Global Food Security 25 (2020) 100328

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Labor supply assumptions - A missing link in food security projections

Marijke Kuiper*, Lindsay Shutes, Hans van Meijl, Diti Oudendag, Andrzej Tabeau

Wageningen Economic Research, Prinses Beatrixlaan 582 – 528, 2595 BM, The Hague, Netherlands

ARTICLE INFO

Keywords:
Food security
Inequality
Projections
Labor supply
Urbanization
Skill rate

ABSTRACT

Improved skills and rural-urban location of labor are generally implicit or ignored in food security projections. We analyze alternative labor supply assumptions for four contrasting scenarios. Changing skill levels and urbanization reverses a decrease in food prices and improves instead of worsens within country income inequality. It however slows the decrease in number of people with less than 2500 calories a day available, and increases the environmental impact of agriculture. With urbanization, observed net income benefits of higher food prices for the poor may no longer hold in the future. Explicitly addressing demographic change is thus key in projections guiding policymakers to address the unequal impacts of food security, combat climate change and promote sustainable food production.

1. Introduction

Agricultural product prices dominate food policy debates (Swinnen, 2010), with high prices triggering concerns about the world's ability to feed a growing population (Godfray and Robinson, 2015; Obersteiner et al., 2016). An expected net negative impact of climate change on global food production further fuels Malthusian concerns for future food security (Wheeler and von Braun, 2013). Given that at global level enough food can be produced for all (Alexandratos and Bruinsma, 2012), a key challenge is assessing the future ability of households to access food. There are four reasons why food security projections need to look beyond agricultural product prices. *First*, price changes convey insufficient information to assess future food security, since a price change either way involves winners and losers. Agricultural price increases benefit households earning an income from agriculture (farmers or laborers) while harming net-food consumers (rural or urban), with the size of the impact depending on a range of factors affecting price transmissions (Swinnen, 2010). Combined price and income effects need to be accounted for to determine changes in food security (Hertel, 2016), a well-known fact in both theory and empirical literature that tends to get lost in food policy debates (Swinnen, 2010). *Second*, unprecedented urbanization (United Nations, 2017) quickly increases the number of urban households with limited, if any, agricultural income. This alters the balance between winners and losers of rising prices and may provide a rationale to target future policies toward lowering agricultural prices, even though currently the majority of the poor benefit from higher agricultural prices (Headey and Martin, 2016). *Third*, agricultural factor supply is a key unknown in current agricultural price projections (Hertel et al., 2016). Changes in land availability and quality are analyzed at length when assessing the expected impacts of climate change (see for example Nelson et al., 2014). Changes in the composition of the labor supply, however, are not explicitly addressed beyond projections of population size and accounting for segmented rural and urban labor markets in economy-wide models. Urbanization and changing skill rates not only affect demand patterns and who wins or loses from changing agricultural prices, but also the availability of agricultural labor and thus agricultural production itself. And *fourth*, investing in agricultural yield improvements, inspired by the success of the Green Revolution, needs to be weighed against investments upstream in the value chain. Food and agriculture are often seen as the same, but food is rapidly changing into a product of manufacturing and services sectors. An industrialized food system with a fraction of food expenditures flowing to primary producers, emerged in high income regions and is spreading around the world (Adam and Gollin 2015). The search for the most efficient use of limited policy resources to benefit food security should account for this changing character of the food system.

Reviewing several leading projections of global future food security, we find none addressing all four points (Hasegawa et al. 2018; von Lampe et al., 2014; van Meijl et al., 2018a,b; Hasegawa et al. 2015). In particular, the role of labor supply and related income generation opportunities for households in rural and urban areas, is absent from existing global assessments. Existing food security projections may thus be improved upon by explicitly addressing changes in labor supply and including different household types across the rural-urban gradient. The main objective of this paper is therefore to explore how contrasting

* Corresponding author.
E-mail address: marijke.kuiper@wur.nl (M. Kuiper).

https://doi.org/10.1016/j.gfs.2019.100328
Received 9 October 2018; Received in revised form 17 February 2019; Accepted 17 October 2019

labor supply assumptions affect global food security assessments and inequality between and within regions. Its contribution lies in combining a global CGE model including representative households for several regions with a set of contrasting scenarios on drivers of inequality through skill development and urbanization. Using four contrasting FoodSecure worlds (van Dijk et al. 2019) as a backdrop highlights the sensitivity of agricultural price developments and broader food security assessments to alternative demographic assumptions.

We find the impact of urbanization and skill development on labor supply to be critical for both price and food security projections. Changing skill levels and urbanization reverses a decrease in food prices and improves instead of worsens within country income inequality. It however slows the decrease in number of people with less than 2500 calories a day available, and increases the environmental impact of agriculture. Demographic change, beyond population size projections, thus needs to be accounted for in studies used as guidance by policymakers addressing the unequal impacts of food security, combatting climate change and promoting sustainable food production. Future food security problems and policies require a look beyond the boundaries of agriculture, by researchers and policymakers alike.

2. Income effects, skill changes and urbanization in current food security projections

Increasingly interlinked economies combined with a need to look decades ahead both for changes in climate and investments in new technologies to materialize, has policymakers turning to ex-ante modeling tools for guidance on food security policies and investments. This call is met by models with varying detail on market feedback loops. Combining statistical extrapolation and expert judgement Alexandratos and Bruinsma (2012) plot plausible future developments given past trends and biophysical limitations, providing an important reference point for global food security studies. Their framework does not impose consistency: projections are modified when deemed inconsistent or infeasible by experts. Focusing on primary production, there is no explicit modeling of feedback effects through income changes, urbanization or factor supply and, while a separate chapter is devoted to analyzing trends in production factors (land, water, yields and fertilizers), changes in agricultural labor supply are not discussed.

More explicit treatment of feedbacks is needed for ex-ante policy analyses aimed at altering the business-as-usual trajectory. Partial equilibrium (PE) models of the agricultural sector capture adjustment mechanisms in a consistent framework. Influential examples are Aglink-Cosimo used for the Agricultural Outlook 2016–2025 (OECD/FAO 2016) and IMPACT featuring in the IFPRI food policy report (IFPRI, 2018). These global recursive-dynamic partial equilibrium models cover main agricultural markets accounting for production, consumption and net trade (OECD/FAO, 2015). While agricultural prices are a key result, incomes are taken as exogenous from GDP projections. GDP combined with population growth determines demand, not accounting for impacts of urbanization or structural change on labor supply. In fact, labor is not mentioned anywhere in the technical documentation of the Aglink-Cosimo model (OECD/FAO, 2015). Some processed foods are included (dairy products, vegetable oils and products, sugar and sweeteners), but seem driven more by agricultural policies affecting their production than an ambition to capture a change toward processed food. Capturing technological detail and the interaction of economic and biophysical processes is the key strength of these agricultural PE models.

The third set of models, global computable general equilibrium (CGE) models, sacrifices agricultural detail for an economy-wide perspective accounting for all real flows of products and production factors in the economy, capturing both price and income effects when addressing food security. By embedding agricultural production in the wider economy, food processing sectors are accounted for, as is the competition for labor between agricultural and non-agricultural sectors. Leading CGE models include the GTAP model (Corong et al., 2017) of which a variety of versions is developed to handle specific questions: ENVISAGE used at the World Bank for commodity price developments from an economy-wide perspective (van der Mensbrugghe et al., 2011); MIRAGE used by IFPRI to assess the costs of ending hunger (Laborde Debucquet et al., 2016); METRO developed at the OECD (OECD, 2016); and MAGNET (Woltjer et al., 2014) developed in a modular fashion to address agriculture, food security, and climate in an integrated manner (van Meijl et al., 2018a,b) and used for example by the European Commission (Philippidis et al., 2018). All starting from the GTAP database (Aguiar et al., 2016), these models share a more aggregate representation of processed food sectors limiting their scope to explore food security implications of investment strategies in the different types of processed food without further disaggregation. Drawing on the GTAP database, these models also share a single representative household representing all private consumption at the national level. To be able to look at sub-national differences in food security they either need to be complemented by a micro-simulation model, as done for agricultural households in Ivanic and Martin (2014) or in the GTAP-POV model (T. Hertel et al., 2015), or the representative household has to be disaggregated into multiple household types as done for MIRAGE (Bouet et al., 2013) and MAGNET (Kuiper and Shutes, 2014). In the absence of sub-national household detail, urbanization can only be implicitly addressed from the income side, for example through segmenting agricultural and non-agricultural factor markets to capture wage differentials. When projecting demographic growth these CGE models keep unskilled to skilled labor rates constant (see for example van der Mensbrugghe (2010, page 30 footnote 35) ignoring, as we will show, an important driver of food security.

None of these typical examples of statistical explorations, agricultural PE models and CGE models used for food security projections satisfactorily addresses all four reasons for looking beyond agricultural prices. GTAP-based CGE models capture both price and income effects (reason 1), while accounting for the interaction of agricultural production with the wider economy including food processing (reason 4). Using a single representative national household, however, they cannot address the impact of urbanization on the interplay of price and income effects to assess food security (reason 2). Furthermore, while the GTAP database includes two types of labor, their ratio is kept fixed in food security projections ignoring a potentially important driver of food security (reason 3). To address reason 2 we use MAGNET, extended to capture for five countries (Ghana, Uganda, India, China, Indonesia) at least rural-urban households. Embedding rural and urban household types in a CGE model allows a change in urbanization rate, while capturing feedback loops between households and the rest of the economy through different income sources and demand patterns. Compared to most CGE models MAGNET includes various specific characteristics of agriculture and food security issues, such as endogenous land markets (e.g. land conservation options), agriculture specific production trees, segmented agricultural and non-agricultural labor markets, and various detailed agricultural and bioeconomy (biofuels, bioenergy, biobased materials) sectors beyond the GTAP aggregation (van Meijl et al., 2018a,b, 2006). We address reason 3 through our scenario set-up, exploring the sensitivity of food security projections to changes in labor supply by skill and urbanization in four contrasting scenarios from the FoodSecure project (van Dijk et al. 2019) to assess the relevance of these additions to the common global food security assessments.

The FoodSecure scenarios translate rich stakeholder narratives into a limited set of drivers suitable for modeling. Table 1 summarizes drivers outlining four contrasting global development pathways: unequal but sustainable *One Percent World* (ONEPW), unequal and unsustainable *Too Little, Too Late* (TLTL), equal but unsustainable *Food For All but Not Forever* (FFANF) and finally equal and sustainable *Ecotopia* (ECO). Equality and sustainability are captured by contrasting assumptions on the extent of global convergence in income per capita (combined effect

Table 1
FoodSecure scenarios of contrasting global developments in inequality and sustainability.

		ONEPW	TLTL	FFANF	ECO
		One Percent World	Too Little Too Late	Food For All but Not Forever	Ecotopia
		Unequal		*Equal*	
		Sustainable	*Unsustainable*	*Unsustainable*	*Sustainable*
Economic	*Population*[a]	High in all regions	Low in HIC; medium in LIC, MIC & BRICS	High in HIC; low in LIC, MIC & BRICS	Low in all regions
	GDP[a]	Low in LIC; medium in other regions	Low in all regions	High with downwards structural change in mid 2040s	High in LIC, MIC; medium in HIC
	Trade tariffs and subsidies[b]	Full liberalization of agri-food trade	Doubling of tariffs with a minimum rate of 20%	Full liberalization of agri-food trade	Doubling of tariffs with a minimum rate of 20%
Agricultural production	*Crop productivity*[b]	Above historical trend with rapid increase in the 2030s	Below historical trend and levelling off	Decreasing below historical trend HIC & increasing above historical trend with downwards structural change in mid 2040s in LIC	Historical trend with downwards structural change after 2020s in all regions and upwards change after 2030s in LIC, MIC and BRICS
	Livestock productivity[b]	Low in LIC, medium or high in other regions	Efficiency stagnates at current regional levels	Convergence to 50% of the levels of the most efficient regions in a ‘middle of the road’ scenario	Convergence to 50% of the levels of the most efficient regions in a ‘middle of the road’ scenario
	Land use change regulation[a]	Protected areas are extended up to 2x Aichi target (34% of terrestrial area)	Protected areas at current level	Protected areas at current level	Protected areas are extended up to 2x Aichi target (34% of terrestrial area)
	Trends in meat consumption[a]	Endogenous dynamics	Endogenous dynamics	Endogenous dynamics	Consumption of animal products 30% lower than endogenous outcome in HIC and MIC
Common drivers	*Fossil fuel prices*[c]	IEA 6 Degrees Scenario: strong growth in oil, coal and gas prices albeit at a decreasing rate			
	Common Agricultural Policy[b]	Abolition of milk and sugar quotas and reduction of first pillar budget by 2% per year in all periods			
	Biofuel mandates[d]	Current policies are continued and biofuels shares kept constant after 2030			

[a] Authors' calculations based on IIASA (2015) and stakeholder provided trends.
[b] Authors' calculations from stakeholder provided trends (van Dijk et al. 2019).
[c] Authors' calculations based on IEA (2015).
[d] Authors' calculations based on Lane (2015).

of population and GDP assumptions affect the global income distribution and pressure to produce enough plant- and animal-based food) and convergence in agricultural productivity by crop and livestock sector (affecting relative price and income changes as well as the pressure on natural resources). Sustainability is further addressed by differences in regulation of the expansion of agricultural land and a change in diet away from animal products in the ECO scenario in high and middle income countries (also addressing the equality dimension by allowing low income countries to increase their animal product consumption). Finally, trade policy warrants attention with an identical assumption of increased trade barriers for agri-food for different reasons in TLTL (fragmentation of the global economy) and ECO (focus on local production motivated by sustainability concerns).

With the FoodSecure scenarios analyzed elsewhere (van Meijl et al. Under review) we focus on exploring the sensitivity of projections by making two changes in the scenario set-up: (1) for all countries we increase the skilled to unskilled labor ratio linked to overall GDP growth based on data from Lutz et al. (2014); (2) we proportionally change the rural-urban household sizes for the five countries with household detail (Ghana, Uganda, India, China, Indonesia) using the Shared Socio-Economic Pathways (SSP) database (IIASA, 2015). The resulting alternative scenarios will be referred to as the demographic (-D) variant of the FoodSecure scenarios. Table 2 summarizes total change in key drivers from 2010 to 2050, implemented in four simulation periods to capture changes in growth rates over time as highlighted in the narratives (Table 1). All variants of the unequal scenarios (ONEPW(-D), TLTL(-D)) have high population growth concentrated in the low income regions. In the equal scenarios (FFANF(-D), ECO(-D)) population growth is far outpaced by GDP growth to reach a convergence of global incomes. The demographic scenarios have additional assumptions on skill development. The demographic versions of the equal scenarios (FFANF-D, ECO-D) have a strong drop in unskilled labor projecting a smaller and better educated world population with higher incomes. Given the fixed skill rates currently used in projections, it is worth noting that the stalled development scenario from Lutz et al. (2014) used for the unequal scenarios (ONEPW-D, TLTL-D) still entails a 3–16% drop in unskilled labor share.

3. Alternative demographic drivers – global food security results

To place our food security projections in context, we compare global average per capita calorie availability to FAO projections (Alexandratos and Bruinsma, 2012). By 2050, differences by FoodSecure scenario are in line with the story lines: FFANF, closest to a business-as-usual scenario is spot-on, while ECO ends 2.6% higher. The two unequal scenarios have fewer calories available, with the least decline in the sustainable case (ONEPW, −1.7%, TLTL – 5.0%). The demographic variant reduces deviation from the FAO number to 0.7% for ECO and −3.5% for TLTL. The impact of changing skill rates is markedly different for the equal scenarios (a drop compared to the standard FoodSecure scenarios) and unequal ones (an increase in calorie availability). Even in the lowest projection, globally there remains sufficient food available to feed all (2917 kCal per day).

We then turn to food prices that dominate food security debates by triggering Malthusian concerns on reaching the limits of the earth's capacity to feed a growing world population (Swinnen, 2010). Changing skill rates push primary producer prices upwards in all scenarios (Fig. 1), reversing the 2050 price change from about 10% decrease in the FFANF and ECO to about 45% increase by FFANF-D and ECO-D. Reactions for ONEPW-D and TLTL-D are smaller and do not reverse the 2050 price change. The FFANF-D and ECO-D scenarios strongly decrease the share of unskilled labor while maintaining the GDP and population growth assumptions (Table 2). Having more skilled (productive) labor in the demographic scenarios lowers the calibrated

Table 2
Population and income drivers by country group (% change from 2010 to 2050) [a].

A – all countries			Low income	Middle income	High income		World
Population[b]	Unequal	ONEPW	115	29	34		39
		TLTL	98	18	22		27
	Equal	FFANF	82	12	36		24
		ECO	85	13	23		23
GDP/capita[b]	Unequal	ONEPW	302	350	115		175
		TLTL	315	201	70		103
	Equal	FFANF	1172	532	143		266
		ECO	1150	481	40		170
Unskilled labor[c]	Unequal	ONEPW - D	−3	−8	−16		−7
		TLTL - D	−3	−8	−16		−7
	Equal	FFANF - D	−41	−55	−47		−51
		ECO - D	−41	−55	−47		−50
B – household regions only			Ghana	Uganda	India	China	Indonesia
Urban population[d]	Unequal	ONEPW - D	37	141	76	49	47
		TLTL - D	37	141	76	49	47
	Equal	FFANF - D	55	253	123	72	69
		ECO - D	55	253	123	72	69

[a] Table reports total percentage change over the 2010–2050 simulation horizon which comprises four 10-year simulation periods; in the model specific shocks for each of the 33 model regions are phased in during the 40-year horizon with the relative size of the shock by period varying according to the scenario narrative.

[b] Population and GDP shocks are constructed by combining data from the Shared Socioeconomic Pathways (SSP) database (IIASA, 2015) with stakeholder narratives (van Dijk et al. 2019).

[c] Changes in share of unskilled to skilled labor are computed from the database reported in Lutz et al. (2014) and available through the Wittgenstein Data Explorer (http://dataexplorer.wittgensteincentre.org/shiny/wic/); we computed the skilled labor share in the population from 'upper secondary' and 'post-secondary' education levels in the Wittgenstein data with our two GTAP labor types defining the remainder as unskilled (in case of household regions with additional labor types their match to the two GTAP labor types is used to allocate skill changes); the projections for the two unequal scenarios (ONEPW-D and TLTL-D) are matched to SSP3 - stalled development education projections (the smallest drop in unskilled labor rates in the Wittgenstein projections given their lower GDP/capita growth) while the equal scenarios (FFANF-D and ECO-D) are matched to SSP2-FT – Medium + fast track education scenario (the strongest drop in the unskilled labor rates given their high GDP/capita growth).

[d] Urbanization shocks are taken from IIASA (2015), following the stakeholder narratives by mapping low urbanization rates to the unequal scenarios and high urbanization rates to the equal scenarios.

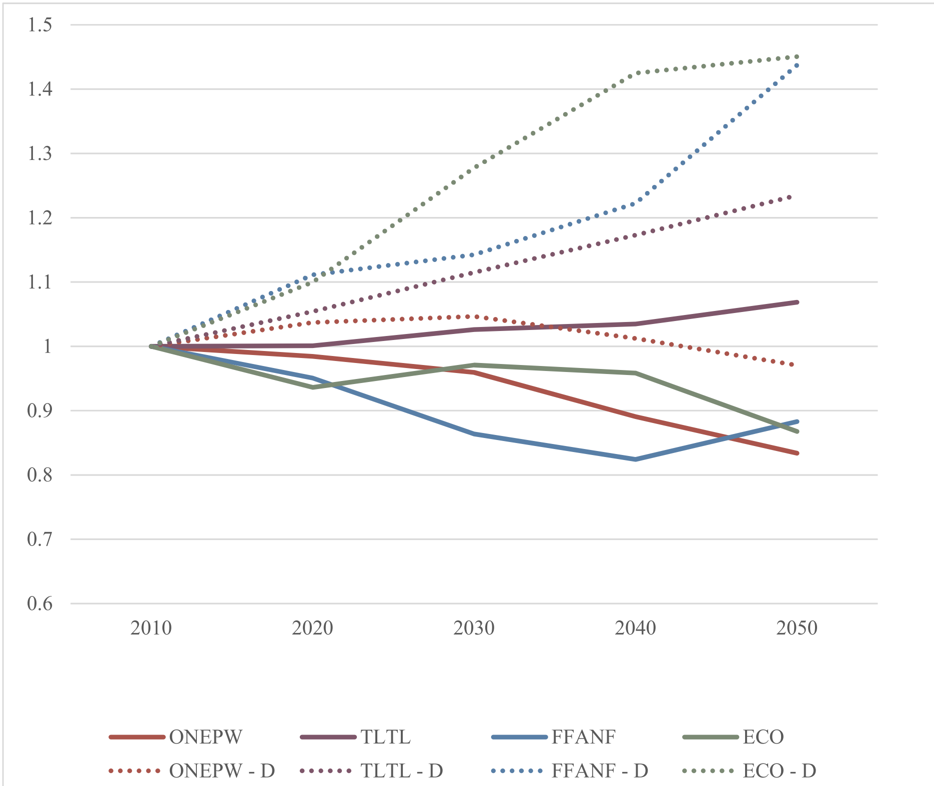

Fig. 1. Index of primary agricultural producer price by scenario (2010 = 1).

agricultural labor productivity growth compared to the regular scenarios for both skilled labor (by 19% in FFANF-D and 31% in ECO-D) and unskilled labor (27% in FFANF-D and 33% in ECO-D). Agriculture relies strongly on unskilled labor of which the demographic scenarios reduce availability and productivity. The critical determinant of the impact on product prices is the ability to substitute unskilled labor for other inputs. MAGNET employs a set of sector-specific nested CES-production structures with agricultural sectors having limited substitution possibilities between the two types of labor and capital (0.25) and even more limited possibility (0.1) to substitute with a land-fertilizer (crops) or land-feed composite (livestock). A reduced availability of unskilled labor then creates a strong agricultural price response and could give rise to concerns about the accessibility of food. In contrast, the manufacturing and services sectors are modeled to be more flexible in their input use, with elasticities of substitution among production factors between 1.12 and 1.36. The non-agricultural sectors will therefore move away from the scarce unskilled labor employing more skilled laborers and capital.

A key advantage of a CGE model is to look beyond agricultural prices to the interplay of price and income effects in determining access to (nutritious) food. We focus on an aggregate indicator of food access most relevant for the poor: ratio of cereal prices to unskilled labor. Cereals provide the most important source of calories in for the poor (Clements and Si, 2015), while unskilled labor is the most important income earning opportunity for poor households lacking other endowments. Cereal prices track the agricultural price development of Fig. 1, increasing in all demographic variants and TLTL, while unskilled wages increase in all scenarios. Fig. 2 plots the resulting 2050 cereal to unskilled wage ratio. The ratio, normalized at 1 in 2010, improves (drops) in all scenarios, i.e. the income effect from rising unskilled wages outpaces cereal price increases. Focusing on the solid bars, we find the two equal scenarios, ECO and FFANF, benefit the poorer country groups more while the unequal TLTL holds least improvement. Results of the ONEPW scenario are more ambiguous, with fewest improvements in the high income and most increases in purchasing power in the middle income countries.

The demographic runs (hatched bars) have a much stronger unskilled wage increase, as unskilled labor becomes increasingly scarce with global investment in education. The resulting positive income effect for the poor, however, is partly undone by stronger cereal prices increases. Purchasing power still improves (all ratios remain well below 1), albeit visibly lower than in the regular FoodSecure scenarios except for high income countries. Although the income effect dominates - rising food prices do not harm access to food in any of the country groups - a knock-on effect arises only in high income countries. Here the ratio drops further due to a moderate cereal price increase outpaced by unskilled wage increases in the alternative scenarios. Agricultural production systems in high income countries have already shifted away from unskilled labor to capital, employing only a small part of the population and thus are less sensitive to labor force changes.

Lacking global data on within-country income distribution, we can only roughly assess the risk of undernourishment. We compute the number of people living in a country with a given average availability of food for a first glimpse at food access. The FAO food balance sheet numbers we use are an overestimation of actual intake, referring to calorie content of household purchases computed from primary content. Depending on the level of food losses and waste, actual consumed calories will be (much) less. This overestimation combined with some form of unequal access in all countries, implies that undernourishment is prevalent if the average national availability of food barely exceeds the minimal daily requirement of 1820 calories per day (Alexandratos and Bruinsma, 2012). Fig. 3 plots the number of people in countries by average calorie availability categories for the 2010 base year and 2050 by scenario.

Despite a significant growth in world population in all scenarios, the number of people living in countries with less than 2500 calories, and thus at risk of undernourishment, declines in all scenarios. In all but TLTL, no persons are projected to live in countries with less than 2000

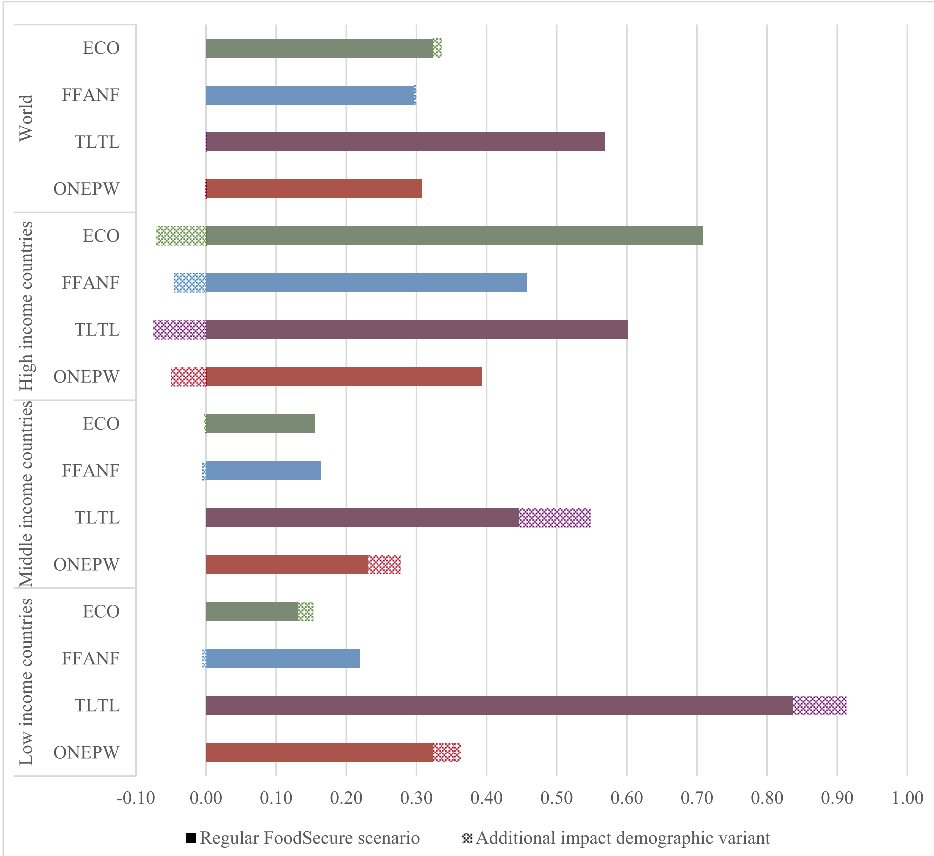

Fig. 2. Ratio of cereal price to unskilled labor wage ratio in 2050 by country group and scenario (2010 = 1)
Source: MAGNET simulations.

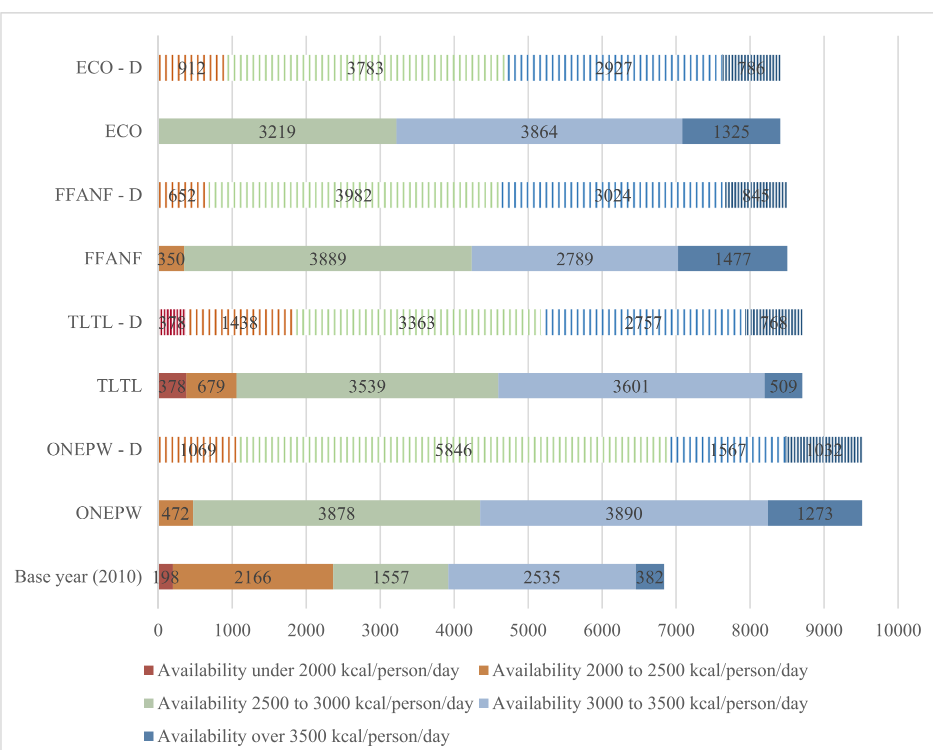

Fig. 3. Population in countries with given average food availability in 2010 and by scenario in 2050 (million people)
Source: MAGNET simulationsNote
This figures is inspired by figure 2.2 in Alexandratos and Bruinsma (2012). In contrast to their figure we did not limited ourselves to developing countries, allowing us to also assess the potential obesity issues at a global level. We exclude the CHR region from all nutrition-related indicators due to lack of FAO data for Taiwan and Hong Kong, together accounting for 92 percent of its population.

calories per day by 2050. TLTL and TLTL-D stand out with a decline in people on less than 2500 calories, but more people on less than 2000 calorie countries. The underlying story, concerning the Rest of Southern Africa (RSF) region, is however more optimistic than it appears at first sight. In 2010, the region by some distance has the lowest calorie availability, a meagre 1400 calories/day and its population nearly doubles by 2050 in ONEPW and TLTL. Even in the worst scenario, TLTL-D, calorie availability reaches 1900 kcal a day, while in the more equal worlds of FFANF and ECO (with lower but still impressive population growth) it even passes the second bracket with between 2570 and 2875 kcal day. While undernourishment strongly declines in all but TLTL, at the other end of the spectrum problems become apparent. Taking an availability of more than 3500 calories per day as indicating potential obesity issues, problems are highest in the equal scenarios (around 17 percent), but these numbers are only considerably lower in TLTL (6 percent) with ONEPW having 13 percent of people in potential risk countries for obesity. All alternative scenarios show a similar pattern on both ends of the distribution: an increase in the number of people with availability of less than 2500 calories and fewer people with an availability of over 3500 calories. While only providing a first glimpse of within country food security problems it clearly illustrates the importance of demographic assumptions in global undernourishment versus obesity challenges.

While capturing income effects is beyond the grasp of agricultural PE models, accounting for the impact of demographic changes on agricultural production is still highly relevant. If unskilled labor, a key agricultural input, becomes scarce farmers will shift to different input mixes. Labor scarcity can thus drive agricultural extensification (using more land per unit of production), as is the case in the demographic variants (see Fig. 4). All demographic variants use more land for the same amount of agricultural production increase, although in both ONEPW scenarios a net intensification by 2050 remains due to high yield assumptions in the ONEPW world. In addition to land, unskilled labor is replaced by fertilizer (10–15% increase), capital (7–9%) and skilled labor (11–33%). These substitutions moderate the increase use of land, even in the equal scenarios with a halving of the share of unskilled labor: FFANF-D uses 2.0% more agricultural land than FFANF, while ECO-D uses 2.4% more than ECO. Expansion of agricultural land coupled with increased chemical fertilizer use has environmental ramifications for biodiversity, GHG emissions from land conversion and pollution.

4. Within country income inequality and food security

So far, we focused on global differences between countries finding encouraging increases in purchasing power and fewer people at risk of undernourishment. National averages, however, cannot capture within-country inequality. The MAGNET household module allows a look at within country inequality for a selected number of countries. It should be noted that lacking individual household data, the MAGNET Gini indices are a rough approximation depending on the number of household types in each region (these numbers are given in Fig. 5). Comparison with the World Income Inequality database (UNU-WIDER) shows the expected underestimation of inequality with the exception of India and Indonesia: Ghana 36 vs 43, Uganda 30 vs. 42, India 40 vs 35, China 28 vs 42 and Indonesia 47 vs 35. Changes in the Gini index show a less rosy picture despite encouraging global trends - in all of the regular scenarios within-country inequality worsens relative to 2010 (Fig. 5). Furthermore, the equal scenarios (ECO and FFANF) while outperforming the unequal ones (ONEPW and TTLT) both in cereal to unskilled wage ratio and people at risk of undernourishment, have the largest increases in Gini index. Global convergence thus does not guarantee within-country income convergence.

The alternative scenarios show labor income to be key for

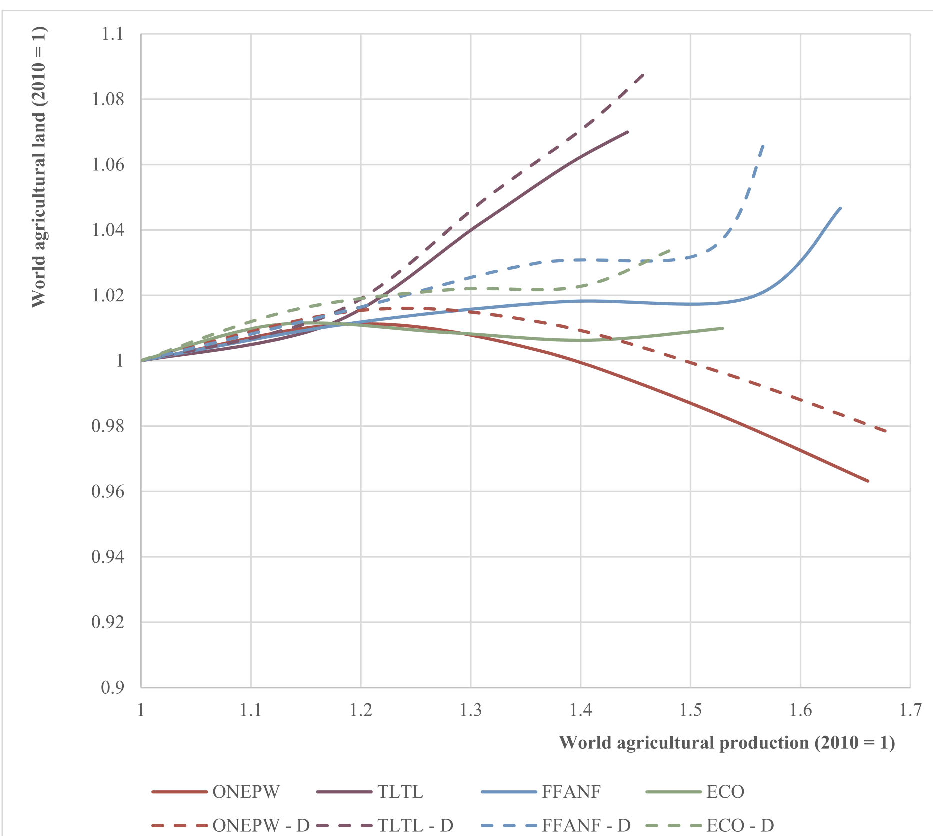

Fig. 4. World agricultural production versus agricultural land by scenario (index of 2010–2050 changes)
Source: MAGNET simulations.

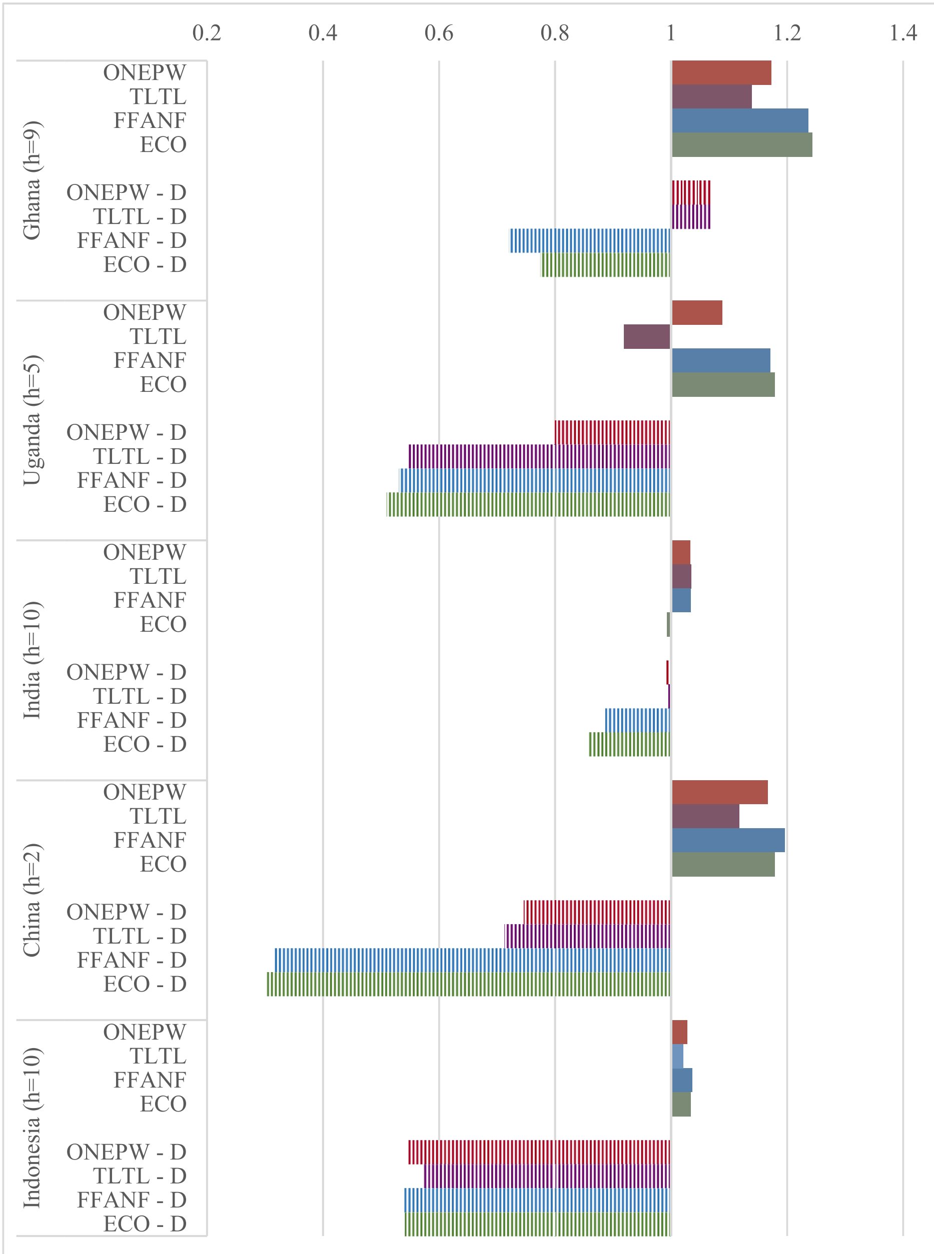

Fig. 5. Index of Gini coefficient for regions with multiple household types in 2050 by scenario (2010 = 1, number of household types by region in brackets) Source: MAGNET simulations.

inequality. FFANF-D and ECO-D consistently and strongly reduce inequality in all countries. First, increased scarcity of unskilled labor coupled with higher land prices due to limited substitution possibilities benefits households relying on agriculture either through wage labor or land ownership. Second, the alternative scenarios contain for household regions an additional shock adjusting the rural and urban household population sizes to reflect increasing urbanization (Table 2). This adds to the scarcity of agricultural labor while placing downward pressure on urban wages, bringing rural and urban wages closer. Although promising from an income distribution point of view, a growing urban population increases vulnerability to rising food prices – without access to agricultural income there is no income effect off-setting increasing food prices for urban households. Past beneficial impacts of higher agricultural prices for the poor mainly located in agricultural areas (Headey and Martin, 2016) may no longer hold in the future.

For a first indication of whether urbanization will have the future poor living in urban areas, Fig. 6 shows per capita rural and urban income in the five household regions and its source (agricultural versus non-agricultural). According to our data, households classified as urban own land thus benefiting from increased land demand by agriculture. Despite the obvious importance of agricultural income for rural households, their non-agricultural income hovers around 50% of total income and cannot be neglected. In 2010 average urban incomes are about 65% higher than rural incomes, and this gap remains in all regular FoodSecure scenarios, increasing to 75% in TLTL and slightly closing in ECO (59%). Alternative demographic assumptions alter the rural-urban income distribution, reversing to a 6% advantage for rural households in the unequal scenarios (ONEPW-D and TLTL-D) and a complete reversal for equal scenarios with a 55% higher income for rural households (FFANF-D and ECO-D). The difference is not only due to increased agricultural income with rising commodity prices (Fig. 1), income from non-agricultural sectors also becomes more evenly

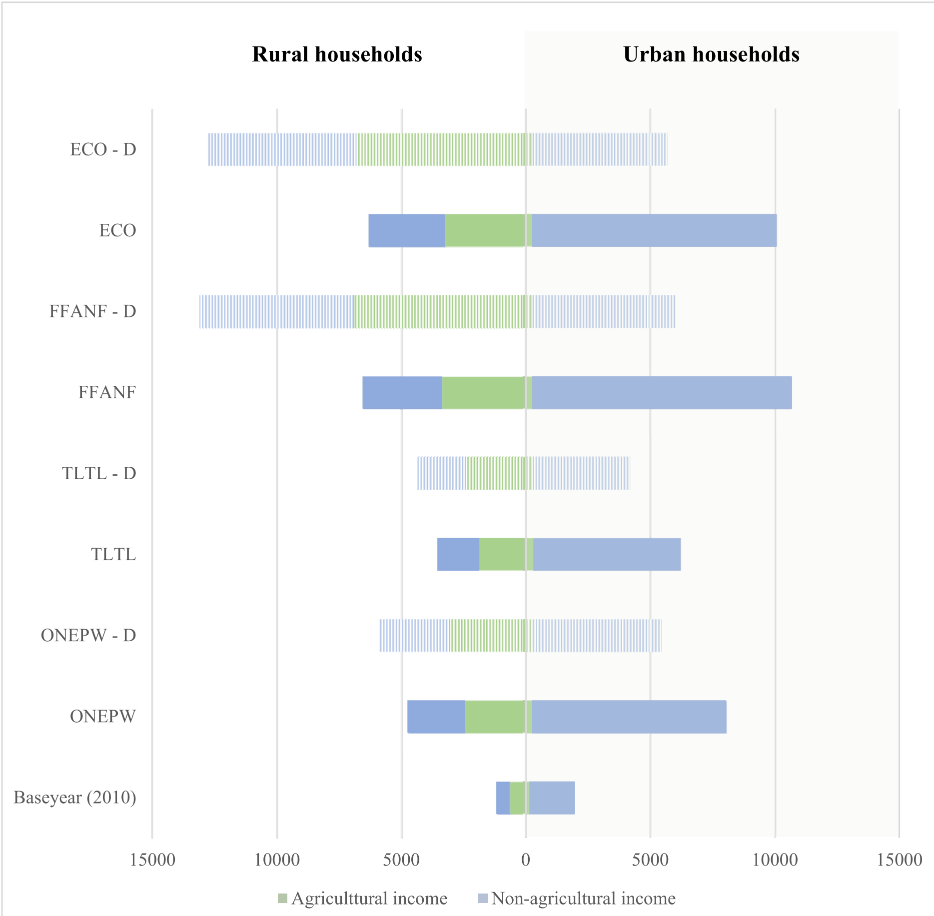

Fig. 6. Per capita income of rural and urban households from agricultural and non-agricultural sectors, base year and 2050 by scenario (2007 $)
Source: MAGNET simulations for five household regions (Ghana, Uganda, India, China and Indonesia)
Note: Production is modeled at sector and not at household level in MAGNET. We can thus only indirectly assess the dependence on agriculture by applying the agricultural share in endowment use (national average) to household-specific endowments. Only if further sector-specific factor detail is included the link between sector developments and household incomes becomes stronger. In the case of Ghana, for example, there are four types of unskilled agricultural labor differentiated by region, providing a direct link between agricultural sectors and household income. In the case of India, the social accounting matrix does not provide data on land ownership. Lacking better information land endowments are allocated to all household types in line with the relative share of non-land income (i.e. richer households get a larger share of land).

distributed. Although our link between sectors and household income is rough, with limited data on household income by sector, for most household regions these findings suggest rapid urbanization and increasing skill rates may have the future poor mainly located in the urban areas. This signals the need to devise food security policies which are robust to changing characteristics of the poor. It also signals a future where high food prices will become a concern if the poor are no longer sheltered through positive agricultural income effects.

5. Conclusions

This paper shows how contrasting assumptions on labor supply affect global food security assessments and inequality between and within regions, combining a global CGE model including representative households for multiple regions with a set of contrasting scenarios on drivers of inequality through skill development and urbanization. Four contrasting FoodSecure worlds highlight the sensitivity of agricultural price developments and broader food security assessments to alternative demographic assumptions.

Although agricultural prices dominate public and policy food security concerns, the interplay of price and income effects determine whether high food prices harm or benefit the poor. This paper underscores the importance of looking beyond agricultural prices as food prices increase instead of decrease when accounting for skill changes and Gini coefficients signal the poor benefiting from the higher food prices. These findings are in line with Headey and Martin (2016) - if agriculture is the main source of income for the poor, a sustained price increase will have the income effect (through wage and land prices) dominate the price effect. Properly capturing the income effect is thus key for policy guidance aiming at future food security.

The second point this paper makes is that the current reliance on agriculture by the poor may not hold in the future with increasing education and urbanization. The positive Gini results flow from a strong upward pressure on unskilled wages with increasing skill rates and urbanization. It hinges on the limited scope to substitute away from unskilled labor in agriculture and an exogenously imposed urbanization process. While improving inequality by reducing the rural-urban income gap, it does create concerns for a growing share of urban poor. This argues for improving the empirical basis for modeling agricultural labor supply and use, accounting for rural-urban migration decisions in which wage differentials may only be part of the driving force, an ignored topic in agricultural economics (Hertel et al., 2016). It also argues for improving the empirical basis of modeling the use of labor types by different sectors in long run projections, agricultural as well as non-agricultural. Recent work by Lofgren and Cicowiez (2017) using sector proximities from the product-space literature as a measure of ease of transition of factors between sectors shows the empirical challenges for sound modeling of labor market dynamics, a major task ahead for policy relevant CGE modeling. Apart from a modeling challenge, these labor market questions also point to a policy challenge, namely, where to invest for pro-poor growth in the future. If the majority of the poor live and work in urban areas, different poverty strategies to those used in the past may be needed.

The third point this paper makes is that trends in education and urbanization not only matter for income distribution and access to food. It also affects agricultural production projections, including its environmental externalities. If unskilled labor, a key agricultural input in most regions, becomes scarce farmers will shift to different input mixes. Labor scarcity can drive agriculture toward extensification requiring larger areas of land to feed the growing world population. This has direct implications for other key policy areas like climate change. The area under agricultural production is a key parameter in climate change policies: converting land to agricultural use increases GHG emissions, biofuels require land for production, and some argue that negative emissions (i.e. carbon sequestration) may be needed from agriculture in order to stabilize the climate (Doelman et al., 2018; Popp et al., 2017; Overmars et al. 2014). When projecting future agricultural land use and scope for reducing area used for food and feed, pressures from increasingly scarce agricultural labor need to be accounted for. Thus, even in agricultural or climate focused analyses, developments in agricultural labor supply linked to demographic trends deserve explicit attention. In addition, the production technology details in sector models could improve the empirical foundations of the labor substitution possibilities in CGE models, were they to make labor use explicit.

Finally, this paper argues for an economy-wide perspective in the design of future food security policies. Whereas current agricultural dependence of the poor argues for primary sector interventions, this may not hold in the future. Simulations with alternative demographic drivers show that skilled wages will decline if more people get educated. Coupled with a move to urban areas the mass of the poor may shift from rural to urban areas. Limited possibilities for self-subsistence and concentration of people in urban areas makes for a potentially explosive situation. Robust policy options, however, are available. For one, investing in infrastructure to unlock rural areas remains key. It provides market access and thus income earning opportunities for farmers while lowering urban food prices. Observing a global shift toward processed food in diets, improved infrastructure may also help in developing domestic food processing industries providing jobs for urban poor and with backward links to domestic (smallholder) farmers. Alongside infrastructure policies, research investments may focus on food processing technologies in line with the relative (urban) labor abundance in low income countries (as opposed to importing capital intensive technologies from high income countries). Such a policy would be robust in promoting the income-earning opportunities for agriculture-dependent households (farmers and wage laborers) supplying food for processing while creating income-earning possibilities for the increasing number of urban households. Focusing on the food supply chain beyond the primary sector thus offers scope for policies supporting both current and future poor. Next to these food-focused policies, urban poor can be supported with broader inequality combating policies. The higher population density in urban areas results in more diverse income earning possibilities, for example in fast growing service sectors, as well as lower cost provision of public services like sanitation, which can be key to help people earn a living.

In summary, this paper argues that the spotlight on the debate between Malthusian doomsday (population growth will exceed planetary boundaries) and Boserup's innovation salvation (searching for new green revolutions) should be turned at least a bit toward the development theory of Lewis focusing on the role of labor in a structural transformation of the economy. While his original model appears too simplistic when tested against empirical evidence (Gollin, 2014), he was onto something by stressing the importance of a movement of people across sectors for development and inequality. Changes in the skill level and location of labor are key for food security and deserve more explicit attention requiring both researchers and policymakers to look beyond the agricultural sector.

Declaration of competing interest

None.

Acknowledgements

This research received funding from the European Union's Seventh Framework Programme FP7/2007–2011 under Grant Agreement n° 2906 93 FOODSECURE and the Dutch Government's Knowledge Base program (KB-22-001-002). Neither the FOODSECURE project nor any of its partner organizations, or any organization of the European Union or European Commission is accountable for the content of this paper. The authors are grateful to Anand Ganesh-Kumar for providing the SAM for India and Terrie Walmsley and Peter Minor for sharing the MyGTAP code.

References

Adam, Christopher, Gollin, Douglas, 2015. 'Editors' introduction: the economics of the global Food and agriculture system'. Oxf. Rev. Econ. Policy 31 (1), 1–7. https://doi.org/10.1093/oxrep/grv010.

Aguiar, Angel, Narayanan, Badri, McDougall, Robert, 2016. An overview of the GTAP 9 data base. J. Glob. Econ. 1 (1), 181–208. https://doi.org/10.21642/JGEA.010103AF.

Alexandratos, N., Bruinsma, J., 2012. World Agriculture towards 2030/2050: the 2012 Revision. FAO. www.fao.org/economic/esa.

OECD-FAO, 2016. OECD-FAO Agricultural Outlook 2016-2025. OECD Publishing, Paris. https://doi.org/10.1787/agr_outlook-2016-en.

Bouet, Antoine, Berisha-Krasniqui, Valdete, Berisha-Krasniqui, Valdete, Estrades, Carmen, Laborde, David, 2013. 'Households Heterogeneity in a Global CGE Model: an Illustration with the MIRAGE-HH (MIRAGE-HouseHolds) Model'. Larefi Working Paper 1301, vol. 4 Larefi, Université Bordeaux. https://ideas.repec.org/p/laf/wpaper/cr1301.html.

Clements, Kenneth W., Si, Jaiwei, 2015. 'Engels'law, Diet Diversity and the Quality of Food Consumption'. Business School, The University of Western Australia.

Corong, Erwin L., Hertel, Thomas W., McDougall, Robert, Tsigas, Marinos E., van der Mensbrugghe, Dominique, 2017. The standard GTAP model, version 7. J. Glob. Econ. 2 (1), 1–119. https://doi.org/10.21642/JGEA.020101AF.

Doelman, J.C., Stehfest, E., Tabeau, A., van Meijl, H., Lassaletta, L., Gernaat, D.E.H.J., Hermans, K., Harmsen, M., Daioglou, V., Biemans, H., van der Sluis, S., van Vuuren, D.P., 2018. Exploring SSP Land-Use Dynamics Using the IMAGE Model: Regional and Gridded Scenarios of Land-Use Change and Land-Based Climate Change Mitigation. Global Environmental Change 48, 119–135. https://doi.org/10.1016/j.gloenvcha.2017.11.014.

van Dijk, Michiel, Maryia Mandryk, Marc Gramberger, David Laborde Debucquet, Lindsay Shutes, Elke Stehfest, Hugo Valin, and Katharina Zellmer. Under Review. 'Scenarios to Explore Global Food Security up to 2050: Development Process, Storylines and Quantification of Drivers'. *Global Food Security* Submitted to GFS Special Issue on the Future of Global FNS.

Godfray, H.C.J., Robinson, S., 2015. Contrasting approaches to projecting long-run global Food security. Oxf. Rev. Econ. Policy 31 (1), 26–44. https://doi.org/10.1093/oxrep/grv006.

Gollin, D., 2014. The Lewis Model: A 60-Year Retrospective. Journal of Economic Perspectives 28 (3), 70–88. https://doi.org/10.1257/jep.28.3.71.

Hasegawa, T., Fujimori, S., Havlík, P., Valin, H., Bodirsky, B.L., Doelman, J.C., Fellmann, T., Kyle, P., Koopman, J.F.L., Lotze-Campen, H., Mason-D'Croz, D., Ochi, Y., Domínguez, I.P., Stehfest, E., Sulser, T.B., Tabeau, A., Takahashi, K., Takakura, J., Meijl, H. van, Zeist, W.-J. van, Wiebe, K., Witzke, P., 2018. Risk of increased food insecurity under stringent global climate change mitigation policy. Nature Climate Change 8, 699–703. https://doi.org/10.1038/s41558-018-0230-x.

Hasegawa, T., Fujimori, S., Takahashi, K., Masui, T., 2015. Scenarios for the risk of hunger in the twenty-first century using Shared Socioeconomic Pathways. Environmental Research Letters 10 (1). https://doi.org/10.1088/1748-9326/10/1/014010.

Headey, Derek D., Martin, William J., 2016. The impact of Food prices on poverty and Food security. Annu. Rev. Resour. Econ. 8 (1), 329–351. https://doi.org/10.1146/annurev-resource-100815-095303.

Hertel, Thomas W., 2016. Food security under climate change. Nat. Clim. Chang. 6 (1), 10–13. https://doi.org/10.1038/nclimate2834.

Hertel, Thomas, Verma, Monika, Ivanic, Maros, Magalhaes, Eduardo, Ludena, Carlos, Rios, Ana R., 2015. GTAP-pov: a Framework for assessing the national poverty impacts of global economic and environmental change. GTAP Technical Paper 31. Purdue: GTAP. https://www.gtap.agecon.purdue.edu/resources/download/7760.pdf.

Hertel, Thomas W., Baldos, Uris Lantz C., van der Mensbrugghe, Dominique, 2016. Predicting long-term Food demand, cropland use, and prices. Annu. Rev. Resour. Econ. 8 (1), 417–441. https://doi.org/10.1146/annurev-resource-100815-095333.

IEA, 2015. Energy technology perspectives 2015 - mobilising innovation to accelerate climate action. http://www.iea.org/etp/etpmodel/assumptions/.

IFPRI, 2018. 2018 Global Food Policy Report. International Food Policy Research Institute, Washington, DC. https://doi.org/10.2499/9780896292970.

IIASA, 2015. 'SSP database'. 2015. https://tntcat.iiasa.ac.at/SspDb.

Ivanic, Maros, Martin, Will, 2014. 'Short- and Long-Run Impacts of Food Price Changes on Poverty'. WPS7011. The World Bank. http://documents.worldbank.org/curated/en/2014/08/20131428/short–long-run-impacts-food-price-changes-poverty.

Kuiper, M.H., Shutes, L.J., 2014. 'Expanding the household coverage of global simulation models: an application to Ghana'. The hague: LEI wageningen UR. http://www.foodsecure.eu/PublicationDetail.aspx?id=72.

Laborde Debucquet, David, Bizikova, Livia, Lallemant, Tess, Smaller, Carin, 2016. 'Ending Hunger: what Would it Cost?' Winnipeg. International Institute for Sustainable Development (IISD), Manitoba, Canada. http://www.iisd.org/sites/default/files/publications/ending-hunger-what-would-it-cost.pdf.

Lane, Jim, 2015. Biofuels mandates around the world: 2015. http://www.biofuelsdigest.

com/bdigest/2014/12/31/biofuels-mandates-around-the-world-2015/.

Lofgren, Hans, Cicowiez, Martin, 2017. A proximity-based approach to labor mobility in CGE models with an application to sub-saharan Africa. J. Glob. Econ. 2 (1), 120–165. https://doi.org/10.21642/JGEA.020102AF.

Lutz, Wolfgang, Butz, William P., Samir, K.C. (Eds.), 2014. World Population and Human Capital in the Twenty-First Century. Oxford University Press, Oxford, New York.

Hans van Meijl, Lindsay Shutes, Hugo Valin, Elke Stehfest, Michiel Van Dijk, Marijke Kuiper, Andrzej Tabeau, Willem-Jan van Zeist, Tomoko Hasegawa, and Petr Havlik. Under Review.2019 'Exploring Future Food Security With Global Land Models: the FOODSECURE Scenarios'. Global Food Sec. Submitted to GFS Special Issue on the Future of Global FNS.

van Meijl, Hans, van Rheenen, T., Tabeau, A., Eickhout, B., 2006. The impact of different policy environments on agricultural land use in Europe. Agric. Ecosyst. Environ. 114 (1), 21–38. https://doi.org/10.1016/j.agee.2005.11.006. Scenario-Based Studies of Future Land Use in Europe.

van Meijl, Hans, Tsiropoulos, I., Bartelings, H., Hoefnagels, R., Smeets, E., Tabeau, A., Faaij, A., 2018a. On the macro-economic impact of bioenergy and biochemicals – introducing advanced bioeconomy sectors into an economic modelling Framework with a case study for The Netherlands. Biomass Bioenergy 108 (January), 381–397. https://doi.org/10.1016/j.biombioe.2017.10.040.

van Meijl, Hans, Havlik, Petr, Lotze-Campen, Hermann, Stehfest, Elke, Peter, Witzke, Ignacio Pérez Domínguez, Leon Bodirsky, Benjamin, et al., 2018b. Comparing impacts of climate change and mitigation on global agriculture by 2050. Environ. Res. Lett. 13 (6). https://doi.org/10.1088/1748-9326/aabdc4. 064021.

van der Mensbrugghe, Dominique, 2010. The environmental impact and sustainability applied general equilibrium (Envisage) model. The World Bank. http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTDECPROSPECTS/0.contentMDK:22520416~menuPK:7067580~pagePK:64165401~piPK:64165026~theSitePK:476883,00.html.

van der Mensbrugghe, Dominique, Osorio-Rodarte, Israel, Burns, Andrew, Baffes, John, 2011. Macroeconomic environment and commodity markets: a longer-term Outlook. In: Macroeconomic Environment and Commodity Markets: A Longer Term Outlook. Piero Conforti. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/014/i2280e/i2280e04.pdf.

Nelson, Gerald C., Valin, Hugo, Sands, Ronald D., Havlík, Petr, Ahammad, Helal, Deryng, Delphine, Elliott, Joshua, et al., 2014. Climate change effects on agriculture: economic responses to biophysical shocks. Proc. Natl. Acad. Sci. 111 (9), 3274–3279. https://doi.org/10.1073/pnas.1222465110.

Obersteiner, Michael, Walsh, Brian, Frank, Stefan, Havlík, Petr, Cantele, Matthew, Liu, Junguo, Palazzo, Amanda, et al., 2016. 'Assessing the land resource–Food price nexus of the sustainable development goals'. Sci. Adv. 2 (9), e1501499. https://doi.org/10.1126/sciadv.1501499.

OECD, 2016. 'METRO: the OECD's Trade Model'. OECD Trade Policy Note. OECD, Paris. https://www.oecd.org/tad/policynotes/METRO-OECD-trade-model.pdf.

OECD/FAO, 2015. Aglink-Cosimo Model Documentation - a Partial Equilibrium Model of World Agricultural Markets. OECD. http://www.agri-outlook.org/abouttheoutlook/Aglink-Cosimo-model-documentation-2015.pdf.

Overmars, K.P., Stehfest, E., Tabeau, A., van Meijl, H., Beltrán, A.M., Kram, T., 2014. Estimating the opportunity costs of reducing carbon dioxide emissions via avoided deforestation, using integrated assessment modelling. Land Use Policy 41, 45–60. https://doi.org/10.1016/j.landusepol.2014.04.015.

Philippidis, G., Bartelings, H., Helming, J., M'barek, R., Ronzon, T., Smeets, E., Van Meijl, H., Shutes, L., 2018. The MAGNET model framework for assessing policy coherence and SDGs: Application to the bioeconomy. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/111111111/51916.

Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B.L., Dietrich, J.P., Doelmann, J.C., Gusti, M., Hasegawa, T., Kyle, P., Obersteiner, M., Tabeau, A., Takahashi, K., Valin, H., Waldhoff, S., Weindl, I., Wise, M., Kriegler, E., Lotze-Campen, H., Fricko, O., Riahi, K., Vuuren, D.P. van, 2017. Land-use futures in the shared socio-economic pathways. Global Environmental Change 42, 331–345. https://doi.org/10.1016/j.gloenvcha.2016.10.002.

Swinnen, Johan, 2010. The right price of Food: reflections on the political economy of policy analysis and communication. LICOS Discussion Paper. LICOS - Centre for Institutions and Economic Performance, KU Leuven. http://econpapers.repec.org/paper/liclicosd/25910.htm.

United Nations, 2017. World Urbanization Prospects: the 2017 Revision. United Nations, Department of Economic and Social Affairs, Population Division ST/ESA/SER.A/366.

UNU-WIDER world income inequality database (WIID4). n.d.. https://www.wider.unu.edu/project/wiid-world-income-inequality-database accessed July 2018.

Wheeler, Tim, von Braun, Joachim, 2013. Climate change impacts on global Food security. Science 341 (6145), 508–513. https://doi.org/10.1126/science.1239402.

Woltjer, Geert, Kuiper, Marijke, Kavallar, Aikaterini, Hans van Meijl, Powell, Jeff, Rutten, Martine, Shutes, Lindsay, Tabeau, Andrzej, 2014. 'The MAGNET Model: Module Description'. LEI Report 14–057. LEI - Wageningen UR, Wageningen. http://www.wageningenur.nl/nl/Publicatie-details.htm?publicationId=publication-way-343535383037.