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SUPPLEMENT ARTICLE

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An egg for everyone: Pathways to universal access to one of nature's most nutritious foods

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Abstract

Eggs are a highly nutritious food but have been shown to be infrequently consumed in many low-income countries, especially by women and children. We collate country-level data on egg production, availability, consumption, prices, industry structure, and contextual trends and use these to estimate current patterns and likely future outcomes under four alternative scenarios. These scenarios are as follows: incremental change based on expected economic growth and urbanisation (the base scenario); enhanced productivity of independent small producers; aggregated production in egg hubs; and the accelerated spread of large-scale intensive production. All scenarios are modelled out to 2030 using a mix of regression and deterministic models. We find that children's consumption of eggs is highly correlated with national availability, and both are a function of egg prices. Eggs are unavailable, expensive, and infrequently consumed by children in much of South Asia and sub-Saharan Africa. The base scenario results in modest increases in production in low-income regions. Focusing efforts on independent small producers can only boost rural consumption in a handful of countries where poultry ownership is unusually high and would be expensive and logistically challenging to scale. Aggregation of production, with minimum flock sizes of 5,000 layers per farm, is a more promising pathway to increasing availability in rural areas. To meet the needs of urban populations, large-scale intensive production is needed. Intensive production brings down prices significantly, allowing many more poor households to access and consume eggs. Recent experience in countries such as Thailand confirms that this is both feasible and impactful.

KEYWORDS

developing countries, diet/economics, eggs, infants, programme appropriateness, young children

1 | INTRODUCTION

Eggs are a highly nutritious food, rich in Essential Fatty Acids, choline, vitamins A and B12, and bioavailable iron, zinc, and iodine (Iannotti, Lutter, Bunn, & Stewart, 2014). The protein in the albumen is abundant, digestible, and complete, and the whole food is naturally "packaged" in a protective "container." With a few notable exceptions, almost all human populations enjoy eating them. They are uniquely positioned to advance the second of the world's Sustainable Development Goals (SDGs)—to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture (United Nations, 2015).

Consumption of eggs, however, falls far below optimal levels among mothers and children living in poorer countries. Lutter and Iannotti, writing in the first paper in this supplement (Lutter, Iannotti, & Stewart, 2018), have shown that in most of Africa and in India, only 13–15% of young children eat egg over a 24-hr recall period. In much of the rest of low- and middle-income Asia, only one fifth to one third of children were given egg, and levels of consumption among women of reproductive age were also found to be very low, especially among

women from households in the lower wealth quintiles. This is in spite of the fact that global egg production is substantial and growing: The Food and Agriculture Organisation (FAO) of the United Nations estimates that 1,387 bn eggs were produced in 2016, which is nearly one egg for every two humans on the planet each day (FAO, 2017).

Previous papers in this supplement (Dumas, Lewis, & Travis, 2018; Marquis et al., 2018) have shown that it is possible for poor rural communities in developing countries to increase their egg production and that increased egg consumption for young children can result. While not a focus of this supplement, other authors have documented the rise of large-scale commercial egg producers, which are expanding rapidly in countries such as Thailand, India, Saudi Arabia, and South Africa (Mehta & Nambiar, 2007; Narrod, Tiongco, & Costales, 2007; WATTAgNet, 2017; Windhorst, 2014). In this paper, we (a) summarise information on the current status of egg availability and consumption, (b) identify the most important demand- and supply-side barriers to greater consumption of eggs, especially by children, and (c) determine which interventions could accelerate egg consumption by 2030, the end of the SDG period.

Key messages

- Eggs are cheap, available, and frequently consumed by young children in high- and middle-income countries; they are expensive, scarce, and rarely consumed by children in much of Africa and South Asia.
- Most countries produce eggs almost exclusively in intensive systems once Gross Domestic Product per capita reaches USD 10,000. This brings down prices, making eggs accessible to poor consumers.
- Trying to improve the productivity of individual small-scale producers is unlikely to significantly improve egg consumption at national level.
- An egg hub model that aggregates clusters of medium-scale producers might increase access to eggs for many poorer countries.

2 | METHODS

This paper synthesises existing knowledge from peer-reviewed and grey literature and supplements it with new analyses taking the country as the primary unit of analysis.

2.1 | Data

Data on poultry ownership and recent consumption of eggs among young children are from the representative household surveys of the Demographic and Health Survey series (www.dhsprogram.com). Data on egg availability are taken from the Food Balance Sheets of the FAO (www.fao.org/faostat) and refer to the most recent year available (2013). These estimates start with domestic production, add net imports, and subtract losses and nonfood uses to determine the quantities available for domestic consumption. Divided by the total population, as estimated by the United Nations Population Division (2014), we treat this quantity as a measure of per capita egg availability for consumption. Where egg statistics are reported by weight, we convert to egg units on the assumption of one egg = 50 g.

Egg prices at the national level are expressed relative to the price of the cheapest cereal staple in each country (market cost per kilocalorie equivalent of produce, in each case). This approach follows Headey and Alderman (2017), who argue that these cereal-relative prices capture the cost of diversifying the diet away from starchy staples. Price data are principally sourced from the World Bank-led International Comparison Program data for 2011 (World Bank, 2015).

We distinguish between eggs produced under extensive, versus intensive, conditions. Extensive production systems are village or backyard poultry with minimal biosecurity and birds and eggs consumed locally; this is referred to by FAO as “Sector 4” (FAO, 2004). Intensive production systems are commercial operations with larger flock sizes, higher investment in inputs, and a market orientation. Gilbert et al. (2015) have estimated the proportion of chicken kept under extensive and intensive systems in each country, and we use the same data. We assume that, on average, 50% of intensive chickens are broilers and 50% layers.

For the development of predictive scenarios for 2030, we use the United Nations predictions of population totals disaggregated by urban and rural domicile (United Nations Population Division 2014) and the U.S. Department of Agriculture Economic Research Service predictions of real Gross Domestic Product (GDP; USDA, 2017). For our base scenario, we use FAO estimates of total future egg production (FAO, 2011). These forecasts are based on spatially mapped projections of both supply and demand, taking into account expected population change, economic growth, and environmental characteristics.

2.2 | Statistical methods

For descriptive analyses by region, we aggregate individual country data using population-weighted means, with each country's weight equal to the ratio of a country's population relative to the region's total population. Regional groupings are as per the World Bank.

We use robust regression (Verardi & Croux, 2009) to explain cross-country patterns in two measures of consumption: (a) egg availability for consumption, because this incorporates potential consumption by both adults and children; and (b) recent reported consumption by children aged 12–23 months. We model these two consumption indicators as a function of GDP per capita (an income proxy), urbanisation (proportion of the population living in urban areas, which reflects improved market access), egg prices relative to the cheapest cereal staple food (which reflects the cost of diversifying consumption out of cereals into eggs), and a dummy variable for India, which has unique cultural restrictions on egg consumption. This dummy variable tests whether India is a significant outlier compared with the rest of the

sample. We then also use robust regression to elucidate why some countries have much higher relative egg prices than others. To do so, we regress egg prices on GDP per capita, urbanisation, and a key measure of commercialisation in the poultry sector: the predominance of intensive versus extensive poultry farming systems (proportion of chicken raised in intensive systems). We use out-of-sample predictions to estimate potential changes in national levels of availability and consumption given expected future levels of the independent variables.

Regression analyses were undertaken using Stata v.14 (College Station, TX).

3 | RESULTS

3.1 | Current status of egg production, availability, and consumption

In sub-Saharan Africa and South Asia (excluding India), 40–50% of rural households report owning poultry (Table 1). However, flock sizes are very small—typically from five to 20 birds (Birola et al., 2010; Guèye, 1998; Pica-Ciamarra & Dhawan, 2010)—and productivity is also very low—30–80 eggs per hen per year in unimproved systems (Wong et al., 2017). Although intensive production systems bring together far larger flocks and achieve much high egg yields, there are relatively few commercial egg producers in the world's poorest countries. In fact, Gilbert et al. (2015) find that "below 1,000 USD [GDP] per capita, over 90% of chicken are raised under extensive systems and the transition from extensive to intensive production really occurs between 1,000 and 10,000 USD per capita; above which most chickens are raised in intensive systems." Based on their mapping, Gilbert and colleagues estimate that 96% of the world's chicken are raised under intensive conditions. This number falls to 70% in sub-Saharan Africa as a whole and 15% in Burkina Faso, for example. Adjusting for the (assumed) proportion of chicken raised for meat ("broiler" chickens) and the differential productivity of intensive and extensive production systems, we estimate that 93% of the world's *eggs* are produced in intensive systems. Three quarters of the world's egg production is concentrated in just 14 countries; none of these are in Africa (FAO, 2017), but India is the third largest egg producer in the world.

As expected, egg availability and consumption also vary greatly across the world's major regions, and we find that availability and children's consumption levels are highly correlated (r = 0.55, p < 0.01). The only sub-Saharan African countries with egg availability in excess of 70 per person per year are South Africa, Cabo Verde, and Mauritius (Figure 1); in South Asia, only Sri Lanka exceeds this threshold. Egg consumption in the past 24 hr is not available for high-income countries, but almost half of young children in Latin America and the Caribbean consumed eggs in the 24 hr prior to the survey, and egg consumption is also reasonably prevalent in other predominantly middle-income regions (Table 1). However, in Africa, just 12.6% of children consumed eggs prior to the survey, and in India—where around one third of adults classify themselves as vegetarians who never consume eggs or flesh foods (2014 Sample Registration Survey cited in Bose, 2016; NHFS IV cited in Bansal & Kishore, 2018)—just 14.7% of children consumed eggs in a 24-hr period, a level much lower than other South Asian countries (25.0%). Children's egg consumption in India is not particularly high even among households where the mother states that she does consume eggs (19.0%).

3.2 | Prices and other constraints to demand

Across the world, eggs are expensive relative to staple cereal crops. In high-income countries, egg calories are 2.3 times as expensive as the cheapest cereal in a country, reflecting the tremendous gains in layer chicken productivity in rich countries in the 20th century, as well as large economies of scale achieved through commercialisation (Narrod et al., 2007). In other more developed regions such as Latin America, Eastern Europe, and Central Asia, a calorie of eggs is three to five

TABLE 1 Regional variation in poultry ownership, egg consumption (children), egg relative prices, and national income

	Chicken ownership (% of households)[a]	Per capita egg availability for consumption per year[b]	Egg consumed in the past 24 hr, children 6–23 m (%)[a]	Ratio of egg price to cereal price (in calorie terms)[c]
High-income countries	NA	265	NA	2.3
Latin America and Caribbean	12.8%	218	42.8%	4.8
Middle East and North Africa[d]	20.5%	129	30.8%	5.4
Eastern Europe and Central Asia	28.8%	238	34.0%	3.6
East Asia[d]	65.6%	241	20.8%	7.1
South Asia, excluding India	43.4%	50	25.0%	5.9
India	16.3%	52	14.7%	4.7
Sub-Saharan Africa	49.2%	40	12.6%	9.5
Cross-country correlation with egg availability per capita[e]	−0.06	N/A	0.55***	−0.59***

Note. FAO: Food and Agriculture Organisation.

[a]Sourced from the Demographic Health Surveys (ICF-International, 2015) for 46 countries. [b]FAO food balance sheets (FAO, 2017), assuming average egg weight of 50 g. [c]Sourced from Headey and Alderman (2017) estimates from the 2011 International Comparison Program data on food prices in 151 countries and various estimates of calorie content of egg and various staple cereals. [d]For these regions, Demographic and Health Survey data are only available for a handful of countries and should therefore not be treated as representative. [e]Bivariate correlations with FAO food balance sheets (FAO, 2017) estimates of egg consumption per capita for 177 countries.

***P < 0.01.

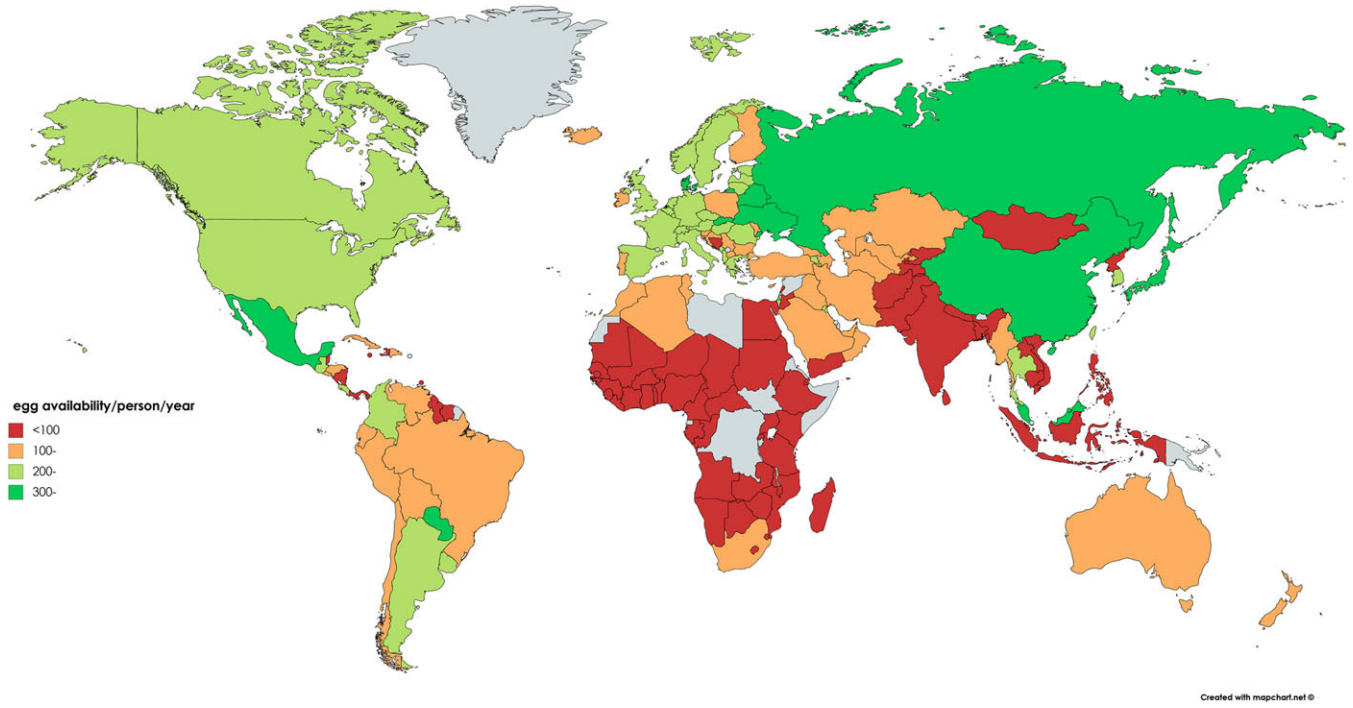

FIGURE 1 Current egg availability by country

times as expensive as the cheapest staple cereal. In India, the poultry sector has commercialised rapidly in recent decades and been one of the fastest growing sectors in the agricultural economy (Mehta & Nambiar, 2007). This, along with relatively modest growth in demand, has kept egg prices lower in India (4.7 times as expensive as rice) than in many other economies at a comparative level of development. In the rest of South Asia, eggs are around six times as expensive as cereals, implying that high prices will be a constraint for many households. In sub-Saharan Africa, the world's poorest region, eggs are 9.5 times as expensive as cereals, on average.

We hypothesised that international variation in egg consumption indicators would be highly sensitive to the price difference between eggs and cereal staples. We tested this in a regression model, controlling for national income (GDP per capita) and the proportion of the population living in urban areas (Table 2). We looked at both per capita availability, using the FAO indicator, and actual consumption of children aged 6–23 months. The first regression model in Table 2 suggests that every 2.5% increase in GDP per capita, or in the proportion of the population residing in urban areas, leads to approximately a one-egg (50 g) increase in per capita availability per year. And although relative egg prices are strongly correlated with GDP per capita (r = −0.66***) and urbanisation (r = −0.47***), relative prices remain a strong independent predictor of egg consumption, even after controlling for these other factors: A one-unit decline in the egg price ratio relative to cereals predicts an increase in per capita availability of approximately four eggs per year, based on standard egg weights. Hence, transitioning from a price ratio of 12 (Burkina Faso) to a level of six (Bangladesh/Indonesia) would predict a 1.3 kg/year increase in per capita availability for consumption or around 24 eggs more per capita per year, based on standard weights. We observe similar patterns of association for the egg consumption among children 6–23 months: Moving from Burkina Faso to Bangladesh price levels

TABLE 2 Robust regressions exploring the relationships between egg availability, consumption (children), and various demand- and supply-side determinants

Regression number		(1)	(2)	(3)
Observations (# countries)		N = 150	N = 60	N = 84
Dependent variable		Per capita egg availability (kg/year)	Children 6–23 months of age consuming eggs in the past 24 hr (%)	Relative egg calorie price (ratio to cereal calorie price)
Log GDP per capita	Coefficient	1.86*** (1.26 to 2.46)	9.21*** (3.01 to 15.41)	−0.36 (−1.13 to 0.40)
Log urban share	Coefficient	2.15*** (0.87 to 3.43)	4.40 (−6.00 to 14.80)	1.18* (−0.14 to 2.51)
Relative egg calorie price	Coefficient	−0.21** (−0.38 to −0.04)	−1.48** (−2.66 to −0.30)	
India dummy	Coefficient	−1.75 (−7.40 to 3.89)	−17.64 (−46.45 to 11.13)	−1.26 (−4.78 to 2.27)
Log intensive share of production	Coefficient			−0.08*** (−0.10 to 0.05)
R-squared		0.63	0.50	0.72

Note. GDP: Gross Domestic Product.

***p < 0.01, **p < 0.05, *p < 0.1. The three regressions are independent of each other.

would predict a nine-percentage-point increase in the prevalence of egg consumption in the past 24 hr (the result of multiplying a price change of six units by the regression coefficient of 1.48).

The low level of consumption of eggs among Indian children highlights the fact that cultural preferences can limit demand for eggs. Simoons (1994), in a wide-ranging review of food avoidances from prehistory to the present, notes that Hindus avoid eggs, motivated both by vegetarian beliefs and the view that the domestic chicken is an unclean animal. Vegetarianism in India is strongest in states, such as Rajasthan (Bose, 2016), and among particular castes. In Africa, Simoons describes a "bewildering diversity" of avoidance norms for both chicken and eggs. "In many places, the avoidance applies to the entire group, but elsewhere it varies with the sex, age, and social position of the individual, and in the case of eggs, with their state of decay and method of preparation. Women are more generally subject to prohibitions than men." However, Lutter et al. (2018) suggest that these stated beliefs are unlikely to prove a binding constraint to increased consumption in Africa; by implication, they are merely a post hoc rationalisation of what is fundamentally an economic constraint.

3.3 | Supply constraints and feedback to lower demand

All forms of poultry production are subject to marked economies of scale (Narrod et al., 2007, document this for broiler chickens, which use similar inputs). Scavenger production systems can operate at small scale because fodder is free, but they have extraordinarily low egg productivity, as noted above. Higher-yield systems require several thousand layer chickens to break even (e.g., Ymeri, Sahiti, Musliu, Shaqiri, & Pllana, 2017), and this requires capital for infrastructure (barns/cages, etc.) and working capital to purchase feed and other inputs, as discussed in detail by Beesabathuni, Lingala, and Kraemer (2018). The lack of access to rural credit is likely a major constraint to the transition to intensive production units, as is the lack of well-developed markets for inputs such as feed. Intensive production units are also at high risk of loss of assets due to disease outbreaks such as Newcastle disease and avian influenza. The H5N1 strain of avian influenza caused millions of birds to be culled after emerging in Asia in December 2003, and many countries in Africa have lost a large proportion of their egg production industry (e.g., BBC, 2017). Large egg producers may also struggle to distribute their production in environments in which the formal retail sector is underdeveloped.

Although, for many products, lack of local supply could be compensated by imports, this is usually not the case for eggs, which are easily damaged, highly perishable, and subject to multiple food safety controls at ports of entry in many countries.

We estimated the extent to which local prices (again, relative to staple cereals) were determined by the presence of intensive production in the country and found that the share of birds in intensive systems accounts for 60% of the international variation in relative egg prices, and a 10-point increase in the intensive share predicts a 0.8 decline in the price ratio. This relationship is robust, even after controlling for GDP per capita and urbanisation (Regression 3 in Table 2).

4 | SCENARIOS FOR 2030

In this section, we look forward to the end of the SDG period and try to identify pathways to greater availability and consumption of eggs, particularly in sub-Saharan Africa and South Asia, where current levels are lowest.

4.1 | Base scenario

In our base scenario, we use FAO forecasts for total egg production in 2030 (FAO, 2011).

We then estimate the proportion of production in each country expected to come from intensive systems, based on the relationship identified by Gilbert et al. (2015) between this variable and GDP per capita, in this case, using expected future national income (USDA, 2017). We find that the total global production of eggs is expected to increase by 44% to just under 2,000 bn eggs a year, but the increase in per capita consumption will be less than that give the concurrent 15% increase in the world population. We assume that in sub-Saharan Africa and South Asia, increases in extensive production are consumed by rural populations and increases in intensive production are consumed by urban populations. The resulting changes in per capita egg production, for each region of the world, are shown in Table 3. There are relatively large increases (>33%) in East Asia, Europe and Central Asia, and North America, all regions that already enjoy high access to eggs. South Asia and sub-Saharan Africa, however, see only minor increases (or even a decrease in rural South Asia) leaving per capita production in both regions well below 100 eggs per person per year. In sub-Saharan Africa, a large projected increase in the urban population leaves per capita production for urban areas unchanged despite a near doubling of intensive egg production.

4.2 | Scenario 2: Improved extensive farming

This scenario envisages a programme of support to enhance the productivity of the many households in Africa and Asia who already rear backyard or scavenging poultry. It builds on models from Ethiopia and

TABLE 3 Current and future (2030) per capita egg production by global region. Base scenario

Region	Current	2030	Change (%)
East Asia and the Pacific	299	401	+34.2
Europe and Central Asia	240	355	+47.7
Latin America and the Caribbean	256	310	+20.9
Middle East and North Africa	144	174	+20.8
North America	303	413	+36.4
South Asia	64	76	+18.8
Rural	23	14	−39.1
Urban	149	169	+13.4
Sub-Saharan Africa	40	47	+17.5
Rural	26	31	+19.2
Urban	63	65	+3.2

Note. Assume that all intensive production in South Asia and sub-Saharan Africa is for urban consumption and all extensive production in these areas is for rural consumption.

India described earlier in this supplement (Beesabathuni et al., 2018). In these models, a farmer rears a maximum of 20 birds in a backyard setting with improved breeds (vaccinated day-old chicks or point-of-lay hens), supplemental feed, and shelter. A government extension agent (or a private brooding entrepreneur) would provide this input package to the households, servicing, on average, 150 households per agent and increasing productivity to 100 eggs per layer per year. Further details of this model are provided in Table S1.

We assume that this intervention is implemented throughout all rural areas, covering all backyard farmers in 57 low- and middle-income countries (LMIC) in Asia and Sub-Saharan Africa. We further assume that all of the eggs produced are consumed in rural areas. Despite the high level of effort, we find that eggs available per capita in rural areas in this scenario remains low in most countries (Table 4). Only eight countries where poultry ownership is already high are likely to benefit with improved productivity. These are Afghanistan in South Asia, Laos in South East Asia; and Senegal, São Tomé and Príncipe, Liberia, Nigeria, Zambia, and Burkina Faso in Sub-Saharan Africa, where per capita availability per week increases to three to four eggs. Countries with medium poultry ownership end up with two to three eggs available per capita per week. These are Bangladesh, Myanmar, Benin, Côte d'Ivoire, Ghana, Guinea, Mali, Mauritania, and Sierra Leone.

TABLE 4 Egg availability in rural areas of 56 low- and middle-income countries in Asia and Africa, by region and level of poultry ownership, following an intervention to increase the productivity of individual small-scale producer households by the year 2030

South Asia		
Poultry ownership	Countries	# of eggs/ capita/year
High	Afghanistan	158
Medium	Bangladesh	121
Low	Bhutan, India, Nepal, Pakistan, and Sri Lanka	Less than 50
East Asia and Pacific		
Poultry ownership	Countries	# of eggs/ capita/year
High	Lao People's Democratic Republic	152
Medium	Myanmar	102
Low	Cambodia, Indonesia, Micronesia (Federated States of), Mongolia, Papua New Guinea, Philippines, Solomon Islands, and Vanuatu	Less than 50
Sub-Saharan Africa		
Poultry ownership	Countries	# of eggs/ capita/year
High	Burkina Faso, Liberia, Nigeria, Sao Tome and Principe, and Senegal	160 to 215
Medium	Benin, Cabo Verde, Côte d'Ivoire, Ghana, Guinea, Mali, Mauritania, and Sierra Leone	100 to 150
Low	Angola, Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Eritrea, Ethiopia, Gambia, Guinea-Bissau, Kenya, Lesotho, Madagascar, Mozambique, Niger, Rwanda, Sudan, Swaziland, Togo, Uganda, and United Republic of Tanzania	6 to 100

Note. Poultry ownership: High: two to three birds per capita; Medium: one to two birds per capita; Low: <1 bird per capita in the year 2030.

4.3 | Scenario 3: Egg hubs

The third scenario again addresses rural markets but envisages a model in which smallholder farmers are organised into groups to facilitate input supply and better reap economies of scale.

In this model, groups of five smallholder farmers constitute one group and are trained to operate a small-scale farm with 5,000 birds, thereby simplifying supply chain coordination of inputs to the farm while also ensuring minimal losses in the transport of eggs to a market closest to the community. Farms with a flock size of 5,000 birds or more are viable in 3 years and are more profitable than those with smaller flock sizes (Beesabathuni et al., 2018; Ymeri et al., 2017). Each farmer group has access to credit, building materials, cages, start-up flock and relevant materials, biosecurity measures, protective clothing, and training in best practices. Several of these farms can be managed together as a hub. The hub acts as the aggregator of inputs and provides training, insurance, and credit to the farmer groups. In typical LMIC conditions, we estimate that each hub can efficiently serve a land area of 5,000 km^2, but beyond that, transporting eggs across long distances becomes a challenge (Beesabathuni et al., 2018). In densely populated rural areas, a land area of 5,000 km^2 could be home to millions of people, and the hub would need to coordinate a thousand or more farmer groups. In less densely populated countries, the population within the same land area might be 100,000 or even less, and the hub might comprise no more than a few dozen farmer groups. Further details of this model are provided in Table S1.

We forecast this scenario for 45 LMIC countries in Asia and Africa where data for rural land area are available. Countries with smaller land area such as Swaziland or Gambia would need to operate only two or three hubs. Large countries such as Indonesia and India would, in theory, need nearly 400 and 600 hubs, respectively. We use rural population data to estimate how many eggs would have to be produced by each such hub to provide the equivalent of one egg per individual per day. Based on the standard farm size of 5,000 layers per farm and a conservative assumption that average layer productivity would be 70%, or 255 eggs per bird, we deduce how many farms would have to be brought under one hub in each setting (Table 5). This ranges from three farms per hub in Mauritania to more than 1,000 in Bangladesh, which is the extreme outlier. The median distance each farm covers is only 3 km, meaning that every rural household can easily access fresh eggs daily or weekly as per their convenience.

4.4 | Large scale commercialisation

The previous discussion is framed in terms of access for rural populations and probably could not meet the needs of rapidly expanding

TABLE 5 Number of egg hubs and number of participating small-scale farms required in rural areas of 45 low- and middle-income countries in Asia and Africa to produce an egg a day for each rural inhabitant by the year 2030

No. of rural farms/hub	<100	100–200	>200
No. of egg hubs			
>200	Indonesia, Angola, Democratic Republic of Congo, Mali, Mauritania, and Sudan	Ethiopia	India
100–200	Myanmar, Madagascar, Mozambique, and Tanzania	Kenya and Nigeria	Pakistan
<100	Lao, Micronesia, Papua New Guinea, Solomon Islands, Vanuatu, Benin, Cabo Verde, Cameroon, Congo, Côte d'Ivoire, Eritrea, Ghana, Guinea, Guinea-Bissau, Liberia, Sao Tome and Principe, Senegal, and Sierra Leone	Afghanistan, Cambodia, Gambia, Swaziland, and Togo	Bangladesh, Sri Lanka, Philippines, Vietnam, Central African Republic, Comoros, and Malawi

Note. Minimum land area an egg hub covers assuming very poor road connectivity = 5,000 km^2; minimum flock size for a viable farm = 5,000 birds.

urban areas. For example, the built-up area around Kampala currently has 2.4-m people and will have over 4 m by the year 2030. Nearly 700 farmer groups would be required to provide all the current population with eggs at 5,000 layers per farm; this is unlikely to be feasible to organise within easy reach of the city; a handful of large-scale intensive producers would be better placed to meet this need. Because market incentives for large-scale commercialisation are strong, policy interventions could be limited to ensuring an attractive investment environment for commercial firms.

We have previously noted that egg prices are responsive to the proportion of all production that is intensive and that consumers are highly sensitive to egg prices. Using the regression results shown in Table 2, we estimate the impact of a significant shift towards intensive egg production in Africa and South Asia. Specifically, we let countries with existing intensive production shares of less than 80% (Indonesia's level) move up to 80%, and we let countries with existing shares of 80% or more converge to 100% (the norm in higher income economies). We find that this strategy increases per capita egg availability in Africa by 49 eggs per person per year and doubles the proportion of children receiving an egg in a 24-hr period; in South Asia, the strategy leads to an increase in egg availability of 28 eggs per person per year and results in a 50% increase in the proportion of children receiving eggs.

5 | DISCUSSION

Our analysis finds that in middle- and high-income countries, eggs are highly available and (relatively) cheap, and mothers regularly give eggs to their young children. In sub-Saharan Africa and South Asia, on the other hand, eggs are rarely given to young children. In these geographies, eggs are produced in quantities only sufficient to provide each inhabitant with a few eggs each month, and long-distance transportation of shell eggs is generally not possible due to the fragile and perishable nature of the product. Relative to other food items that the household might purchase, eggs are remarkably expensive. We show that the high cost of eggs is a direct result of the dominant production system: Extensive poultry rearing is inefficient and low-yield, and associated with high egg prices and low consumption. Intensive production of eggs, on the other hand, is much more efficient and associated with much higher laying rates and much lower market prices. Although cultural avoidance of egg consumption is clearly important in some geographies (notably northern and western India), we believe that cost is by far the biggest global constraint to greater consumption, even when it comes to consumption by young children.

We examine a number of different pathways to greater consumption of eggs by 2030, the end of the SDG period. Our base scenario is essentially "business as usual," with economic growth enhancing purchasing power and urbanisation moving people in less developed regions from rural areas to cities. It does little to improve the availability of eggs in sub-Saharan Africa and South Asia, because predicted growth rates are too anaemic and are partly offset by population growth. Because large-scale intensive poultry rearing typically takes root at GDP levels of around USD 10,000 per annum (Gilbert), this scenario leaves the global structure of egg production largely unchanged.

In the 20th century, non-governmental organisations were keen to promote productivity-enhancing inputs for very small-scale extensive egg production. A previous paper in this supplement (Nordhagen & Klemm, 2018) shows just how challenging this can be. For the beneficiary households, wafer-thin margins are unlikely to justify the necessary expense in vaccines, feed, and better breeds, and scaling this approach would require establishing a vast network of extension agents, which would be expensive and hard to manage and sustain. Our analyses suggest that this model cannot bring down egg prices significantly (except perhaps in a handful of countries where poultry ownership is unusually high), and without this, major increases in egg consumption are impossible—the income/alternative expenditure foregone from giving an egg to a child is simply too great to contemplate for most families living in areas where eggs are extremely expensive.

On the other hand, the establishment of egg "hubs" could be a promising approach to meeting the need in rural areas as it drastically reduces the number of clusters of training centres and delivery points required, as well as the number of farmers involved in adopting and following best practices. Margins are adequate, with a net income per farmer of USD 144 per month. A similar approach is described in two previous papers in this supplement (Beesabathuni et al., 2018; Dumas et al., 2018). For countries with large rural land areas, which, as we have seen, would require more than 200 hubs to ensure an

egg for everyone, creating incentives for private companies to set up the hubs is the likely accelerated pathway to scale. Thailand is a good example for creating a large and fair open market economy in broiler production with smallholders (Farrelly, 1996). The key innovation that Thailand implemented historically was institutionalising a system of contracts for farmers and integrators.

Meeting the needs of urban populations will undoubtedly require very large-scale poultry industries. This path to scale spread half a century ago from Europe and North America to countries such as China and Japan (Windhorst, 2014), which now have the highest per capita availability in the world. More recently, countries such as Thailand, India, and the Philippines have developed very large-scale poultry industries (WATTAgNet, 2017), but there are relatively few examples in Africa outside South Africa. Preisinger (2013) has estimated that in order to meet growing demand for eggs (most of it from the world's growing urban middle class), about 50 million additional laying chickens will have to go into production each year. These growing and new companies will confront all the usual challenges of doing business in developing countries, plus industry-specific challenges relating to the cost of feed and the risk of disease spread from local to hybrid breeds (and to humans). Companies will also have to assess their commitment to animal welfare, as raising chickens in battery cages is increasingly viewed as unacceptable in parts of the world.

Although we have focused on increasing access to eggs, in countries that already enjoy relatively cheap egg prices it may also be worth investing in demand creation. Colombia is a country that led the way in doing this, with the National Federation of Poultry Producers (FENAVI) investing heavily in egg promotion campaigns with a significant focus on television and radio advertisement and cooking shows highlighting the health benefits of eggs. India also has a long history of egg promotion campaigns, although this contends with significant opposition to egg consumption from some conservative cultural and political groups. In general, promotion of egg consumption in low- or middle-income countries lags far behind promotion of dairy, for example. There is a particular case for promoting egg consumption for infants aged 6–11 months, who often do not receive eggs even in households which provide them to older children.

Our analyses are subject to a number of limitations. The egg market in less developed countries has not been well characterised and we rely heavily on modelled estimates, including FAO food supply measures, which have well-documented challenges when interpreted as a measure of dietary habits (del Gobbo et al., 2015). We also extrapolate from cross-sectional relationships that may or may not prove to be causal. For our future scenarios, we rely additionally on input estimates for future values of national income and population, which are themselves associated with high levels of uncertainty. Finally, we are basing our business model assumptions on a relatively small number of case studies that may or may not turn out to be more broadly representative. All of this means that the exact magnitude of our findings is highly contestable, but we believe that the broad inferences from the scenarios are instructive and very likely to be valid. We should also emphasise that we have analysed the poultry landscape purely in relation to its potential to increase the consumption of eggs; rural households may have other, very legitimate, reasons for keeping poultry (particularly related to their meat value), and we are not suggesting that extensive poultry raising is per se undesirable.

Future studies should look in detail at price differentials between rural and urban areas and factor this in to scenario modelling. It would be of great use to develop an economy-wide model for egg production and consumption, which also allows researchers to investigate the differential impacts of policies on rural and urban populations. It would also be important to examine how medium-scale production such as egg hubs can evolve over time into the industrial scale production needed to meet the needs of growing urban areas.

Eggs are one of our best tools to help end hunger, achieve food security, and improve nutrition. In order to reap the benefits of this opportunity, it is essential that aggressive action be taken to increase their availability and affordability in sub-Saharan Africa and South Asia. This can only be done by investing heavily in production systems that can bring down prices significantly across the entire economy, rather than focusing effort on limited benefits for individual farmers.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

SM conceived the paper, modelled the base scenario, and drafted the Introduction, Methods, and Discussion sections. KB modelled the individual smallholder and egg hub scenarios and contributed text on supply-side constraints. DH modelled demand-side constraints and the large-scale intensification option. All authors reviewed and approved the final text.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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