **	1.081	1.057	0.889	**0.742** **	**0.906*** **
	(0.035)	(0.034)	(0.041)	(0.067)	(0.065)	(0.084)	(0.110)	(0.019)
Number of members	2.058***	**1.906*** **	**1.641*** **	**1.512*** **	**1.469** **	1.744	0.861	**1.858*** **
from 14 to 17	(0.162)	(0.134)	(0.170)	(0.217)	(0.278)	(0.620)	(0.266)	(0.083)
Number of members	1.023	0.946	0.996	1.088	0.929	1.120	1.178	0.964
from 18 to 24	(0.055)	(0.049)	(0.071)	(0.121)	(0.102)	(0.180)	(0.238)	(0.035)
Number of members	**0.711*** **	**0.642*** **	**0.816*** **	**0.607*** **	**0.552*** **	**0.483*** **	**0.414*** **	**0.686*** **
from 25 to 64	(0.048)	(0.044)	(0.056)	(0.060)	(0.071)	(0.091)	(0.084)	(0.030)
Number of members	0.961	0.962	1.026	0.911	**0.747** **	1.141	0.990	0.981
older 64	(0.063)	(0.053)	(0.072)	(0.095)	(0.094)	(0.124)	(0.112)	(0.039)
Head in non-agric.	1.292	0.811	**2.548*** **	0.575	1.156	**0.000*** **	0.780	**1.588** **
self-empl.	(0.369)	(0.231)	(0.809)	(0.278)	(0.639)	(0.000)	(0.535)	(0.285)
Head in agric.	1.136	0.856	1.135	**0.359*** **	**0.475*** **	0.749	**0.114*** **	**1.551*** **
self-empl.	(0.183)	(0.122)	(0.230)	(0.079)	(0.130)	(0.312)	(0.043)	(0.156)
Constant	**0.000*** **	**0.000*** **	**0.000*** **	**0.000*** **	**0.000*** **	**0.000*** **	**0.000*** **	**0.001*** **
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Observations: 10,353; Pseudo $R^2 = 0.268$.
(Source: own elaboration)

Table C3.6: Occupational choice probabilities of other household members (2012)

Variable	Non-agricultural wage earner	Agricultural wage earner	Non-agricultural self-employed	Maize farmer	Potato farmer	Coffee farmer	"Other" farmer	Non-remunerated
Medium skilled	**4.525*****	**2.892*****	**3.049*****	**3.655*****	**1.977*****	**3.697*****	**2.836*****	**3.512*****
	(0.702)	(0.356)	(0.601)	(0.815)	(0.507)	(1.282)	(1.068)	(0.267)
High skilled	**3.519*****	**0.510*****	1.170	0.726	0.652	1.058	1.056	**0.722*****
	(0.624)	(0.084)	(0.250)	(0.181)	(0.186)	(0.386)	(0.405)	(0.090)
Age	**2.017*****	**2.030*****	**2.081*****	**2.401*****	**2.336*****	**2.261*****	**2.319*****	**1.727*****
	(0.057)	(0.056)	(0.073)	(0.094)	(0.110)	(0.120)	(0.136)	(0.036)
Age squ.	**0.992*****	**0.992*****	**0.992*****	**0.991*****	**0.991*****	**0.992*****	**0.991*****	**0.994*****
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)
Female	**0.673*****	**0.246*****	0.926	**0.195*****	**0.411*****	**0.080*****	**0.553****	1.098
	(0.053)	(0.025)	(0.113)	(0.038)	(0.083)	(0.029)	(0.138)	(0.064)
Number of children	**0.929*****	**0.932****	**0.832*****	**1.213*****	1.022	**0.864***	1.033	**0.840*****
	(0.026)	(0.027)	(0.042)	(0.066)	(0.072)	(0.067)	(0.096)	(0.018)
Number of members	**2.092*****	**2.280*****	**1.675*****	**1.722*****	**1.581*****	**1.808*****	**1.812*****	**2.154*****
from 14 to 17	(0.114)	(0.136)	(0.149)	(0.236)	(0.256)	(0.322)	(0.384)	(0.086)
Number of members	**1.152*****	**1.266*****	**1.202*****	1.140	1.093	**1.262***	**1.272****	**1.078****
from 18 to 24	(0.049)	(0.060)	(0.078)	(0.107)	(0.112)	(0.152)	(0.151)	(0.037)
Number of members	**0.731*****	**0.696*****	**0.746*****	**0.592*****	**0.500*****	**0.738*****	**0.645*****	**0.768*****
from 25 to 64	(0.036)	(0.039)	(0.052)	(0.048)	(0.052)	(0.081)	(0.084)	(0.031)
Number of members	**0.874****	0.947	1.004	1.057	**0.792***	1.103	**0.759***	**0.902****
older 64	(0.051)	(0.059)	(0.082)	(0.107)	(0.102)	(0.147)	(0.122)	(0.042)
Head in non-agric.	1.127	0.869	**2.478*****	**0.349****	0.833	0.608	1.681	1.115
self-empl.	(0.195)	(0.195)	(0.595)	(0.180)	(0.377)	(0.423)	(0.691)	(0.169)
Head in agric.	0.913	1.162	1.037	**0.656****	**0.688***	1.064	**0.369*****	**1.647*****
self-empl.	(0.090)	(0.130)	(0.162)	(0.123)	(0.148)	(0.297)	(0.099)	(0.134)
Constant	**0.000*****	**0.000*****	**0.000*****	**0.000*****	**0.000*****	**0.000*****	**0.000*****	**0.000*****
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Observations: 15,635; Pseudo $R^2 = 0.327$.
(Source: own elaboration)

Appendix C4. Real and simulated occupational choices of rural population

	Observed occupational choices 2004									
Simulated occupational choices 2012	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
0	3,098,109	1,351	4,517	5,235	4,124	1,893	0	1,461	76,815	**3,193,505**
1	32,845	255,348	8,924	11,362	9,996	12,175	2,994	2,540	63,475	**399,659**
2	14,529	1,039	250,387	7,040	2,477	5,393	844	696	55,326	**337,731**
3	7,751	189	608	284,249	4,372	4,186	354	272	20,845	**322,826**
4	2,521	728	1,574	3,780	473,269	5,979	774	1,408	10,369	**500,402**
5	2,602	2,187	2,039	6,069	8,508	577,397	1,673	2,877	14,164	**617,516**
6	2,475	665	3,541	4,397	14,794	12,111	151,743	2,763	7,287	**199,776**
7	3,522	2,829	3,091	4,007	8,400	8,589	670	147,516	11,833	**190,457**
8	28,651	1,355	617	6,680	4,345	6,273	913	1,755	1,485,489	**1,536,078**
Total	**3,193,005**	**265,691**	**275,298**	**332,819**	**530,285**	**633,996**	**159,965**	**161,288**	**1,745,603**	**7,297,950**

Note:Simulated occupational choices reflect the occupational structure of year 2012 derived by the multinominal logit model. 0 = Inactive or unemployed; 1 = Non-agricultural wage-employed; 2 = Agricultural wage-employed; 3 = Non-agricultural self-employed; 4 = Maize farmer; 5 = Potato farmer 6 = Coffee farmer; 7 = “Other” farmer; 8 = Non-remunerated family worker.
(Source: own elaboration)

Appendix C5. Decomposition results aggregated over all occupations

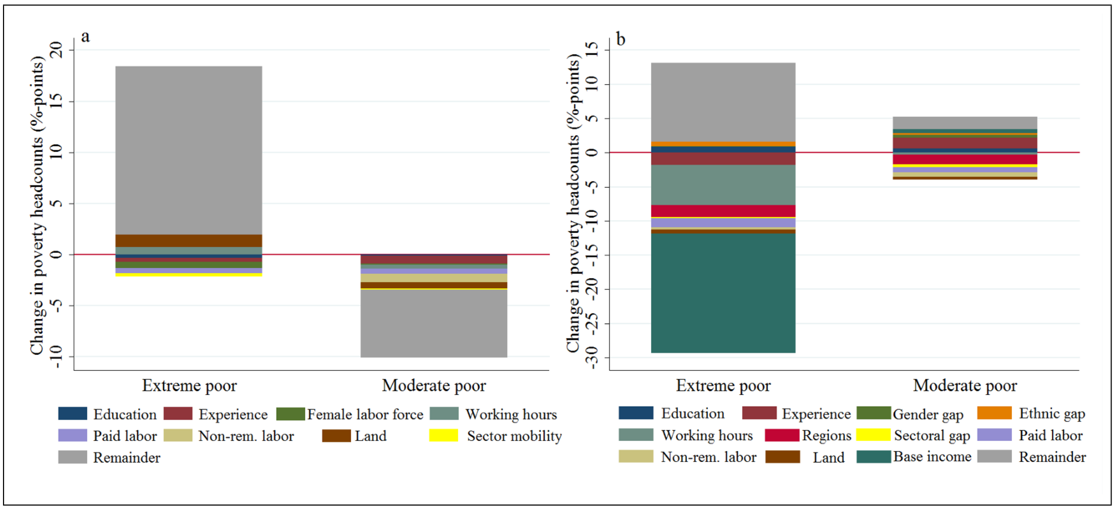


Figure C5.1: a) Decomposing the endowment effect into its components (%-points); b) Decomposing the price effect into its components (%-points)
Note: The components are aggregated over all occupations.
(Source: own elaboration)

Table C5.1: Aggregate decomposition results of changes in poverty and inequality indices (in%-points)

	Extreme poverty			**Moderate poverty**			**Income inequality**			
	P(0)	**P(1)**	**P(2)**	**P(0)**	**P(1)**	**P(2)**	**GINI**	**E(0)**	**E(1)**	**E(2)**
2004 observed	44.7	13.2	5.4	42.0	27.6	17.4	38.8	25.3	29.0	52.0
2012 observed	20.9	4.8	1.7	34.6	13.4	6.3	40.2	27.3	29.2	46.3
Δ 2004-2012	-23.8	-8.4	-3.8	-7.4	-14.2	-11.1	+1.3	+2.0	+0.2	-5.7
Total occupational choice effect	-3.8	-1.0	-0.3	-0.5	-1.8	-1.2	-1.1	-1.6	-3.4	-17.2
Non-labor income effect	-15.5	-6.2	-3.2	+3.3	-4.0	-4.0	-2.8	-4.8	-4.5	-9.6
Total endowment effect	+19.0	+7.2	+3.5	-9.7	-0.6	+0.8	+1.0	+1.2	+0.3	-3.8
Education	-0.3	-0.1	n.e.	-0.1	-0.1	-0.1	+0.3	+0.4	+0.5	+0.8
Experience	-0.5	+0.4	+0.5	-0.7	-0.8	-0.3	+0.4	+0.5	+2.0	+43.0
Female labor force participation	-0.6	-0.2	-0.1	-0.1	-0.2	-0.2	+0.1	+0.2	+0.2	+0.1
Working hours	+0.6	+0.8	+0.7	-0.2	-0.4	n.e.	-0.2	-0.4	-0.1	+5.2
Paid labor	-0.2	+0.6	+0.6	-0.9	-0.7	-0.2	-0.7	-1.2	-2.8	-22.1
Non-remunerated labor	-0.2	+0.6	+0.6	-0.5	-0.7	-0.2	n.e.	+0.1	+1.4	+42.1
Land	+1.1	+1.1	+0.8	-0.8	-0.3	+0.1	+0.3	+0.3	+1.1	+15.4
Sector mobility	-0.3	-0.1	n.e.	n.e.	-0.1	-0.1	+0.1	+0.1	+0.1	-0.2
Remainder	+19.4	+4.1	+0.4	-6.4	+2.8	+1.9	+0.7	+1.1	-2.0	-88.2
Total price effect	-24.1	-8.0	-3.3	-0.7	-8.5	-6.9	+2.7	+5.0	+5.3	+50.0
Education	+0.5	+0.2	+0.1	+0.8	+0.3	+0.2	-0.3	-0.4	+0.6	+21.9
Experience	-1.7	-0.7	-0.3	+1.8	-0.1	-0.4	-0.9	-1.3	-1.0	+2.2
Female income gap	+0.1	n.e.	n.e.	+0.2	-0.1	n.e.	-0.2	-0.3	-0.5	-1.8
Ethnic income gap	+0.9	+0.2	+0.1	-0.2	+0.1	+0.1	+0.3	+0.5	+1.7	+37.1
Working hours	-5.9	-2.1	-0.9	-0.4	-2.2	-1.8	+1.8	+2.5	+3.6	+23.5
Regional income gap	-2.1	-0.3	n.e.	-1.1	-1.2	-0.6	+1.0	+1.5	+1.8	+35.4
Sectoral income gap	-0.4	n.e.	n.e.	n.e.	-0.2	-0.1	-0.6	-0.7	-1.2	-3.2
Paid labor	-1.3	+0.1	+0.4	-0.7	-0.9	-0.5	+0.3	+0.5	+0.7	+2.9
Non-remunerated labor	-0.2	+0.6	+0.6	-0.8	-0.7	-0.2	n.e.	-0.1	-0.4	-2.6
Land	-0.5	+0.5	+0.6	-0.7	-0.8	-0.3	+0.1	+0.1	n.e.	-1.4
Baseline income	-18.1	-5.8	-2.2	+0.7	-6.2	-5.2	+1.3	+2.6	+1.6	+1.7
Remainder	+4.7	-0.8	-1.7	-0.3	+3.5	+2.1	-0.2	+0.1	-1.7	-65.7
Total unobserved effect	-0.4	+0.6	+0.6	-1.3	-1.0	-0.4	+0.8	+1.2	+1.8	+10.4
Total Remainder	+1.0	-1.1	-1.2	+1.5	+1.8	+0.7	+0.7	+1.1	+0.7	-35.4

Note: n.e. = no effect. The table reports the observed three Foster-Greer-Thorbecke poverty measures ($P(\alpha)$, $\alpha = 0, 1, 2$), computed with respect to region-specific poverty extreme and moderate poverty lines), and four inequality indices (the GINI coefficient, the Theil-L index $E(0)$, the Theil-T index $E(1)$ and $E(2)$) in 2004 and 2012. All indices can take on values between 0% and 100%. Higher values indicate higher poverty incidences or higher income inequality, respectively. Each effect shows the proportionate contribution to observed total changes in poverty or inequality (given in Δ 2004-2012). Thus, the decomposition results (contribution of each effect) is given in %-points, which means that the sum of all effects amount to the observed total changes of each index between 2004 and 2012.
(Source: own elaboration)

Appendix C6. Decomposition of the occupational choice effect (in %-points)

	Extreme poverty			Moderate poverty			Income inequality			
	P(0)	**P(1)**	**P(2)**	**P(0)**	**P(1)**	**P(2)**	**GINI**	**E(0)**	**E(1)**	**E(2)**
Shifts including movement out of non-remunerated work										
Move to non-agricultural wage-employment	-1.2	-0.4	-0.2	-0.2	-0.6	-0.5	-0.2	-0.2	-0.5	-1.8
Move to agricultural wage-employment	-0.5	-0.3	-0.1	+0.1	-0.1	-0.2	-0.1	-0.1	-0.2	-0.5
Move to non-agricultural self-employment	-0.1	-0.1	n.e.	n.e.	n.e.	-0.1	-0.9	-1.3	-3.5	-32.5
Move to maize farming	-0.1	-0.1	n.e.	+0.1	n.e.	n.e.	n.e.	n.e.	n.e.	-0.3
Move to potato farming	-0.3	-0.1	-0.1	+0.2	n.e.	-0.1	-0.6	-0.9	-2.0	-11.5
Move to coffee farming	-0.2	-0.1	-0.1	n.e.	-0.1	-0.1	-0.1	-0.1	-0.1	-0.4
Move to “other” farming	-0.2	-0.1	n.e.	+0.1	-0.1	-0.1	-0.2	-0.2	-0.5	-2.6
Move out off non-remunerated work	-1.4	-0.6	-0.3	+0.4	-0.4	-0.5	-0.1	-0.1	-0.3	-1.2
Shifts excluding movement out of non-remunerated work										
Move to non-agricultural wage-employment	-0.6	-0.2	-0.1	n.e.	-0.3	-0.2	-0.1	-0.1	-0.3	-0.9
Move to agricultural wage-employment	-0.1	-0.1	n.e.	-0.1	-0.1	-0.1	n.e.	n.e.	n.e.	-0.1
Move to non-agricultural self-employment	-0.1	-0.1	n.e.	+0.1	n.e.	n.e.	-0.6	-0.9	-2.2	-17.1
Move to maize farming	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	-0.1	-0.1	-0.6
Move to potato farming	-0.2	-0.1	n.e.	+0.1	n.e.	n.e.	-0.3	-0.4	-0.8	-3.3
Move to coffee farming	-0.2	-0.1	n.e.	n.e.	-0.1	-0.1	n.e.	n.e.	-0.1	-0.3
Move to “other” farming	-0.1	n.e.	n.e.	-0.1	-0.1	n.e.	-0.1	-0.1	-0.2	-0.5
Shifts away from agricultural self-employment										
Move to non-agricultural wage-employment	-0.2	-0.1	n.e.	+0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.3
Move to agricultural wage-employment	n.e.	n.e.	n.e.	+0.1	n.e.	n.e.	n.e.	-0.1	-0.1	-0.2
Move to non-agricultural self-employment	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.

Note: n.e. = no effect. The table reports changes in the three Foster-Greer-Thorbecke poverty measures ($P(\alpha)$, $\alpha = 0, 1, 2$), computed with respect to region-specific poverty extreme and moderate poverty lines), and four inequality indices (the GINI coefficient, the Theil-L index $E(0)$, the Theil-T index $E(1)$ and $E(2)$) due to occupational shifts in the rural labor force. The changes, in %-points, measure the proportionate contribution of each effect to the total observed changes of poverty and income inequality between 2004 and 2012. Observed changes in poverty and income inequality between 2004 and 2012 are given in the upper rows of table C5.1.
(Source: own elaboration)

Appendix C7. Decomposing the price and endowment effect in different sectors

Table C7.1: Decomposition of the price effect in different sectors (in %-points)

	Extreme poverty			Moderate poverty			Income inequality			
	P(0)	**P(1)**	**P(2)**	**P(0)**	**P(1)**	**P(2)**	**GINI**	**E(0)**	**E(1)**	**E(2)**
Decomposition of price effect in non-agricultural wage-employment										
Total price effect	-2.5	-0.3	+0.2	-2.7	-1.9	-1.0	+2.2	+3.2	+3.0	+5.0
Education	+0.4	+0.1	n.e.	+0.6	+0.3	+0.2	-0.8	-1.1	-1.1	-1.1
Experience	+0.5	+0.1	+0.1	+0.4	+0.3	+0.2	-0.8	-1.1	-1.0	-0.8
Female income gap	-0.1	n.e.	n.e.	+0.3	n.e.	n.e.	-0.3	-0.3	-0.3	n.e.
Ethnic income gap	n.e.	n.e.	n.e.	+0.2	n.e.	n.e.	-0.2	-0.2	-0.1	+0.7
Working hours	-0.9	-0.3	-0.1	-1.3	-0.7	-0.4	+1.0	+1.3	+1.3	+2.2
Regional income gap	-1.6	-0.5	-0.2	-1.1	-0.8	-0.5	+0.5	+0.8	+0.5	+0.3
Sectoral income gap	-0.1	-0.1	n.e.	n.e.	-0.1	n.e.	-0.4	-0.5	-0.6	-0.6
Baseline income	-2.2	-0.7	-0.3	-1.9	-1.3	-0.8	+1.9	+2.6	+2.6	+4.0
Remainder	+1.5	+1.0	+0.6	+0.2	+0.3	+0.4	+1.2	+1.8	+1.7	+0.4
Decomposition of price effect in agricultural wage-employment										
Total price effect	-2.3	-0.2	+0.2	-0.6	-1.4	-0.8	+0.5	+0.8	+0.4	-0.3
Education	-0.1	n.e.	n.e.	-0.1	-0.1	n.e.	n.e.	n.e.	n.e.	-0.2
Experience	+0.5	+0.1	+0.1	+0.2	+0.2	+0.1	-0.1	-0.2	-0.2	-0.3
Female income gap	+0.2	n.e.	n.e.	-0.1	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Ethnic income gap	+0.2	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Working hours	-1.0	-0.3	-0.1	-0.1	-0.4	-0.3	+0.2	+0.2	n.e.	-0.7
Regional income gap	-0.3	-0.1	n.e.	-0.1	-0.2	-0.1	+0.1	+0.1	n.e.	-0.3
Baseline income	-0.8	-0.2	-0.1	-0.1	-0.4	-0.3	+0.1	+0.1	-0.1	-0.8
Remainder	-0.9	+0.2	+0.3	-0.4	-0.5	-0.3	+0.3	+0.6	+0.7	+1.9
Decomposition of price effect in non-agricultural self-employment										
Total price effect	-1.8	n.e.	+0.3	-1.2	-1.3	-0.7	+1.1	+1.5	+2.1	+7.7
Education	-0.2	n.e.	n.e.	-0.4	-0.2	-0.1	n.e.	n.e.	n.e.	-0.4
Experience	+0.4	+0.2	+0.1	-0.3	n.e.	+0.1	-0.3	-0.5	-0.9	-6.0
Female income gap	+0.3	+0.1	+0.1	-0.5	n.e.	n.e.	-0.2	-0.3	-0.5	-1.7
Ethnic income gap	+0.1	+0.1	+0.1	-0.6	-0.1	n.e.	n.e.	n.e.	-0.1	-0.3
Working hours	-0.2	n.e.	n.e.	-0.6	-0.2	-0.1	+0.1	+0.1	n.e.	-0.4
Regional income gap	-0.5	n.e.	n.e.	-0.5	-0.3	-0.1	+0.1	+0.2	n.e.	-0.2
Sectoral income gap	n.e.	n.e.	+0.1	-0.4	-0.2	-0.1	-0.1	-0.1	-0.3	-1.5
Paid labor	-0.3	n.e.	n.e.	-0.5	-0.2	-0.1	+0.1	+0.1	n.e.	-0.1
Non-remunerated labor	+0.1	n.e.	n.e.	-0.4	-0.1	n.e.	-0.1	-0.2	-0.4	-1.5
Baseline income	-0.9	-0.2	-0.1	-0.6	-0.5	-0.3	+0.4	+0.5	+0.4	+0.4
Remainder	-0.6	-0.2	n.e.	+3.6	+0.6	-0.1	+1.2	+1.8	+3.8	+19.5

Note: n.e. = no effect. The table reports changes in the three Foster-Greer-Thorbecke poverty measures ($P(\alpha)$, $\alpha = 0, 1, 2$), computed with respect to region-specific poverty extreme and moderate poverty lines), and four inequality indices (the GINI coefficient, the Theil-L index $E(0)$, the Theil-T index $E(1)$ and $E(2)$) due to different price effects in different rural sectors. The changes, in %-points, measure the proportionate contribution of each effect to the total observed changes of poverty and income inequality between 2004 and 2012. Observed changes in poverty and income inequality between 2004 and 2012 are given in the upper rows of table C5.1.
(Source: own elaboration)

Table C7.2: Decomposition of the endowment effect in different sectors (in %-points)

	Extreme poverty			Moderate poverty			Income inequality			
	P(0)	**P(1)**	**P(2)**	**P(0)**	**P(1)**	**P(2)**	**GINI**	**E(0)**	**E(1)**	**E(2)**
Decomposition of endowment effect in non-agricultural wage-employment										
Education	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	+0.1	+0.1	+0.1	+0.1
Experience	-0.2	-0.1	n.e.	+0.3	n.e.	n.e.	-0.2	-0.2	-0.2	+0.1
Female labor force participation	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	-0.1	-0.1
Working hours	+0.2	n.e.	n.e.	+0.3	+0.1	n.e.	-0.4	-0.6	-0.5	+0.1
Sector mobility	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	-0.2	-0.3	-0.4	-0.9
Decomposition of endowment effect in agricultural wage-employment										
Education	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Experience	+0.2	n.e.	n.e.	-0.1	n.e.	n.e.	n.e.	n.e.	-0.1	-0.1
Female labor force participation	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Working hours	+0.3	+0.1	n.e.	-0.1	+0.1	+0.1	n.e.	-0.1	n.e.	+0.3
Decomposition of endowment effect in non-agricultural self-employment										
Education	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	+0.1	+0.2
Experience	+0.1	+0.1	+0.1	-0.4	-0.1	n.e.	-0.1	-0.1	-0.3	-1.0
Female labor force participation	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Working hours	n.e.	+0.1	+0.1	-0.3	-0.1	n.e.	-0.1	-0.1	-0.3	-0.8
Paid labor	n.e.	+0.1	+0.1	-0.2	-0.1	n.e.	-0.5	-0.7	-1.7	-9.3
Non-remunerated labor	+0.2	+0.1	+0.1	-0.5	-0.1	n.e.	-0.1	-0.1	-0.2	-0.9
Sector mobility	-0.1	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	-0.1

Note: n.e. = no effect. The table reports changes in the three Foster-Greer-Thorbecke poverty measures ($P(\alpha)$, $\alpha = 0, 1, 2$), computed with respect to region-specific poverty extreme and moderate poverty lines), and four inequality indices (the GINI coefficient, the Theil-L index $E(0)$, the Theil-T index $E(1)$ and $E(2)$) due to different endowment effects of the rural population in different rural sectors. Total endowment effects separate for the non-agricultural wage-sector is not reported, because it cannot be simulated due to missing information of other household members with other occupations in the simulated year. The changes, in %-points, measure the proportionate contribution of each effect to the total observed changes of poverty and income inequality between 2004 and 2012. Observed changes in poverty and income inequality between 2004 and 2012 are given in the upper rows of table C5.1.
(Source: own elaboration)

Appendix C8. Decomposition of the occupational choice effect within agricultural self-employment (in %-points)

	Extreme poverty			Moderate poverty			Income inequality			
	P(0)	**P(1)**	**P(2)**	**P(0)**	**P(1)**	**P(2)**	**GINI**	**E(0)**	**E(1)**	**E(2)**
Move to maize farming	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Move to potato farming	-0.1	-0.1	n.e.	+0.1	n.e.	n.e.	n.e.	n.e.	n.e.	-0.1
Move to coffee farming	-0.1	-0.1	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	-0.2
Move to “other” farming	-0.1	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	-0.1

Note: n.e. = no effect. The table reports changes in the three Foster-Greer-Thorbecke poverty measures ($P(\alpha)$, $\alpha = 0, 1, 2$), computed with respect to region-specific poverty extreme and moderate poverty lines), and four inequality indices (the GINI coefficient, the Theil-L index $E(0)$, the Theil-T index $E(1)$ and $E(2)$) due to occupational shifts within agricultural self-employment. Occupational shifts can be interpreted as production shifts in this case. The changes, in %-points, measure the proportionate contribution of each effect to the total observed changes of poverty and income inequality between 2004 and 2012. Observed changes in poverty and income inequality between 2004 and 2012 are given in the upper rows of table C5.1. (Source: own elaboration)

Appendix C9. Decomposing the price and endowment effects within agricultural self-employment

Table C9.1: Decomposition of the price effect in agricultural self-employment (in %-points)

	Extreme poverty			**Moderate poverty**			**Income inequality**			
	P(0)	**P(1)**	**P(2)**	**P(0)**	**P(1)**	**P(2)**	**GINI**	**E(0)**	**E(1)**	**E(2)**
Decomposition of price effect in maize farming										
Total price effect	-5.4	-1.8	-0.7	+0.2	-1.8	-1.6	n.e.	n.e.	n.e.	+0.8
Education	+0.7	+0.4	+0.3	-0.7	-0.1	+0.1	+0.1	+0.1	+0.2	+6.9
Experience	n.e.	+0.1	+0.1	-0.4	-0.2	-0.1	+0.2	+0.3	+1.0	+36.5
Female income gap	+0.1	+0.2	+0.2	-0.4	-0.2	n.e.	+0.3	+0.5	+1.9	+78.8
Ethnic income gap	+0.3	+0.2	+0.2	-0.6	-0.2	n.e.	+0.5	+0.8	+3.3	+47.9
Working hours	-1.2	-0.4	-0.1	-0.2	-0.5	-0.4	+0.6	+1.0	+4.0	+235.7
Regional income gap	+0.1	+0.2	+0.2	-0.4	-0.2	n.e.	+0.6	+1.1	+5.9	+7.0
Paid labor	+0.1	+0.2	+0.2	-0.5	-0.2	-0.1	+0.4	+0.7	+2.7	+57.7
Non-remunerated labor	+0.4	+0.3	+0.2	-0.5	-0.1	n.e.	+0.3	+0.5	+1.6	+24.7
Land	n.e.	+0.1	+0.1	-0.4	-0.2	-0.1	+0.1	+0.2	+0.5	+3.9
Baseline income	-4.2	-1.5	-0.6	+0.2	-1.4	-1.3	+0.3	+0.4	+1.4	+14.5
Remainder	-1.7	-1.8	-1.6	+4.1	+1.5	+0.2	-3.5	-5.4	-22.5	-512.8
Decomposition of price effect in potato farming										
Total price effect	-6.8	-2.0	-0.6	+1.0	-2.3	-2.0	-0.1	+0.2	-0.2	-0.8
Education	+0.4	+0.4	+0.4	-0.2	-0.1	n.e.	+0.3	+0.4	+0.3	+0.7
Experience	-1.2	-0.2	+0.1	+0.4	-0.4	-0.4	n.e.	n.e.	n.e.	+0.2
Female income gap	+0.1	+0.4	+0.4	-0.2	-0.2	-0.1	+0.2	+0.3	+0.3	+0.8
Ethnic income gap	+0.7	+0.5	+0.4	-0.3	-0.1	n.e.	+0.3	+0.5	+0.5	+1.2
Working hours	-1.5	-0.3	+0.1	+0.3	-0.6	-0.5	n.e.	+0.1	n.e.	+0.1
Regional income gap	+1.2	+0.7	+0.5	-0.5	n.e.	+0.2	+0.4	+0.6	+0.4	-0.7
Paid labor	-0.7	n.e.	+0.2	+0.3	-0.3	-0.3	+0.1	+0.1	+0.1	+0.6
Non-remunerated labor	-0.2	+0.2	+0.3	n.e.	-0.3	-0.2	+0.2	+0.3	+0.3	+0.7
Land	n.e.	+0.3	+0.4	n.e.	-0.2	-0.1	+0.2	+0.3	+0.3	+0.7
Baseline income	-7.2	-2.4	-0.9	+1.7	-2.0	-1.9	-0.6	-0.7	-1.0	-2.0
Remainder	+1.7	-1.6	-2.3	-0.5	+1.9	+1.3	-1.1	-1.7	-1.5	-3.2

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Table C9.2: continued

	Extreme poverty			Moderate poverty			Income inequality			
	P(0)	**P(1)**	**P(2)**	**P(0)**	**P(1)**	**P(2)**	**GINI**	**E(0)**	**E(1)**	**E(2)**
Decomposition of price effect in coffee farming										
Total price effect	-1.1	n.e.	+0.2	-1.5	-1.1	-0.5	+0.8	+1.2	+1.0	+1.0
Education	-0.1	n.e.	n.e.	+0.2	-0.1	n.e.	n.e.	-0.1	n.e.	+0.1
Experience	-0.6	-0.2	-0.1	+0.3	-0.2	-0.2	n.e.	n.e.	n.e.	-0.2
Female income gap	-0.2	n.e.	n.e.	+0.1	-0.1	n.e.	n.e.	-0.1	-0.1	-0.1
Ethnic income gap	n.e.	n.e.	n.e.	+0.1	n.e.	n.e.	n.e.	-0.1	n.e.	+0.1
Working hours	-0.1	n.e.	n.e.	+0.3	n.e.	n.e.	-0.1	-0.1	-0.1	-0.2
Regional income gap	-0.6	-0.1	n.e.	+0.3	-0.2	-0.2	n.e.	n.e.	n.e.	n.e.
Paid labor	-0.2	n.e.	n.e.	+0.2	-0.1	n.e.	n.e.	n.e.	n.e.	+0.2
Non-remunerated labor	-0.2	n.e.	n.e.	+0.3	n.e.	n.e.	n.e.	-0.1	-0.1	-0.2
Land	-0.5	-0.1	n.e.	+0.3	-0.2	-0.2	+0.1	+0.1	+0.2	+0.3
Baseline income	-1.2	-0.3	-0.1	+0.1	-0.5	-0.4	+0.1	+0.1	+0.1	+0.3
Remainder	+2.5	+0.9	+0.5	-3.6	+0.3	+0.5	+0.6	+1.5	+0.9	+0.7
Decomposition of price effect in "other" farming										
Total price effect	-0.1	+0.2	+0.2	-1.1	-0.5	-0.2	+0.8	+1.1	+1.3	+3.2
Education	+0.2	+0.1	n.e.	-0.3	n.e.	n.e.	n.e.	-0.1	-0.2	-1.5
Experience	-0.7	-0.3	-0.1	-0.3	-0.3	-0.2	+0.3	+0.4	+0.5	+1.0
Female income gap	+0.2	+0.1	n.e.	-0.2	n.e.	n.e.	n.e.	n.e.	-0.1	-1.2
Ethnic income gap	+0.2	+0.1	n.e.	-0.2	n.e.	n.e.	n.e.	n.e.	n.e.	-0.1
Working hours	-0.5	-0.2	-0.1	-0.2	-0.2	-0.2	+0.3	+0.4	+0.4	+0.5
Regional income gap	+0.1	+0.1	n.e.	n.e.	n.e.	n.e.	-0.2	-0.3	-0.6	-3.2
Paid labor	+0.1	+0.1	n.e.	-0.2	n.e.	n.e.	n.e.	n.e.	-0.1	-0.8
Non-remunerated labor	+0.2	+0.1	n.e.	-0.2	n.e.	n.e.	-0.1	-0.1	-0.3	-2.0
Land	+0.2	+0.1	n.e.	+0.1	n.e.	n.e.	-0.1	-0.2	-0.2	-1.1
Baseline income	+0.5	+0.2	+0.1	-0.1	+0.1	+0.1	-0.2	-0.2	-0.5	-2.6
Remainder	-0.6	n.e.	+0.1	+0.5	n.e.	n.e.	+0.8	+1.4	+2.4	+14.1

Note: n.e. = no effect. The table reports changes in the three Foster-Greer-Thorbecke poverty measures ($P(\alpha)$, $\alpha = 0, 1, 2$), computed with respect to region-specific poverty extreme and moderate poverty lines), and four inequality indices (the GINI coefficient, the Theil-L index $E(0)$, the Theil-T index $E(1)$ and $E(2)$) due to different price effects in different agricultural sectors. The changes, in %-points, measure the proportionate contribution of each effect to the total observed changes of poverty and income inequality between 2004 and 2012. Observed changes in poverty and income inequality between 2004 and 2012 are given in the upper rows of table C5.1. (Source: own elaboration)

Table C9.3: Decomposition of the endowment effect in agricultural self-employment

	Extreme poverty			Moderate poverty			Income inequality			
	P(0)	**P(1)**	**P(2)**	**P(0)**	**P(1)**	**P(2)**	**GINI**	**E(0)**	**E(1)**	**E(2)**
Decomposition of endowment effect in maize farming										
Education	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	+0.1	+0.1	+0.4
Experience	+0.2	+0.2	+0.2	-0.5	-0.1	n.e.	+0.2	+0.3	+1.1	+13.8
Female labor force participation	n.e.	n.e.	n.e.	-0.1	n.e.	n.e.	n.e.	+0.1	+0.1	+0.3
Working hours	+0.5	+0.3	+0.2	-0.6	-0.1	+0.1	+0.3	+0.4	+0.9	+8.3
Paid labor	+0.2	+0.2	+0.2	-0.4	-0.2	n.e.	-0.1	-0.2	-0.7	-8.3
Non-remunerated labor	+0.3	+0.2	+0.2	-0.6	-0.1	n.e.	+0.5	+0.7	+2.5	+50.2
Land	+0.6	+0.4	+0.3	-0.3	n.e.	+0.1	+0.4	+0.6	+2.2	+38.5
Decomposition of endowment effect in potato farming										
Education	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	+0.1
Experience	-0.1	+0.3	+0.3	-0.1	-0.3	-0.1	+0.2	+0.3	+0.3	+0.6
Female labor force participation	-0.1	n.e.	n.e.	+0.1	n.e.	n.e.	n.e.	n.e.	n.e.	+0.1
Working hours	n.e.	+0.3	+0.4	-0.1	-0.2	-0.1	+0.2	+0.3	+0.3	+0.6
Paid labor	n.e.	+0.3	+0.3	-0.2	-0.2	-0.1	+0.2	+0.4	+0.4	+1.0
Non-remunerated labor	-0.1	+0.2	+0.3	n.e.	-0.2	-0.1	+0.2	+0.3	+0.3	+0.7
Land	+0.5	+0.5	+0.4	-0.2	-0.1	n.e.	+0.3	+0.5	+0.5	+0.9
Decomposition of endowment effect in coffee farming										
Education	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	+0.1
Experience	-0.2	-0.1	n.e.	+0.2	-0.1	-0.1	n.e.	-0.1	n.e.	+0.2
Female labor force participation	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Working hours	-0.2	n.e.	n.e.	+0.2	n.e.	n.e.	n.e.	-0.1	n.e.	+0.1
Paid labor	-0.1	n.e.	n.e.	+0.1	n.e.	n.e.	n.e.	-0.1	n.e.	+0.3
Non-remunerated labor	-0.1	n.e.	n.e.	+0.1	n.e.	n.e.	n.e.	n.e.	n.e.	+0.2
Land	n.e.	+0.1	n.e.	+0.3	n.e.	n.e.	n.e.	n.e.	n.e.	+0.1
Decomposition of endowment effect in "other" farming										
Education	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	-0.1	-0.4
Experience	+0.1	n.e.	n.e.	-0.1	n.e.	n.e.	-0.1	-0.2	-0.3	-2.0
Female labor force participation	n.e.	n.e.	n.e.	-0.1	n.e.	n.e.	n.e.	n.e.	-0.1	-0.2
Working hours	+0.3	+0.1	+0.1	-0.1	n.e.	n.e.	-0.1	-0.2	-0.3	-1.8
Paid labor	+0.1	n.e.	n.e.	-0.1	n.e.	n.e.	-0.1	-0.2	-0.6	-4.5
Non-remunerated labor	+0.2	+0.1	n.e.	-0.1	n.e.	n.e.	-0.1	-0.1	-0.3	-2.0
Land	+0.2	+0.1	n.e.	-0.1	n.e.	n.e.	-0.1	-0.1	-0.3	-1.7

Note: n.e. = no effect. The table reports changes in the three Foster-Greer-Thorbecke poverty measures ($P(\alpha)$, $\alpha = 0, 1, 2$), computed with respect to region-specific poverty extreme and moderate poverty lines), and four inequality indices (the GINI coefficient, the Theil-L index $E(0)$, the Theil-T index $E(1)$ and $E(2)$) due to different endowment effects of the farmers in different agricultural sectors. Total endowment effects separate for the non-agricultural wage-sector is not reported, because it cannot be simulated due to missing information of other household members with other occupations in the simulated year. The changes, in %-points, measure the proportionate contribution of each effect to the total observed changes of poverty and income inequality between 2004 and 2012. Observed changes in poverty and income inequality between 2004 and 2012 are given in the upper rows of table C5.1.
(Source: own elaboration)