Analysis of the nexus between population, water resources and Global Food Security highlights significance of governance and research investments and policy priorities

Running title: Governance and research investments critical drivers of food security

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Running title: Governance and research investments as priorities for food security

Abstract

BACKGROUND: Analyses of sensitivity of Global Food Security (GFS) score to a key set of supply or demand factors often suggest population and water supply as being the most critical and on which policies tend to focus. To explore other policy options, we characterised the nexus between GFS and a set of supply or demand factors including defining including population, agricultural and industrial water-use, agricultural publications (as a surrogate for investment in agricultural research and development [R&D]), and corruption perception index (CPI), to reveal opportunities for attaining enduring GFS.

RESULTS: We found that despite being the primary driver of demand for food, population showed no significant correlation with GFS scores. Similarly agricultural water-use was poorly correlated with GFS scores, except in countries where evaporation exceeds precipitation and irrigation is significant. However, GFS had a strong positive association with industrial water-use as a surrogate for overall industrialisation. Recent expansions in cultivated land area failed to yield concomitant improvements in GFS score since such expansions have been mostly into marginal lands with low productivity and also barely compensated for lands retired from cropping in several developed economies. However, GFS was positively associated with agricultural R&D investments, as it was with the CPI scores. The apparent and relative strengths

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of these drivers on GFS outcome amongst countries were in the order: industrial water-use ≈ publication rate ≈ corruption perception >> agricultural water-use > population.

CONCLUSIONS: We concluded by suggesting that to enshrine enduring food security, policies should prioritise (1) increased R&D investments that address farmer needs, and (2) governance mechanisms that promote accountability in both research and production value chains.

Key words: agriculture, food security, governance, industrialisation, population, research and development, water allocation

1. Introduction

Feeding the growing global population remains a major challenge in many parts of the world, where supply of food often lags demand. The Global Food Security (GFS) was defined at The World Food Summit held in Rome in 1996 as "When all people at all times have access to sufficient, safe, and nutritious food to maintain a healthy and active life" (http://www.fao.org/docrep/005/y4671e/y4671e05.htm#TopOfPage). Attainment of enduring GFS is under constant stress from both the demand and supply sides of affordable and nutritious food for all the peoples. Demand for food is generally driven by rising global population that has increased by 14% from 6.4 to 7.3 billion in the decade ending in 2014 (Population Institute, undated). Population is commonly identified as the primary threat to attainment of a global food security (Alexandratos and Bruinsma, 2012), and was further emphasised by an expert panel that argued for 60 –70% increase in food production by 2050 to meet the food needs for the projected global population of 9.1 billion (Alexandratos, 2005; Alexandratos and Bruinsma, 2012; FAO, 2009; Snoeck et al., 2000). Population *per se* is thus widely used by world leaders and institutions to highlight threats to GFS, with statements such as "... over one billion hungry people in the world..." (FAO, 2009), and "Food security is the issue of our time." (Clinton, 2012).

Population can be considered as the prime driver on the demand side of GFS especially in much of the developing world. However, as it only reflects part of the balance, the distribution of sub-optimal food security is heterogeneous among and within countries (Alexandratos, 2005).

Furthermore, recent economic and technological developments, including several developing countries with large populations, have significantly reduced *hunger* as we know it (Njoroge et al., 1992; Vermeulen et al., 2012) and may therefore weaken link between population and GFS. There are however other population-linked factors such as the interaction between population and changing dietary preferences that could profoundly impact GFS. The middle class in the emergent economies increasingly prefer protein- rich diets that require greater resources to produce, often at the expense of grain production for direct human consumptions (Soto-Pinto et al., 2000). This is a part of the new and different signals for GFS that reflect differences in economic development amongst countries. Availability/affordability of starch food features strongly in low income countries, while protein-rich food is the main factor in medium – high income countries. Indeed, Baldos and Hertel (2014) argued that the high income driven demand for protein-rich diet would eclipse population as the main driver of GFS. Thus, any correlation between GFS scores and population is likely to be tenuous and unlikely to be consistent across nations.

The supply side of GFS is driven by production and availability of food crops and thus requires access to natural resource base. Maintaining current production levels and expansion of cultivation into new lands depend on access to water. The capacity of the current cultivated land in meeting food crop production is being strained further by the diversion of food crops to other uses, mostly for biofuels. Crops used for biofuels are estimated to account for about 2.5% of total harvested food crops, equivalent to cropping 350,000 km^2 of the total agricultural land cultivated globally (Soto-Pinto et al., 2000). Compensating for this diversion of grains in order to sustainably provide enough food and fibre solely for direct human consumption requires expansion of cultivated land by 60–70% by some estimates (Alexandratos and Bruinsma, 2012). Such expansion is only possible if quality water supply is assured, but fresh water supply is limited and considered as the second most critical constraint, after population, on attainment of GFS by several national and international institutions, such as the Australian International Food Security Centre (http://aciar.gov.au/aifsc/) and the Food Secure (http://www.foodsecure.eu/). Its significance will become even more acute with projected shits in rainfall and evaporation patterns due to climate change (Gregory et al., 2005). These adverse climatic impacts are already being manifested in the declines of yield and nutritional qualities of grain crops such as maize, rice and wheat, especially in the tropics, where majority of the food insecure populations live (Vermeulen and Cotula, 2010). Baldos and Hertel (2014) concluded that economic growth notwithstanding, global hunger and malnutrition will deteriorate if agricultural productivity does not keep pace.

Management of the current water resources, along with the efficacy of the crop production practices, is likely to be more important than mere quantitative availability of resources. Practices and technologies that drive efficiency in resource use and the resulting productivity gains are commonly the products of research and development (R&D) investments. Countries that have made significant investments in agricultural R&D continue to reap productivity gains for decades (Alston et al., 2006). To achieve the desired outcomes, R&D investments have to be underpinned with appropriate strategies and implementation practices that address the interest and priorities of their national agricultural sector. This is relatively easily achieved under a system of responsive and accountable governance.

Factors on both sides of GFS are often considered separately (e.g. Vermeulen et al., 2012; Hanjra and Qureshi, 2010) and rarely are majority of the key factors considered together in an analysis to quantify the relative strengths of their associations with GFS outcomes. In this paper, we used the GFS score and its component parameters, along with indices of economic development, investment in agricultural R&D, and governance, to analyse their impacts on GFS. We focus on those regions of the world where there are concerns over their current and future outlook in food security. Our aims are to (1) characterise associations between GFS and availability of water resources and population, (2) analyse the impact of other selected key drivers of GFS, and (3) identify opportunities for productivity gains from the development and management of natural resources for the attainment of food security in vulnerable countries.

2. Methodology

2.1 Data, data source and analyses

This study relies on data produced and published by various international organisations. Data published for 2014 were used in most cases, except for publication or stated otherwise, and are explained in the following sections. These data as used in our analyses were categorised into supply factors (water resources, cultivated land area, research investment), demand factor (population), governance and their impact on the GFS analysed.

2.1.1 Food security scores

The food security data were obtained from the database of the Global Food Security Index created by the Economist Intelligence Unit (EIU, www.eiu.com). Derivation and compilation of the GFS by the EIU started in 2012 and has been updated annually since. Here, we used indices for the 2014 in most of the analysis, except where stated otherwise. Full details on derivation of indices are available at http://foodsecurityindex.eiu.com/Country. Briefly, the overall food security indices of countries are determined based on scores of three broad criteria agreed upon at the 1996 FAO World Food Summit, namely: availability, affordability and utilisation (quality and safety) of food. These three criteria are weighted (2.5:2.75:1, respectively) and scored points out of a maximum of 100. The indices are used to rank food security scores for countries that have relevant data available. Each of these three criteria has multiple sub-categories, whose scores are sequentially/hierarchically aggregated, or disaggregated, depending on a top-down or bottom-up perspective/analysis.

2.1.2 Population and sectoral water allocation

Population figures for the various countries were obtained from *Worldometers* (http://www.worldometers.info/world-population/population-by-country/). Data on global water resources and use were all obtained from the Food and Agricultural Organisation (FAO) of the United Nations (http://faostat.fao.org/default.aspx). These data include sectoral water allocation (e.g., agricultural, industrial or domestic use) and changes in agricultural land areas for individual countries. Data for 2014 were used for both variables.

2.1.3 Publication and governance data

Publication data on agricultural sciences were obtained from ISI Web of Science database, using "agriculture" in the subject field, and country name in the author affiliation field to identify papers published from the respective countries between 1950 and 2010. These were used as a surrogate for level of investment in agricultural research and development during that period. The governance of a country was assessed based on Corruption Perception Index (CPI) published by the Transparency International (http://www.transparency.org/research/cpi/overview). The index is published annually and measures how corrupt the public sector is perceived to be and portray the daily reality in terms of quality of life for those living in those countries. These countries are awarded points between zero (high perception) and 100 (minimal perception) points.

2.2.4 Data analysis

The data from the different sources did not have coverage of the same number of countries. Thus, the first step involved data harmonisation. This generated a dataset containing 102 countries, which had all the relevant data considered in this study. Association of GFS with the various factors was examined via correlation analyses.

3.0 Results and Discussion

Analyses reveal that the factors on the supply-side (water resources, cultivated land area, research investment) and on the demand-side (population) impact the GFS to different degrees as indicated by the size of the correlation coefficients (Figure 1). Each of these factors will be explored further, by analysing their contribution either on the demand or supply side of the GFS.

[insert Figure 1 near here]

3.1 Demand drivers of Global Food Security

3.1.1 Population

Population is often considered the prime driver on the demand side of GFS (e.g., Alexandratos & Bruinsma, 2012; FAO, 2009; Snoeck et al., 2000; Godfray et al. 2010), but analysis at global scale shows no apparent association between population size and food security scores amongst countries (Figure 2). This result refutes the common notion that population size, which is the major component on the demand side of food security, negatively impacts food security status of countries generally. The data show that there are many countries with high FS scores at both the low and high ends of the population spectrum. For instance, countries such as China and India, the two most populous countries of over 1.2 billion each, have FS score of about 50-65 between them; while many countries with populations of less than 10 million such as Sierra Leone and Tajikistan have FS score below 40. The low FS scores for some low population countries, e.g., the Democratic Republic of Congo (DRC), Burundi and Sudan are associated, in large part, with civil unrest. This is, however, not the case with the majority of low population countries, e.g., Zambia, Tajikistan, and Senegal, which have not experienced any significant civil unrest in recent years. These are consistent with an earlier observation by Alexandrators (2005) that the "population explosion" being witnessed in low-income food insecure countries would localise issues of food and agriculture, and thus not of global consequence.

An important component of the demand side of GFS is the ongoing shift towards proteinaceous and dairy products in emerging economies in Asia and Eastern Europe. Although we did not include it directly in our analysis, the general trend in the consumption of animal products mirrors the trends in per capita income and in industrialisation of nation states (WHO, Undated), which we used in the analysis of supply side of the GFS. The dietary shift towards livestock products is viewed as having adverse impact on GFS by its disproportionate resource requirement for producing a unit amount of calorie (Ausubel, 2013; Kearney, 2010). Elam (2006) attributed this shift in dietary habit to a combination of urbanisation, economic transformation and expansion, and product promotion that have facilitated 'nutrition transition' from starchy diets to animal products, prior to which these countries obtained up to 70% of energy intake from cereals. Thus while the increase in meat consumption between 1984 and 2004 was a mere 3% in the industrialised countries, it was 76% across the developing world, and by more than 3.5-fold in China; during the same period, wheat production, as a surrogate for cereals, rose by a mere 1% in developed, and 6% in developing, countries (Elam, 2006).

[insert Figure 2 near here]

Wirsenius et al. (2010) estimated that by 2030 the global cultivated area needs to increase by 5.9%, from the current 5.1 billion ha, to maintain current level of calorie intake. This is to also cater for the projected increases in meat production of almost 90% over the 2015 figures to meet the global demand by 2050 (Elam, 2006). These trends in dietary changes along with diversion of grains to biofuels will further intensify pressure on the supply side of GFS. For instance, the combined proportion of annual maize production diverted to the two end-uses will rise from the current 67% (~370 Mt) to over 77% (~490 Mt) by 2030 (OECD-FAO, 2017). Ecological footprint for animal products is already larger by up to a factor of four compared with starchy products (Davis et al., 2016) underscoring the significance of managing resources in supply part of the equation.

3.2 Supply drivers of global food security

3.2.1 Availability of arable lands

The total availability of arable lands has not kept pace with demand for expanding cropping land. Data presented in Figure 3 show changes in agricultural land area in 2012 relative to the turn of the century (2000). They show that the cultivated land area has been generally static at about 38% of the global landmass and are consistent with recent reports that expansions of cropping lands in some countries have more/less cancelled out ongoing reductions in others (http://data.worldbank.org/indicator/AG.LND.AGRI.ZS). There is a mostly negative relationship between FS scores with expansion in cultivated land area amongst nations. This may be because the new farmlands are unlikely to be used to cultivate food crops for local consumption. They are often developed by large international commercial entities to produce feedstock for biofuels and animal feed, or cash crops for export, in addition to timber, at the expense of local food crops. This has created the new phenomenon of *land grab* (Borras et al., 2010; Van Asten et al., 2011). For example, in the tropics and subtropics, expansions in farmlands have often been into high rainfall forest ecosystems in Indonesia (IDN) and Uganda (UGA), and used to cultivate crops for biofuels such as oil palm in Southeast Asia, Jatropha in Africa and sugarcane in South America (Gao et al., 2011). A recent global study found that 40% of new Jatropha plantings in 2011 were on land cleared of pre-existing native vegetation primarily for logging, while only about 25% of new Jatropha farms were on previously cropped or grazing lands (Walmsley et al., 2016).

[insert Figure 3 near here]

Meanwhile, cultivation of food crops for human consumption remains confined to poorly managed farmlands that are under threat of degradation with the result that further expansion of cropping is increasingly into fragile and marginal lands that have low productivity potential. In many parts of East Africa, expansion in small scale dairy production has been into drier environments (Mwendia et al., 2016). Indeed, total area of cultivated land generally exceeds arable lands in many countries (Table 1), suggesting that farming of marginal and ecologically fragile landscape is widespread. This is especially so in countries with montane landscapes such as Papua New Guinea, Ethiopia and Columbia. A similar phenomenon is being observed with cropping in Australia expanding into drier environments (T Farrell, pers. comm). In either case, the new farmlands by their ecological fragility are prone to erosion and general degradation that can quickly nullify any newly acquired intrinsic gains in production.

[insert Table 1 near here]

In the majority of the countries that have experienced expansion in land clearance for farming, therefore, it has not been matched with increases in the production of local food crops to raise GFS scores. In industrialised countries meanwhile, contractions in cultivated land area are mostly the result of peel back of farming from fragile marginal farmlands with low productivity that are returned to nature conservation purpose without measurable penalty FS scores (Figure 3). In Australia, for instance, the area devoted for conservation has increased by more than 50% (~ 100 M ha) between 2000 and 2011 (DSEWPaC, 2011). Increased afforestation was also identified as a major contributor to the contraction of farmed land in Poland (Ciołkosz, 2011). Conversion of farmlands to conservation in USA was also used historically to reduce production and hence cost of storage of surplus grain stock (McDonald, 2016). Despite experiencing contraction in agricultural lands, these countries maintained high FS score through high crop productivity. These contrasting FS outcomes from changes in cultivated area between developed and developing economies are predicated on technology that underpins intensification of farming systems. It has been estimated that the global amount of land required to produce a given amount of crop is at least 30% less today than it was 50 years ago, driven mostly by the productivity gains in the industrialised countries (Ausubel et al., 2013). Such gains were underpinned by advances in technology both in materials and processes used in agriculture and some of these will be considered further later here.

3.2.2 Water resource: availability and use in agriculture

Water is the most critical of all land resources underpinning agriculture. However, a casual observation of freshwater-use would fail to find a significant link between its use for agriculture and GFS scores amongst nations. Thus, when considered across all countries, the quantum of water-used in agriculture appeared to have limited contribution to food security outcomes (Figure 4, blue dash trend line/spline). This is contrary to expectation and common wisdom that food security can be further enhanced by increasing allocation of water resources to agriculture, which already accounts for about 70% of total freshwater-use in most countries (Godfray et al., 2010). Moreover, increasing competition for limited fresh water supply by domestic and industrial users and environmental needs makes further increases in irrigation allocation difficult.

This however, does not totally obviate the importance of water as a resource in agricultural production and hence GFS. This is clearly revealed by the relationship between FS score and agricultural water-use when we factored into the analysis the ratio of precipitation to evapotranspiration for the countries considered (Figure 4). This approach reveals three distinct patterns in the intrinsic impact of agricultural water-use on global food security. The first pattern identifies countries (symbolized by solid blue squares) that show apparent statistical “independence” of food security from agricultural water-use; these all have FS score ≥75% (Figure 4). In these countries, food security is insensitive to the quantum of water input into agricultural production. These countries are located at high latitudes, where atmospheric water demand (evapotranspiration) and supply (precipitation) are either closely matched or the supply exceeds the demand.

[insert Figure 4 near here]

The second pattern revealed a group of countries (red triangles) that includes Australia, Spain, Israel, Greece, Mexico and Saudi Arabia, where FS scores are high and positively correlated with agricultural water-use. These countries have substantial imbalance in their supply-demand for water, i.e. precipitation is well below evaporation. Therefore, the relatively high-water allocation to agriculture (≥ 300 m^3/year per capita agricultural water) arises from irrigation that underpins high food production and, hence, high FS scores (Figure 4, red trend line). Inclusion of Japan and South Korea in this group, where despite precipitation exceeding evaporation, is unique and is because paddy rice dominates agriculture and hence the high (>90%) allocation of water resources to agriculture.

The pattern showed a group of countries that includes Brazil, US and Chile, which have either parity between supply and demand or the supply exceeds demand. Normally, these countries are not expected to lie within the cloud of points relating agricultural water supply and food security score, but do so (Figure 4, red trend line). This “anomaly” may be partly the result of the strong seasonality in the cropping being mostly confined to periods of low evaporative demand. The seasonality and the production mix (high value crops such as fruit crops and vegetables) may contribute to the observed anomaly in these countries.

Thus, once precipitation-evapotranspiration balance is taken into account a positive dependence of food security on agricultural water-use will emerge for a majority of the countries (Figure 4, red trend line).

3.2.3 Water resource availability and industrialisation

The unexpectedly weak impact of agricultural water allocation on food availability and food security, suggests other factors must be exerting strong influence on converting water input into crop productivity. Deriving high productivity from water input requires efficient management of the precious water resources, along with other inputs, through development and deployment of appropriate technologies. This can be evaluated by taking industrial water-use as surrogate for technological development in crop production systems both on the farm (e.g. tillage, seed technology, crop protection and agronomy) and in supporting services (extension, input supplies, machinery, financial services, marketing, etc.). It is unsurprising that food security of nations shows strong dependence on per capita industrial water-use (Figure 5) to reflect the general industrial and/or economic development of the various countries. This is because countries with high level of economic development have a correspondingly high capacity (economic, technological and skills) to access food either through local production or from global market or both to achieve high GFS score.

[insert Figure 5 near here]

Crop yields (production per unit land area) are as such generally higher in industrialised agricultural systems than they are in less technologically advanced countries. Using the USDA data on productivity of grain crops (www.fas.usda.gov/data/grain-world-markets-and-trade) for instance, the mean yields for coarse grains in recent years are larger in South Africa (3.75 t/ha) by nearly a factor of two than in Nigeria (1.38 t/ha). This disparity in yields can be associated with differences in efficiency of delivery and utilisation of input resources as well as timely implementation of management decisions. Khan et al. (2006) in their comparison of irrigated agriculture in the semi-arid environments of Australia, China and Pakistan, found that losses of water during conveyance and on-farm were minimal in Australia compared to the other two countries. Consequently, the on-farm net water availability in China and Pakistan was less than half that in Australia. These differences in the management technologies and outcomes were consistent with FS scores achieved these countries presented in Table 1: Australia (82.6), China (65.6), Nigeria (39.4), Pakistan (47.8) and South Africa (62.9). Efficient practices and technologies are generally the products of research and development (R&D) and their subsequent adoption. Sustaining and further improving upon current productivity gains requires substantial investments in R&D. Efficiency gains such as these are reassuring and go a long way in reducing the overall environmental burden of food production (Davis et al., 2016), which can be further dimmed with further developments in technology and techniques.

3.2.4 Research, development and innovation

Investments in agricultural research and development closely reflect technological and economic development of a country, and directly impact its FS score. The contribution of the research and development (R&D) to the attainment of GFS ideals can be effectively captured through the quantum of its outputs, primarily publications in refereed scientific journals. Data on publications in refereed journals are more readily accessible for majority of countries than data on the monetary value of R&D investments. Publication data provide an added advantage as a credible reflection of the effective management of the resources allocated the sector. Using the per capita publications for several decades should measure the benefits of agricultural R&D over the long-term. A strong positive impact of scientific publication output on GFS scores identifies 16 bins (discrete vertical line-up of data points distributed along the x-axis) with the first one consisting only of Yemen that had the lowest GFS score and the least publication output, while at the top bin has the USA as a lone member and the most output (Figure 6). The GFS benefits of publication output became particularly apparent from 70 papers over the 60-year period, additional papers up to 800 yielded especially strong GFS benefits in these predominantly middle-income countries (bins 8 to 12) and where research investments focus on productivity as priority. The top four (13 –16) bins consist of predominantly rich and technological advanced countries each publishing over 800 papers and where research investments address issues beyond productivity to include issues of environmental sustainability. China and India in the second and third bins, respectively, have much lower GFS scores than their technologically more advanced countries in their respective groups. This GFS relationship with publication output underscores the importance of continued effective investment in this sphere to underwrite the food security of future generations. Research and development play significant roles in enhancing both the volume and quality of production in developed economies, where rapid productivity gains have been recorded in recent years (Alston et al., 2009).

[insert Figure 6 near here]

Undertaking international comparisons of R&D expenditure is difficult due to differences in cost of inputs. Pardey et al. (2016) therefore used purchasing power parity to account for the significant price differential for similar goods and services amongst countries to provide comparable global data. Investment in agriculture R&D is dominated by developed economies that account for over 60% of the total global research expenditure (Alston and Pardey, 2006). Examples presented in Table 1 show that R&D investment in Ethiopia with a population of 94 million translated to a per capita value of $0.80 compared with $6.26 for South Africa, $4.24 for Colombia and $3.48 for China. This disparity in per capita investment in research notwithstanding, research output per unit investment in many developing economies are small fractions of those in developed economies such as USA, Australia and Germany (Table 1).

A further demonstration of R&D driven productivity gains is apparent in the average cereal yield that also broadly reflects pa capita agricultural R&D investment (Table 1). Investment in agricultural R&D has increased by several factors in the past 50 years, similar to the trend in the later years in 2000–2008, when these investments were mostly driven by the large countries in the various regions (Beintema et al., 2012). In Asia-Pacific region, China along with India account for 90% of the growth in agricultural R&D investment, while Nigeria is the dominant investor in sub-Sahara Africa. These growths in R&D investment are reflected in increased cereal yields by over 50% in the past decade, along with improvements in GFS scores, in recent years in these countries (Table 1). The exception was Australia, where there were slight declines in the yield largely due to the prolonged drought during much of the first decade of this century termed *Millennium drought* (Annonymous, 2016); this caused widespread crop failures, and was in addition to 27% yield reduction associated climate change (Hochman et al., 2017). These losses were partly compensated for by an expansion of cropping to marginal lands increasing the total cropped area by 13.5%, and possibly contributed to the doubling of production of winter cereals, between 2002/03 and 2012/13 in Australia (http://www.agriculture.gov.au/abares/publications).

The high crop productivity experienced in countries with large R&D investments can thus be associated with efficiency gains (Figure 6), i.e. producing more with less. For instance, rice yield in the US is larger by a factor of more than 2.5, but used just 3% of the water, than in India (2.93 t/ha) partly by minimising in on-farm water losses (Chapagain, 2009). This is consistent with comparatively small losses of water (<50%) in conveyance for rice farms in Australia compared to those in China and Pakistan (Khan et al., (2006).

Significant increases in agriculture R&D investments of at least 50% over the levels of decades ending in 2010 are required in the next decade to ensure future global food security in developing countries (Fischer et al., 2014). In light of their low R&D capacity, many of these countries obtain support for R&D activities through international research centres in the Consultative Group of International Agricultural Research (CGIAR) network. It is to be noted, however, that R&D investment by and in itself would not necessarily guarantee productivity benefits, and correlations between GFS and long-term research expenditure may be generally weak, especially so in developing economies. This is because resource allocations for R&D are not effectively used for such purpose in many countries. Furthermore, poor technology transfer and adoption can confound benefit of research investment and its correlation with productivity. Deriving full benefits from investments in R&D and extension/technology transfer activities require efficient management of the allocated resources ensuring that these are used for what they are intended. Governance is thus a critical factor and will be considered further.

3.2.5 Governance and social stability

The state of the civil governance impacts both the demand and supply sides of global food security, it is imperative to consider this further. Corruption perception of a country provides a credible surrogate for the state of governance. It is evaluated using the Corruption Perceptions Index (CPI) compiled annually by Transparency International (http://www.transparency.org/country). The CPI is thus an appropriate surrogate for the operating environment for the whole of the value chain in the food system, including affordability and quality of food. As shown earlier (Figure 1), there was a strong negative correlation between GFS scores and CPI amongst the countries of the world. Extreme forms of governance failures often lead to poor state of security, law and order, and even complete breakdown of law and order as precursors to civil wars. Hence, GFS score for Syria has fallen from 42.0 in 2012 to 36.3 in 2016 and in Ukraine from 58.4 to 55.2. The ability and willingness of nations to enshrine effective decision making, appropriate polices and implementation, and accountability, all profoundly impact the whole of the food system directly and indirectly through general welfare of the community. Indeed, food affordability has been found to be strongly correlated with political openness of countries (http://foodsecurityindex.eiu.com/Resources). This is consistent with our observation that countries with CPI >60 generally have GFS score >70, while those with CPI <50 have precarious GFS scores that are often <40% (Figure 7).

[insert Figure 7 near here]

Countries with low CPI tend to have disjointed policy making and implementation that are spread across several agencies and regulatory authorities that severely restrict desired impacts of policies and strategies, while promoting inefficiencies. Such a fragmented approach leads to inconsistency, overlap, wastage and poor outcomes in both the demand and supply sides of food systems (Slade and Wardell-Johnson, 2013). Often the civil service tends to be lowly paid and unmotivated, and thus unresponsive to the responsibilities of their positions (Economist, 2015). Where such attitude permeates much of the socio-economic environment, malnutrition and subsequently low life expectancy are often the result (Uchendu and Abolarin, 2015). To the extent that high CPI is associated with accountability and responsive governments, such governance systems help improve food security of countries such as Singapore, where the high GFS score is underpinned by reliance on food imports (https://knoema.com/cduhihd/world-exports-and-imports-of-agricultural-products). A deficit of accountability in many other countries such as Nigeria and PNG also partly explains the low research output from the investments made in R&D such that average cost for a paper is several factors larger in these countries than in Australia and USA. In addition to differences in technological development, governance partly explains the vertical distribution of countries within individual bins in the publication-GFS score relationships (Figure 6).

The state of governance therefore outweighs all other extenuating factors either on the supply or demand side of GFS. Complete failure of governance often culminates in civil unrests and wars and extreme cases of food insecurity. Recent examples of these are seen in Yemen, South Sudan and parts of Nigeria (Wade, 2017). In such environments, the impact of population on GFS also begins to manifest to further exacerbate hunger and malnutrition currently affecting an estimated 70 million people worldwide (Wade, 2017).

3.3 Summary and concluding remarks

Attainment of Global Food Security is complex and involves interactions amongst a number of biophysical, economic, social and technical challenges. The acceptance of this common narrative is accentuated by the fact that the majority of global population (85%) lives in the driest parts of the globe, primarily in the developing countries that would account for almost all of the projected growth in global population (Alexandratos and Bruinsma, 2012). This unfortunate confluence of population, which is the primary driver on the demand side, and declining availability of freshwater resources strike a chord with the popular narrative as the existential threat to GFS. This is especially evident through most of sub-Saharan Africa between 15^{o} N and 23^{o} S and in southern Asia across India and Bangladesh between 23^{o} and 30^{o} N. In these regions, weak economy and/or technology base have constrained development of the latent water resources for agricultural and other uses. These regions were identified as being particularly vulnerable to declining rainfall and droughts associated with climate change (Gregory et al., 2005; Hanjara et al., 2010).

The arguments and available supporting evidence presented here, however, suggest a weak association between GFS and either population or gross availability of water resources and their use in agriculture. We have shown here that the manner of use of the water resources rather than availability has a far greater impact on GFS situation, such that industrialised countries with the technological knowhow have been successful in meeting supplies of affordable quality food products. Farmers in these technically advanced economies such as Australia are close the upper limits of their biophysical productivity potential with the current conventional technologies with limited scope for further significant gains (Fischer et al., 2014). This suggests that the potential for significant quantum increase in global food production resides mostly in the developing countries.

Policies for attaining GFS should therefore prioritise R&D investments that unlock productivity potential in these countries, where the potential for relative productivity gains is larger than in the developed economies (Fischer et al., 2014). Increased agricultural R&D to boost production for enduring food security has been emphasised even for a country such as China that is apparently self-sufficient in food production (Anderson and Strutt, 2014). The second policy priority is to improve governance in the research, extension and production value-chain, primarily responsible for the generally poor return on RD&E investments. This policy priority is in fact badly needed in the overall governance of a nation state in the vast majority of developing economies.

In conclusion, of all the factors that we used in our analysis, population and water resources have the weakest impact on attaining GFS, while technical innovation through investments in R&D, while minimising mismanagement would raise productivity and security of food availability. The influence of the six factors on GFS score amongst countries was in the order: industrial water-use ≈ publication rate (R&D investment) ≈ corruption perception >> agricultural water-use > population. Therefore, GFS can be attained generally, but especially in the developing countries, through policies targeting investments in R&D and effective technology transfer mechanisms, while minimising mismanagement, unaccountability and corruption. These in conjuction with other important factors argued elsewhere such as credit access (IFC, 2014), equitable land tenure system (Maxwell and Weibe 1999), and promotion of urban farming (Zezza and Tasciotti 2010) can contribute to improvements in food security in low income and emerging economies.

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Compliance with ethical standards

Competing interests The authors declare that we have no conflict of interest in reporting this work.

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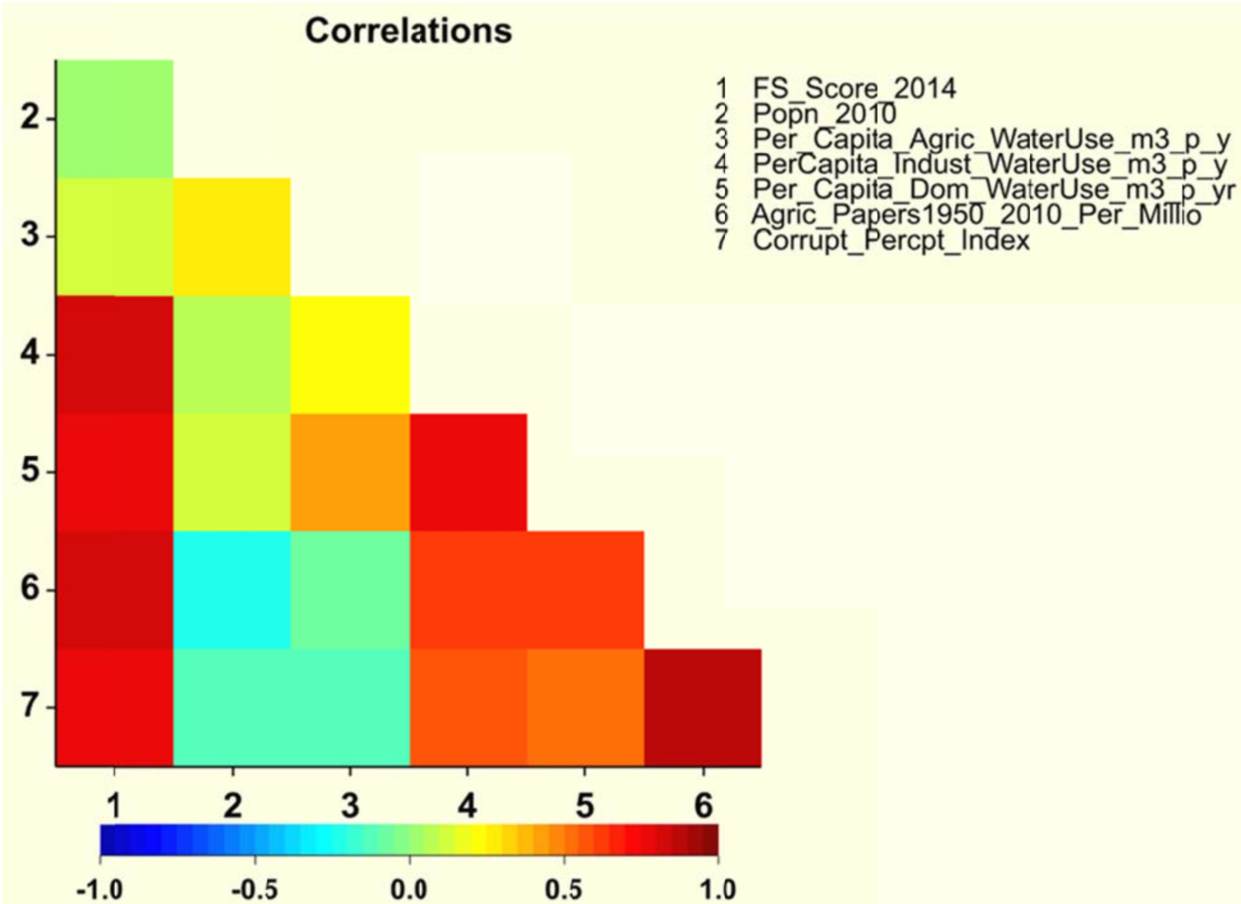

Figure 1. Summary of the strength of associations of food security status of countries with demand- and supply-side factors that are deemed to contribute and/or influence food security. All variables are natural log-transformed.

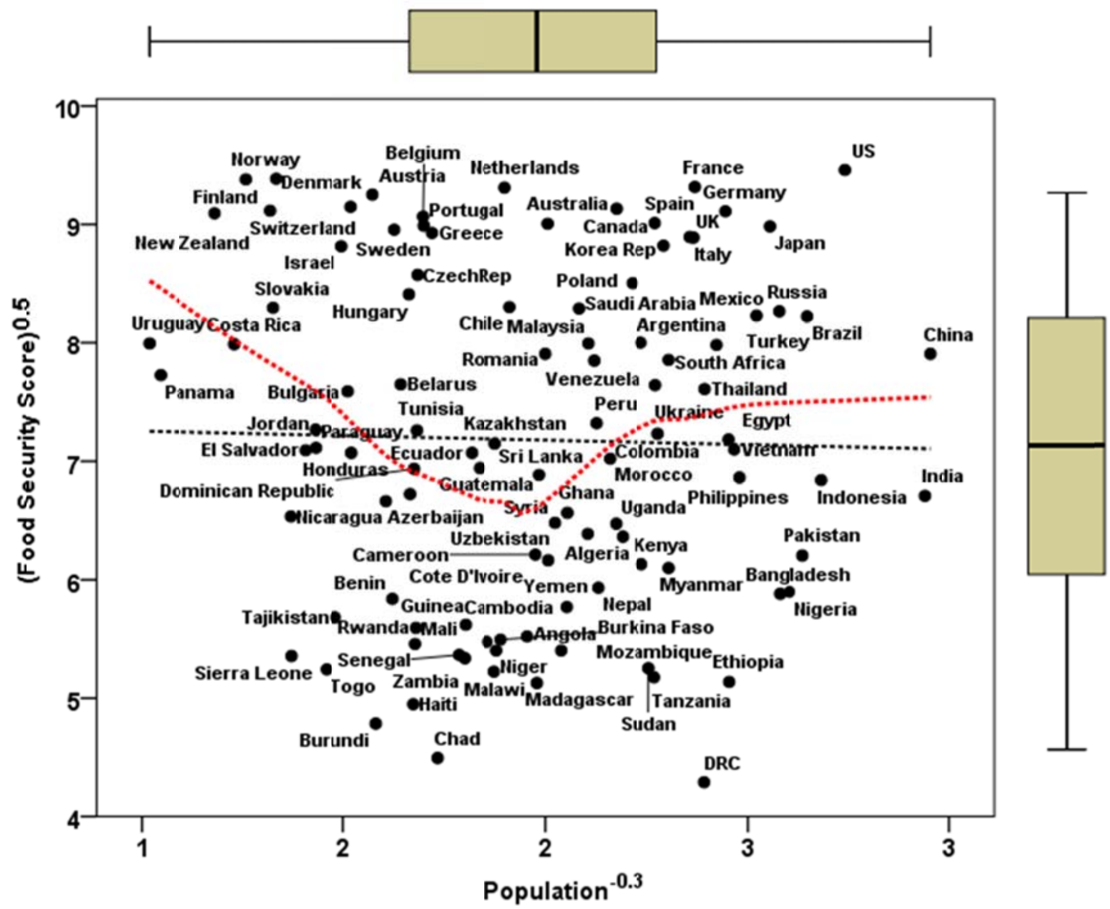

Figure 2. Relationship between population size and food security scores of nations (n= 104 countries).

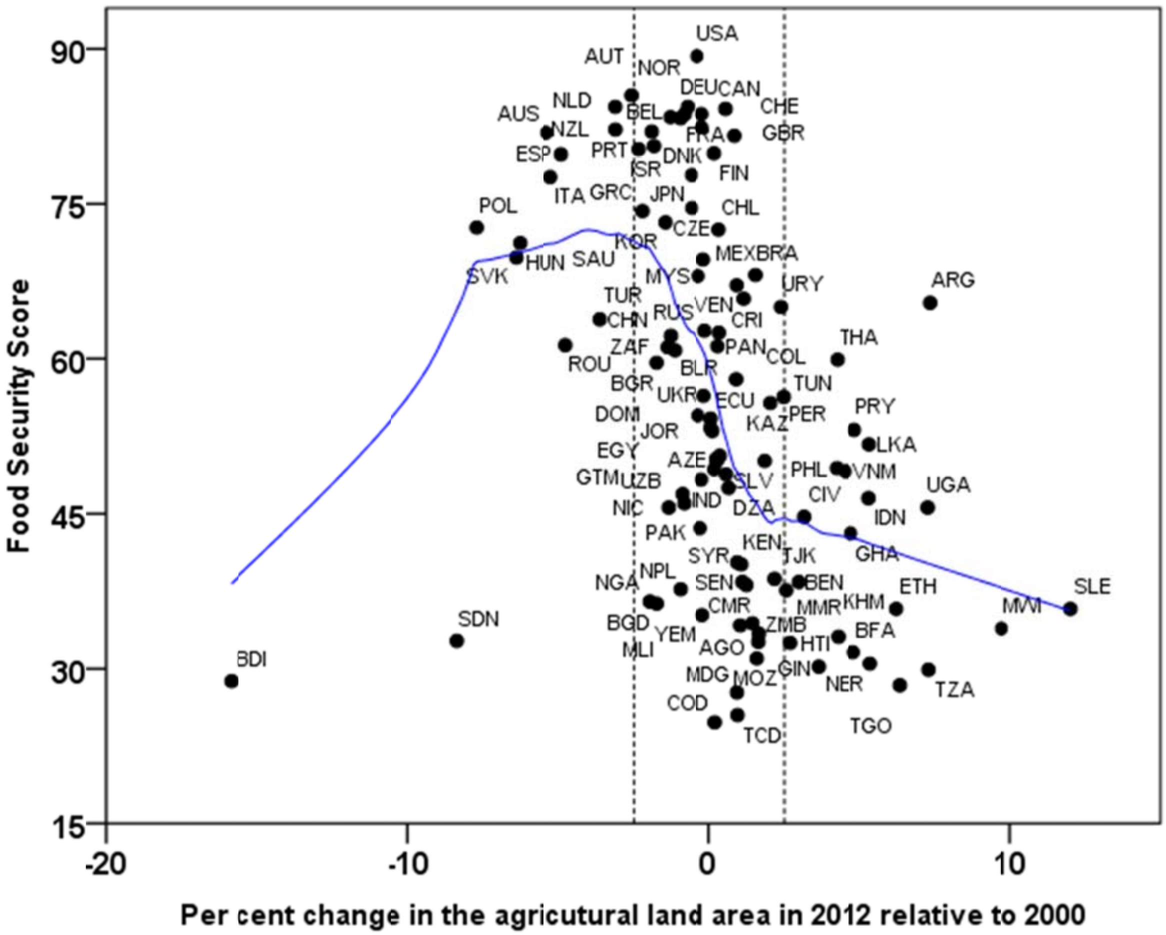

Figure 3. Changes in agricultural land area in 2012 relative to the turn of the century (2000).
Note: countries which increased their agricultural area tended to have low food security status.

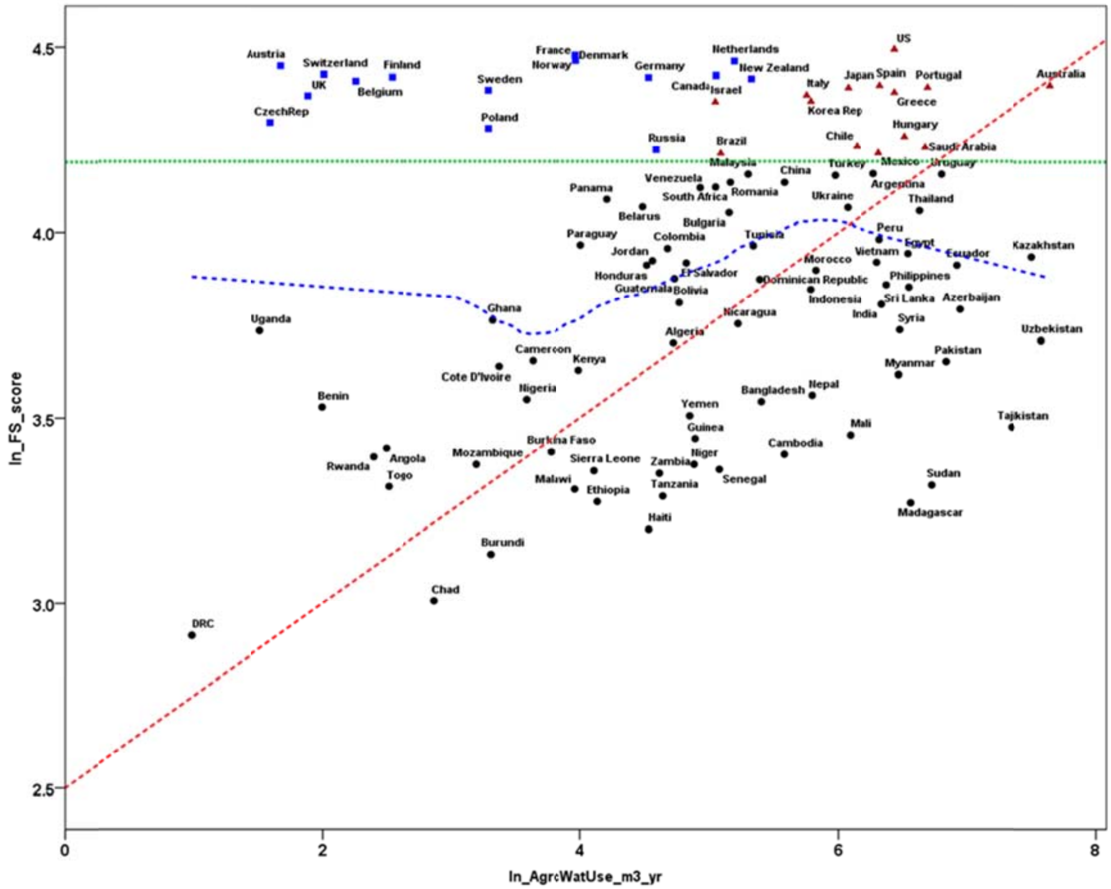

Figure 4. Relationships between logs of Global Food Security scores and of per capita annual water allocation to agricultural activities amongst countries (n = 103 countries): blue dash spline, overall pattern; green dash line (FS = 75%) separates countries into notionally “high” and “low” food security status; red dash line, trend line between FS and per capita agricultural water-use (solid circles and triangles), i.e., excluding high latitude countries with balanced atmospheric water demand and supply (blue rectangles).

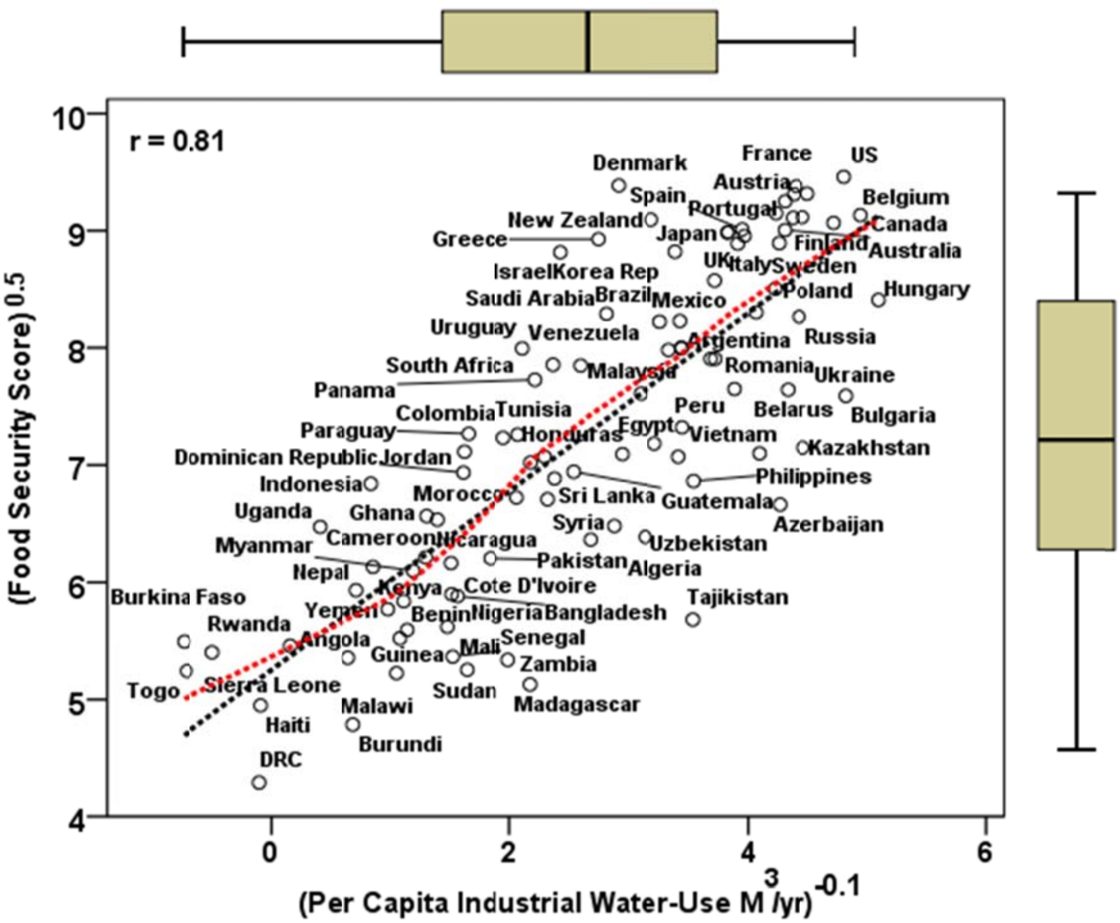

Figure 5. Apparent positive association between the food security status of nations and their per capita industrial water consumption. Note the tight alignment between the spline (dashed red) and fitted (dashed black) lines

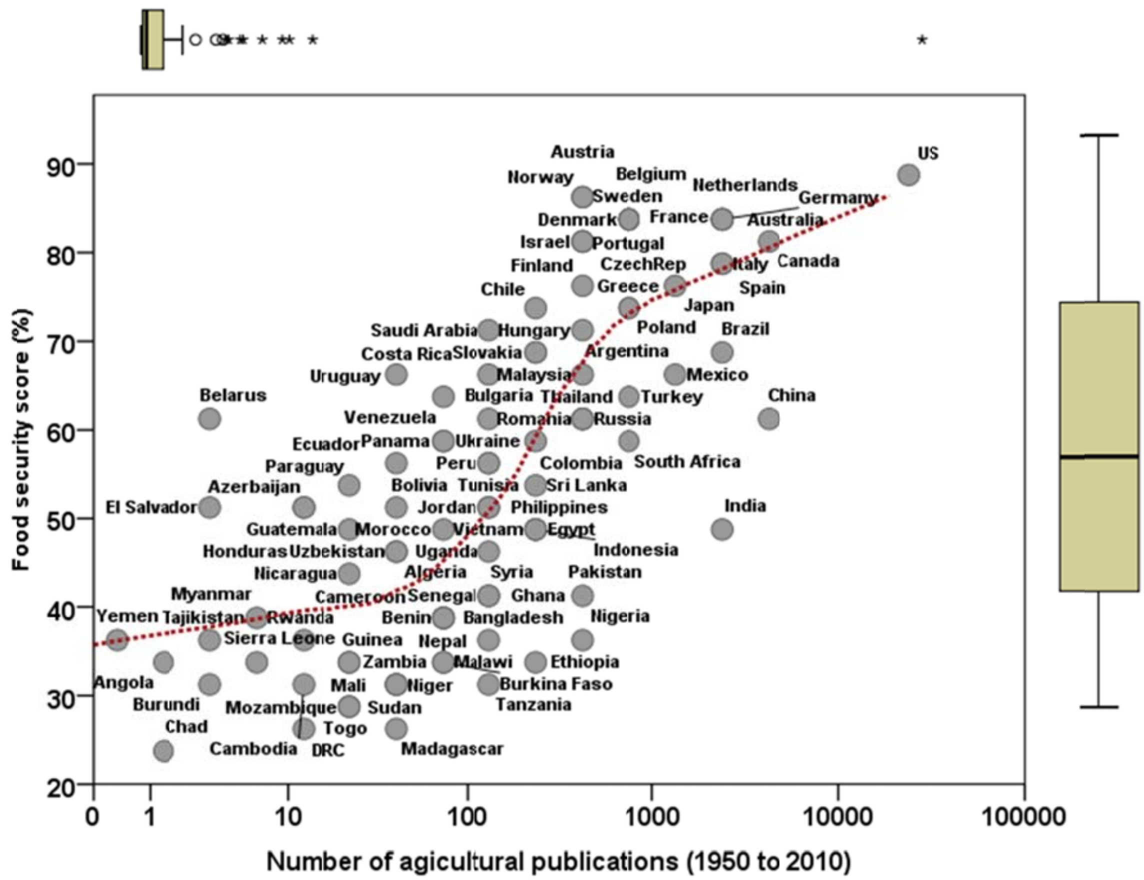

Figure 6. Apparent relationship between food security scores of nations and agricultural publications per million of population used as a surrogate for investment in agricultural research. Publication was total number of papers published between 1950 and 2010.

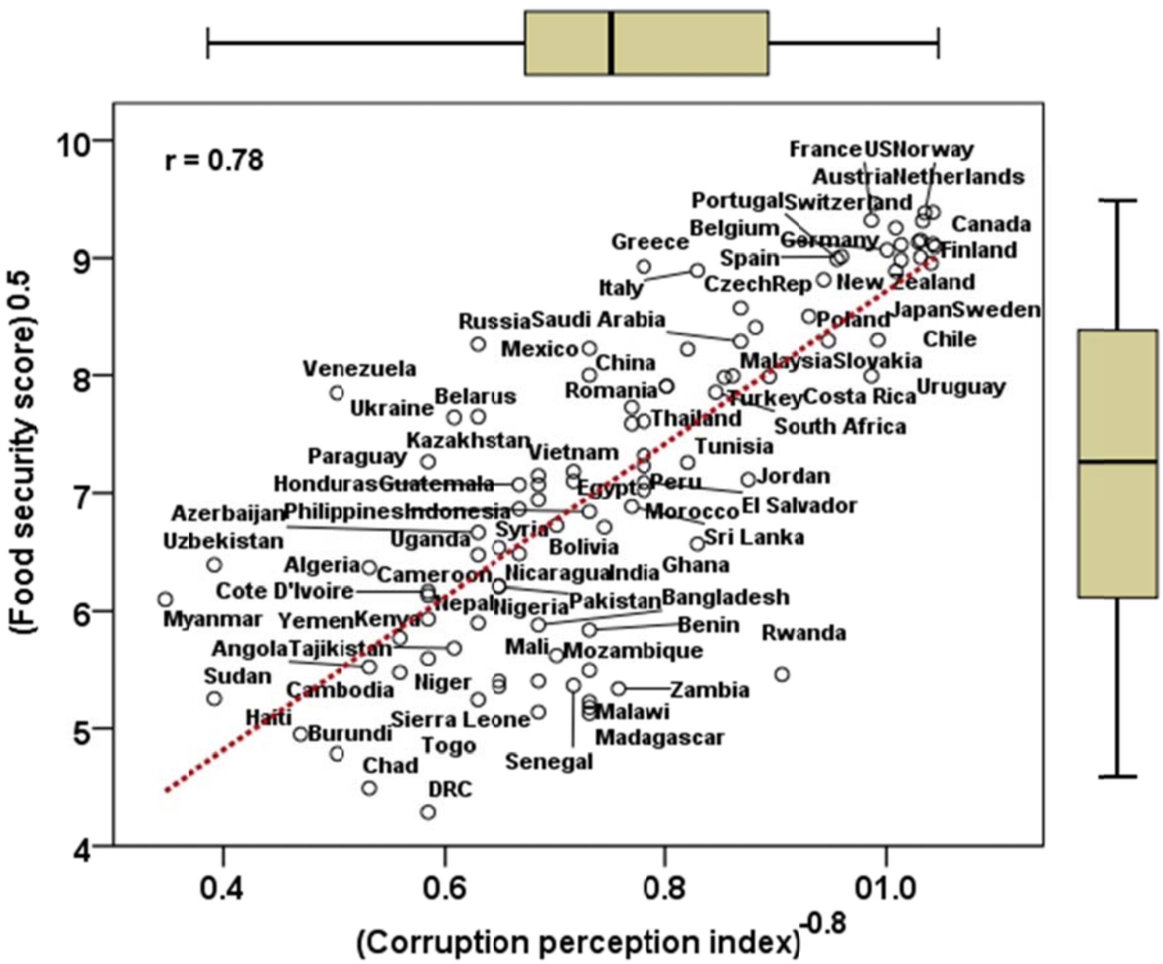

Figure 7. Global Food Security Score and Corruption Perception Index for countries

Table 1. Selected key demographic, agricultural and crop productivity parameters for selected countries

Key Indicators	Australia	USA	Germany	Ethiopia	Nigeria	South Africa	China	Bangladesh	Indonesia	Singapore	PNG	Brazil	Chile	Columbia
Population density (no./km^2)[a]	3.2	33.0	230	96	202.0	43.0	143.3	1123.6	137	7797	16.0	24.0	22.0	43.0
Global Food Security Score, 2016 (% over 2012)	82.6 (+2)	86.6 (-4)	82.3 (-1)	34.7 (+34)	39.4 (+13)	62.9 (+2)	65.5 (+5)	36.8 (+1)	50.6 (+8)	83.9 (n.a.d)	n.a.d	67.6 (0)	74.4 (+16)	61.0 (+17)
Arable land area ($x10^6$ km^2)[b]	0.469	1.650	0.116	0.113	0.301	0.148	1.385	0.055	0.201	0.001	0.222	0.586	0.022	0.021
Cultivated land areas ($x10^6$ km^2)[2]	0.472	1.700	0.118	0.119	0.329	0.157	1.504	0.061	0.333	0.002	0.856	0.661	0.022	0.351
Agric R&D Investment ($US million) in 2011 and change (%) from 1960[c]	493 (+200)	4403 (+252)	1189 (+204)	80 (+1832)	484 (+513)	338 (+43)	4723 (+1506)	195 (+803)	661 (+420)	210* (n.a.d)	27 (n.a.d)	1839 (+434)	84 (+277)	200 (+79)
Ave cost publication ($US/paper, $x10^3$)[d]	304	576	697	584	2762	674	0.905	1294	4170	3853	13500	775	423	571
Corruption Perception Index, 2015	79	83	81	33	26	44	37	25	36	85	25	70	70	37
Ave. cereal yields (kg/ha), 2005–2014, (% change from 1994–2004)[e]	1795 (-4%)	6812 (+23)	6922 (+9)	1786 (+55)	1456 (+20)	3764 (+59)	5580 (+16)	4154 (+38)	4768 (+20)	n.a.d	4397 (+16)	3914 (+44)	6187 (+32)	3485 (+15)

Data sources: [a]Wikipedia (https://en.wikipedia.org/wiki/List_of_countries_and_territories_by_population_density, accessed January 22, 2017); [b]Wikipedia (https://en.wikipedia.org/wiki/Land_use_statistics_by_country, Accessed January 22, 2017), [c]Pardey et al. (2016), except [*]Singapore from Anon (2014) all in purchasing power, parity; [d]based on R&D investment in 2011 and average number of papers published during 2012–2015; [e]World Bank (http://data.worldbank.org/indicator/AG.YLD.CREL.KG, accessed January 22, 2017); n.a.d., no available data.