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Economic Perspectives on Analysis of Ensuring Cereal Production and Consumption Security

Ryusuke Oishi

Abstract

Cereals are essential for human nutrition. However, the ever-increasing world population makes it difficult to maintain the cereal production and consumption security. It is essential to overcome this situation by increasing cereal yield. An additional issue is the fact that while some countries suffer from hunger, a significant amount of food is discarded in others. This study analyses both production and consumption of cereals with the goal of ensuring food security. On the production side, many developing countries lack production capacity in contrast to developed countries. This is mainly due to a lack of capital, technology and human resources skills. In this study, we first theoretically demonstrated a cereal production gap between developing and developed countries. Second, we performed an empirical analysis to confirm the theoretical demonstration. On the consumption side, we focused on the cause of food loss and waste. We apply economic theories to demonstrate the situation where food loss and waste are occurring in the market. Then we introduced the related data to interpret the current world situation. Finally, we discussed the potential measures to improve cereal production and consumption.

Keywords: cereals, rice, wheat, maise, production, yield

1. Introduction

Cereals are essential for human nutrition. However, the ever-increasing world population makes it difficult to maintain the security of this food source. It is essential to overcome this situation by increasing cereal yield. An additional issue is the fact that while some countries suffer from hunger, a significant amount of food is discarded in others. This study analyses both production and consumption of cereals with the goal of ensuring food security.

On the production side, many developing countries lack production efficiency mainly due to a lack of capital and human resources skills. First, we theoretically demonstrated a cereal production gap between developing and developed countries. Second, we performed empirical analysis to confirm the theoretical demonstration. We also clarified how the production and consumption status of three typical cereals (wheat, rice and maize—or corn in United States English) are related to the regional food cultures.

On the consumption side, we investigated the cause of food loss and waste. We applied economic theories to demonstrate the market situation where food loss and waste are occurring. We then introduced the data relating to food loss and waste in G20 and the least developed countries in the world to interpret the current world situation. In addition, we also considered some cases of macroeconomic impacts on cereal productions (i.e. weather extremes and changes in commodity prices).

The remainder of this chapter is organised as follows. Section 2 provides the formal definition of food security. Section 3 provides both the theoretical and empirical analysis of cereal production. Section 4 analyses the causes of food loss and waste. Section 5 interprets the additional issues of cereal production (i.e. the macroeconomic impacts) and Section 6 concludes the chapter.

2. Food security

According to the Food and Agriculture Organisation of the United Nations (FAO), food security exists when all people—at all times—have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life [1]. The issue of food security has been raised as a major agenda at the United Nations (for example, Goal 2 of the Sustainable Development Goals: End Hunger, Achieve Food Security and Improved Nutrition and Promote Sustainable Agriculture) [2].

The above agenda is mainly due to the expected increase in the world population potentially make it difficult to ensure food security with the current level of food production. Overcoming this situation will require increasing the production capacity of nutritious foods for human consumption (especially wheat, rice and maize). However, the cereal production capacity varies across countries. In particular, there is more room for improvement in the crop yield in developing countries than in developed countries. Moreover, a significant amount of edible food is being discarded without being consumed in many developed countries whereas some developing countries concern food shortages. Eliminating such consumption waste can contribute to food security as much as increasing production capacity.

3. Cereal production

3.1 Theoretical analysis

In this section, we used a simple economic model to illustrate the problems of cereal production in developing countries and the methods for its improvement[1]. In order to highlight the problem of cereal production in developing countries, we comparatively analysed developing and developed countries. A farmer produces a product (i.e. cereals) by using labour and capital as demonstrated in Eq. (1).

$$Y_i = L_i^{\alpha_i} K_i^{1-\alpha_i} \qquad (1)$$

Eq. (1) takes the form of a Cobb–Douglas production function, where Y_i is an output of cereals. i is a subscript that informs on whether the farmer lives in a developed or developing country (i.e. $i = R, i = P$ for developed and developing

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[1] Because many readers of this paper are not expected to be specialised in economics, we will deal with a simple model that can easily be understood.

countries, respectively); L_i denotes the labour in country i and K_i denotes the capital used to produce cereals (e.g. machinery). The degree of contribution of L_i in producing cereals is measured by α_i. We assume that $\alpha_R > \alpha_P$. Because capital is often exported from industrialised countries to the rest of the world, we assume that there is no significant difference in performance of capital between developing and developed countries. In this case, the degree of α_i is determined by the production capacity of L_i relative to the performance of K_i. By considering its relationship to K_i, labourers in developing countries are often under trained and less productive than in developed countries.

Next, we investigated the relationship between labour and capital in production for further details. Specifically, by fixing the production of cereals at a certain level (i.e. $\overline{Y}_i$), the marginal rate of technical substitution of i ($MRTS_i$) is derived as Eq. (2).[2]

$$MRTS_i = -\frac{\partial L_i}{\partial K_i} = \left(\frac{1-\alpha_i}{\alpha_i}\right)\left(\frac{\overline{Y}_i}{K_i}\right)^{\frac{1}{\alpha_i}} \qquad (2)$$

According to Eq. (2), $MRTS_P$ is larger than $MRTS_R$. This indicates that, as compared to developed countries, introducing one unit of capital can replace a larger number of labourers to produce a given amount of cereal in developing countries. This is because, as compared to when there is enough farming machinery, productivity is more likely be improved by introducing one machine when there is a shortage of farming machinery.

Next, we set the farmer's budget constraints. To use labour and capital, wages and purchase/maintenance costs for capital resources were incurred, and the farmers are supposed to cover them out of their budgets. Eq. (3) shows the farmer's budget constraints.

$$B_i = L_i I_i + K_i C \qquad (3)$$

B_i is a farmer's budget in country i, I_i is an income of L_i and C is the cost of purchasing and maintaining K_i. We assumed that $B_R > B_P$ and $I_R > I_P$ because, in most cases, the income level in developed countries is higher than in developing countries. In contrast, we did not distinguish C in terms of subscript i. This is because capital is often exported from industrialised countries around the world, and hence its prices do not differ largely between countries.

By using Eqs. (1)-(3), we demonstrate the farmer's cereal production regarding to its first-order conditions. The first-order condition is derived by solving the problem with a Lagrange multiplier (Eq. (4)).

$$LF_i = L_i^{\alpha_i} K_i^{1-\alpha_i} + \lambda_i(B_i - L_i I_i - K_i C) \qquad (4)$$

where LF_i is the dependant variable of the Lagrange function in country i and λ_i is a Lagrange multiplier of the problem in country i, respectively.

To solve the problem, we first differentiate LF_i with respect to L_i, K_i and λ_i shown in Eqs. (5)-(7), respectively.

$$\frac{\partial LF_i}{\partial L_i} = \alpha_i L_i^{\alpha_i-1} K_i^{1-\alpha_i} - \lambda_i I_i \qquad (5)$$

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[2] The $MRTS_i$ measures the number of L_i to be replaced by increasing one unit of K_i to maintain a certain level of production (i.e. $\overline{Y}_i$).

$$\frac{\partial LF_i}{\partial K_i} = (1 - \alpha_i)L_i^{\alpha_i}K_i^{-\alpha_i} - \lambda_i C \qquad (6)$$

$$\frac{\partial LF_i}{\partial \lambda_i} = B_i - L_iI_i - K_iC \qquad (7)$$

By using the first-order conditions of Eqs. (5)-(7), we can derive the optimal level of L_i (L_i^*) and K_i (K_i^*) as follows:

$$L_i^* = \frac{\alpha_i B_i}{I_i} \qquad (8)$$

$$K_i^* = \frac{(1 - \alpha_i)B_i}{C} \qquad (9)$$

Eq. (8) specifies the optimal number of labourers to produce cereals in country i. By assuming that the difference between B_i and I_i in developing and developed countries is the same (i.e. $\frac{B_R}{I_R} = \frac{B_P}{I_P}$), the optimal number of labourers in developing countries is smaller than in developed countries.

Eq. (9) specifies the optimal amount of capital resources to produce cereals in country i. Due to the comparison of B_i and α_i between developing and developed countries, we are unable to comparatively conclude the size of K_R^* and K_P^*.

The optimal set of inputs $\left(L_R^*, K_R^*\right)$ and $\left(L_P^*, K_P^*\right)$ are illustrated in **Figures 1** and **2**, respectively.

The figures are two-dimensional, with the number of labourers in country i (L_i) on the vertical axis and the quantity of capital in country i (K_i) on the horizontal axis. The negative slope straight line in each figure illustrates the farmers' budget constraints in country i (B_i).[3] The curves illustrate the farmers' production in country i ($\overline{Y_i}$).[4] In this situation, the farmers' best option is to produce a certain amount of cereals by minimising the cost, which is reflected by the points where the production curve touches the budget constraint.

As illustrated in **Figures 1** and **2**, due to the small budget, the optimal amount of both inputs in developing countries is less than in their developed counterparts.[5] However, closer inspection reveals that the optimal amount of capital is relatively larger than the number of labourers in developing countries. This is due to the lack of skilled labourers and the fact that there is more room for productivity improvements through capital in the case of developing countries.[6] Even though this is the optimum input situation based on the model, the situation in reality differs. In many developing countries, development support has not sufficiently progressed, and agriculture is often carried out manually.

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[3] The farmers are only able to purchase the set of inputs allocated inside (lower left) of the budget constraints.

[4] The curve of $\overline{Y_i}$ illustrates the sets of L_i and K_i to maintain the fixed amount of the farmer's production in country i. Moreover, slope of the curve is reflected by size of $MRTS_i$ (without the negative sign). Because $MRTS_P$ is larger than $MRTS_R$, slope of the curve in **Figure 2** is steeper than **Figure 1**.

[5] In this case, it is assumed that the difference in B_i is larger than the difference in α_i between the countries.

[6] However, as the country develops, the optimal input of labour and capital changes. As the country develops, labourers acquire higher skills. Moreover, capital accumulation leaves less room for marginal productivity gains. Hence, the developing country's optimal condition converges toward that of developed countries.
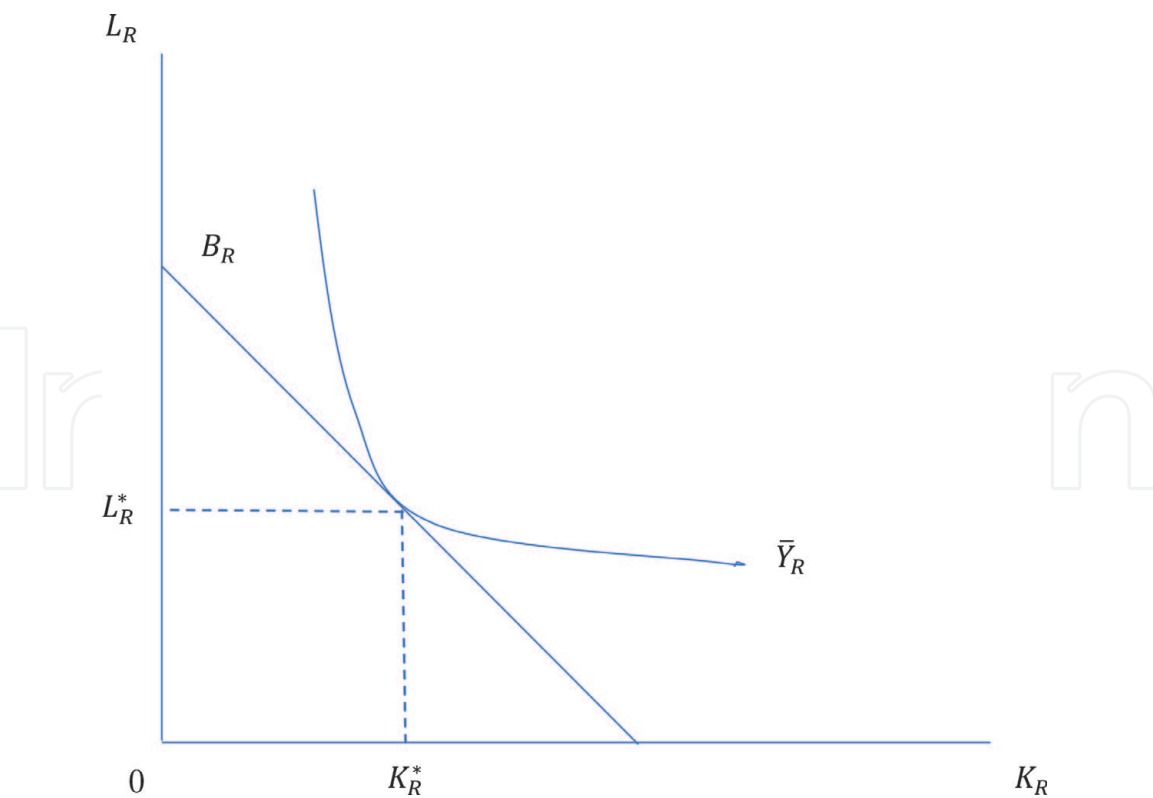
Figure 1.
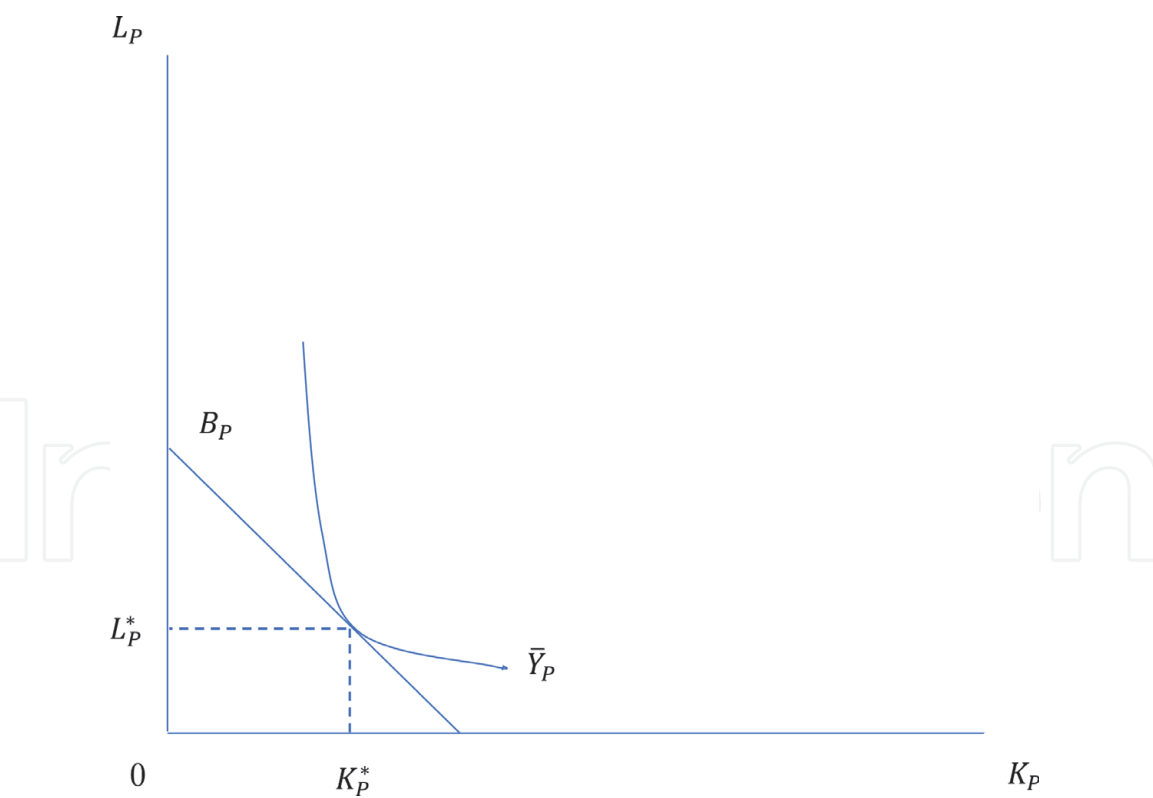*Optimal Set of Imputs in Developed Countries.*

Figure 2.
Optimal Set of Imputs in Developing Countries.

3.2 Empirical analysis

Although we theoretically demonstrate the optimal input of cereal production in developing and developed countries, it does not reflect the actual situation. In this

section, we investigate the empirical data to identify the discrepancies between the optimality condition (L_i^* and K_i^*) demonstrated in 3.1 and reality.

3.2.1 Data source

The data employed for the empirical analysis was extracted from FAOSTAT.[7] Specifically, the production quantity (Element code: 5511) and domestic supply quantity (Element code: 5301) of wheat (Item code: 2511), rice (Item Code: 2805) and maize (Item code: 2514) in the group of 20 (G20) countries and the least developed countries in 2018 (Year code: 2018) are extracted from a domain of new food balance (Domain code: FBS).[8] The number of tractors (Element code: 5116 and Item code: 2455009) in the G20 and least developed countries in 2006 (Year code: 2006) is extracted from a domain of machinery (Domain code: RM).[9] The population (Element code: 511 and Item code: 3010) in the G20 and least developed countries in year 2018 were extracted from a domain of annual population (Domain code: OA). The food losses (Element Code: 5123) of wheat, rice and maize in the G20 countries and the least developed countries in 2018 are extracted from the domain of new food balance.[10]

3.2.2 Data description

Tables 1 and **2** in the Appendix show the domestic production quantity and the production quantity of wheat, rice and maize, the number of tractors used for agriculture and the population in the world's least developed countries and the G20 countries. Close inspection of the tables reveals the problems related to cereal production and food security in developing countries.

First, in many developing countries, both the quantity of production and the domestic production of cereals are far below those of the G20, which indicates that developing countries lack cereal production capacity. Moreover, many G20 countries' production exceeds its domestic supply, indicating that those countries import cereals to cover shortages in their national consumptions. However, the opposite is true in the case of the least developed countries. A low level of production is indicative of threatened food security.

Second, although based on scarce information, the number of tractors in the G20 countries is significantly higher than in developing countries. As demonstrated in the theoretical analysis, abundant machinery contributes to the production of cereals. The lack of machinery likely causes the difference in the productivity between developed and developing countries.

Third, the production of wheat, rice and maize varies according to the country's region. For example, wheat production in many countries in **Table 1** is lower than that in countries in **Table 2**. This is because many developed countries are Western countries whose staple food is wheat (i.e. bread). On the contrary, many countries

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[7] FAOSTAT (http://www.fao.org/faostat/en/#data).

[8] The production quantity is a value that considers import / export and change in stocks from domestic production quantity.

[9] Due to a small data availability, the author decided to show the number of tractors in 2006, which reports more data than other years.

[10] The author identifies G20 countries in the 'countries' and the least developed countries in the 'special group: Least Developed Countries > List) in the domains of the items (i.e. new food balance, machinery and annual population). We excluded the European Union (EU) from G20 because the latter is not a single nation.

in **Table 1** produce more rice. This is because rice is often consumed in Asia and Africa, and those regions include many countries in **Table 1**. Unlike the other two cereals, maize is actively produced in the countries listed in both **Tables 1** and **2**. This is because maize is often consumed in Africa as well as in Western countries.

3.2.3 Empirical analysis

To make the discussion in 3.2.2 more reliable, we performed regression analyses. We confirmed the first (as compared to developed countries, developing countries lack cereal production capacity) and third argument (i.e. the production of wheat, rice and maize varies according to the country's region).[11]

$$Cereal_{cit} = \beta_{c0} + \beta_{c1}G_{20i} + \beta_{c2}Africa_i + \beta_{c3}Asia_i + \beta_{c4}America_i + \beta_{c5}Europe_i$$
$$+ \sum_{t=2015}^{2018} Year_t + \varepsilon_{it} \tag{10}$$

In Eq. (10), the dependent variable $Cereal_{cit}$ represents the domestic supply quantity of cereal c in country i at year t.[12] Subscript c distinguishes three types of cereals (i.e. wheat, rice and maize). Subscript t specifies the year in the sample period.[13] The explanatory variable G_{20i} is a dummy variable that takes the value of 1 if country i is a member of G20, and 0 otherwise. $Africa_i$, $Asia_i$, $America_i$ and $Europe_i$ are dummies that take the value of 1 if country i is in that region and 0 otherwise.[14] $\beta_{c0}, \beta_{c1}, \beta_{c2}, \beta_{c3}, \beta_{c4}$ and β_{c5} are a constant term, the coefficients for $G_{20i}, Africa_i, Asia_i, America_i$ and $Europe_i$ in the case of regressing for cereal c, respectively. $\sum_{t=2015}^{2018}Year_t$ is the sum of the dummies between 2015 and 2018 for capturing the year fixed effect.[15] ε_{it} is an error term for country i at year t.[16]

Table 3 presents the descriptive statistics for the data employed for the regression analysis of Eq. (10). As mentioned earlier, the G20 production of all cereals far exceeds that of the developing countries. The difference is particularly noticeable in maize production and smallest of the three (wheat, rice and maize) in rice production. This is because there are many countries that have rice as their staple food in poor regions such as Southeast Asia.

Table 4 shows the estimation results of Eq. (10). Close inspection of the estimation results reveals some features that are consistent with the argument in 3.2.2. First, the estimated coefficients of G_{20i} $\left(\hat{\beta}_{c1}\right)$ in the case of all three cereal types are

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[11] Due to the small amount of available data, we did not perform the regression analysis on the second argument (i.e. the number of tractors in the G20 countries is significantly higher than that in developing countries).

[12] We separately regressed Eq. (10) for the three cereals types (i.e. $Cereal_{Wheat\ i\ t}$, $Cereal_{Rice\ i\ t}$ and $Cereal_{Maize\ i\ t}$). Although i is used to distinguish developed or developing country (i.e. $i = R, i = P$) in subsection 3.1, in this subsection, i is used to distinguish the countries in the dataset (i.e. $i = the\ US, i = the\ UK, etc\ ...$).

[13] Although **Tables 1** and **2** only show the 2018 data for each country, we decided to use the 2014–2018 data for the estimation. This is because a larger data size helps to perform a more significant quantitative analysis.

[14] To deal with collinearity, we dropped $Oceania_i$ from the regression equation.

[15] To deal with collinearity, we dropped $Year_{2014}$ from the regression equation.

[16] The data employed in subsection 3.2.3 are extracted from the source introduced in 3.2.1. The dummies were created by the author. The regional dummies $Africa_i, Asia_i, America_i, Europe_i$ and $Oceania_i$ were created by using FAOSTAT information: Regions (Africa > (List), Asia > (List), Americas > (List), Europe > (List), Oceania > (List)).

positively estimated with strong significance, indicating that G20 countries produce larger amounts of all three cereals than the least developed countries. Second, by looking at the estimation result of the regional dummies, differences in cereal production by region can be found. For example, in case of $Cereal_{Rice\ i\ t}$, the size of the estimated coefficient for $Asia_i$ ($\hat{\beta}_{Rice\ 3}$) is significantly larger than those for other regions. This finding makes sense given that rice is the staple food for people in Asian countries. Similarly, in the case of $Cereal_{Maize\ i\ t}$, the size of the estimated coefficient for $America_i$ ($\hat{\beta}_{Maize\ 4}$) is much larger than those for other regions. This is also understandable because people in the United States consume many foods made from maize. In case of $Cereal_{Wheat\ i\ t}$, estimation of the regional dummies is different from our expectation. Given that wheat-based foods are mainly consumed in Europe, the estimated coefficient for $Europe_i$ ($\hat{\beta}_{Wheat\ 5}$) was expected to be larger than for other regions. However, $\hat{\beta}_{Wheat\ 3}$ is larger than that of $\hat{\beta}_{Wheat\ 5}$. This might be due to China's wheat production, that surpassed that in European countries. Finally, the low R^2 value in all three cases indicates that the explanatory ability of these estimation results is not high. This is because all the explanatory variables (except the constant) are dummy variables.

In order to comparatively analyse cereal production in the developed and developing countries in greater detail, in addition to Eq. (10), we conducted another estimation procedure. The production of cereals in a country depends on its population. By using per capita productivity, we can exclude the impact of the population. In order to reveal the latter issue, we set Eq. (11) as follows:

$$Cereal\ Per\ Capita_{cit} = \beta_{c6} + \beta_{c7}G20_i + \beta_{c8}Africa_i + \beta_{c9}Asia_i + \beta_{c10}America_i$$
$$+ \beta_{c11}Europe_i + \sum_{t=2015}^{2018} Year_t + \varepsilon_{it} \qquad (11)$$

Eq. (11) is different from Eq. (10) in that it uses $Cereal\ Per\ Capita_{cit}$ as a dependant variable. This variable was obtained by dividing $Cereal_{cit}$ by population of country i.[17]

Table 5 shows the descriptive statistics for $Cereal\ Per\ Capita_{cit}$. Information in **Table 5** is significantly different from **Table 3**. Specifically, as compared from the developed country, the mean value of $Cereal\ Per\ Capita_{Rice\ i\ t}$ is higher in the least developing countries. This is probably because the large populations in developed countries used as a denominator value of $Cereal\ Per\ Capita_{Rice\ i\ t}$ lowered their value of $Cereal\ Per\ Capita_{Rice\ i\ t}$.

Table 6 shows the estimation results of Eq. (11); the interpretation of these results requires careful consideration. In the case of wheat and maize, the coefficients of $G20_i$ ($\hat{\beta}_{Wheat\ 7}\ and\ \hat{\beta}_{Maize\ 7}$) are positively significant, indicating that even if the effects of the population are eliminated, G20 countries are more productive than the least developed countries, which is consistent with our view. In contrast, in the case of rice, surprisingly, the estimation of $G20_i$ ($\hat{\beta}_{Rice\ 7}$) is negatively significant. This is probably because G20 countries with rice food cultures include populous countries (i.e. China and Indonesia).

In the case of rice, looking at the estimated result of the regional dummies shows that only $Asia_i$ ($\hat{\beta}_{Rice\ 9}$) is positively significant. This confirms that Asia stands out in

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[17] The regression of Eq. (11) additionally uses population data of the countries in 3.2.1 (in the period between 2014 and 2018) to the data employed for the regression of Eq. (10). To distinguish from the coefficients in Eq. (10), the constant, coefficient of $G20_i$, $Africa_i$, $Asia_i$, $America_i$ and $Europe_i$ in Eq. (11) are expressed as $\beta_{c6}, \beta_{c7}, \beta_{c8}, \beta_{c9}, \beta_{c10}$ and β_{c11}, respectively.

terms of rice productivity. Similarly, in the case of maize, the estimated coefficient of $America_i$ ($\hat{\beta}_{Rice\ 10}$) is significantly larger than those of other regions, indicating that maize productivity in the American region is higher than in other regions. One unexpected observation is that, in the case of wheat, all regional dummies are estimated to be negative. Because the estimated coefficient for $Europe_i$ ($\hat{\beta}_{Wheat11}$) has the smallest negative value, we can argue that the per capita production of wheat in Europe is the largest; however, the reason for this is not clear.

Compared to **Table 4**, all the R^2 values are slightly higher in **Table 6**. Therefore, the explanatory power of the estimation results improved slightly in **Table 6**.

4. Cereal consumption

In Section 3, we describe both the theoretical and empirical analyses of the cereal supply. In this section, we identify the problems with and the methods for improving the consumption of cereals as food security issues. One might think that the only issue regarding food security is the improvement of production capacity; however, management of consumption is also important. Among many problems relating to cereal consumption, we focused on food loss and waste.

The food situation differs from country to country. While some countries suffer from poverty and lack of food, others have excessive food supply in their markets and dispose of consumable foods.

Table 7 shows the amount of food lost in the least developed and G20 countries.[18] Not surprisingly, as compared to that in the least developed countries, the larger amount of food loss is reported in the G20 countries. Considering the larger production volume and the population, the loss in the G20 can be understood as a natural consequence of its food consumption. However, the developing countries are not completely devoid of food loss; although small comparatively, food loss is also reported in the least developed countries. However, reasons for food loss are different between the G20 and the least developed countries. In the case of the G20 countries, the cause of food loss is overstocking. For example, in Japan, consumers strongly demand food safety and quality [3]. As a result, foods that are not sold by the expiration date are discarded [3]. Moreover, consumable foods with slight scratches or incompatible size are discarded [3]. Another issue is that the main concern of business food suppliers is to make profit. When such economic agents compete with each other to form a market is a basis of capitalism. However, in order to make profits, they sometimes make decisions that are detrimental to society. For example, convenience stores in Japan often overstock foods, because they do not want to lose customers due to out of food stock [3].

In the case of developing countries, due to a lack of sufficient capital for processing and preserving food, some foods are rarely delivered to consumers while fresh. For example, in developing countries, most of the postharvest grains are stored in traditional storage structures, which cannot prevent insect infestation and mould during storage [4].

Figure 3 illustrates an excess supply of food (caused by overstocking) in developed countries.[19] According to economic theory, if goods are traded at their market equilibrium (i.e. the intersection of the demand and supply curves), production and

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[18] Because the food loss data is reported from a limited number of countries, the countries with no data were deleted from **Table 7**.

[19] S, D, P, Q, Q_S and Q_D in **Figures 3** and **4** represent supply, demand, price, quantity, quantity supplied and quantity demanded for a product in the market.
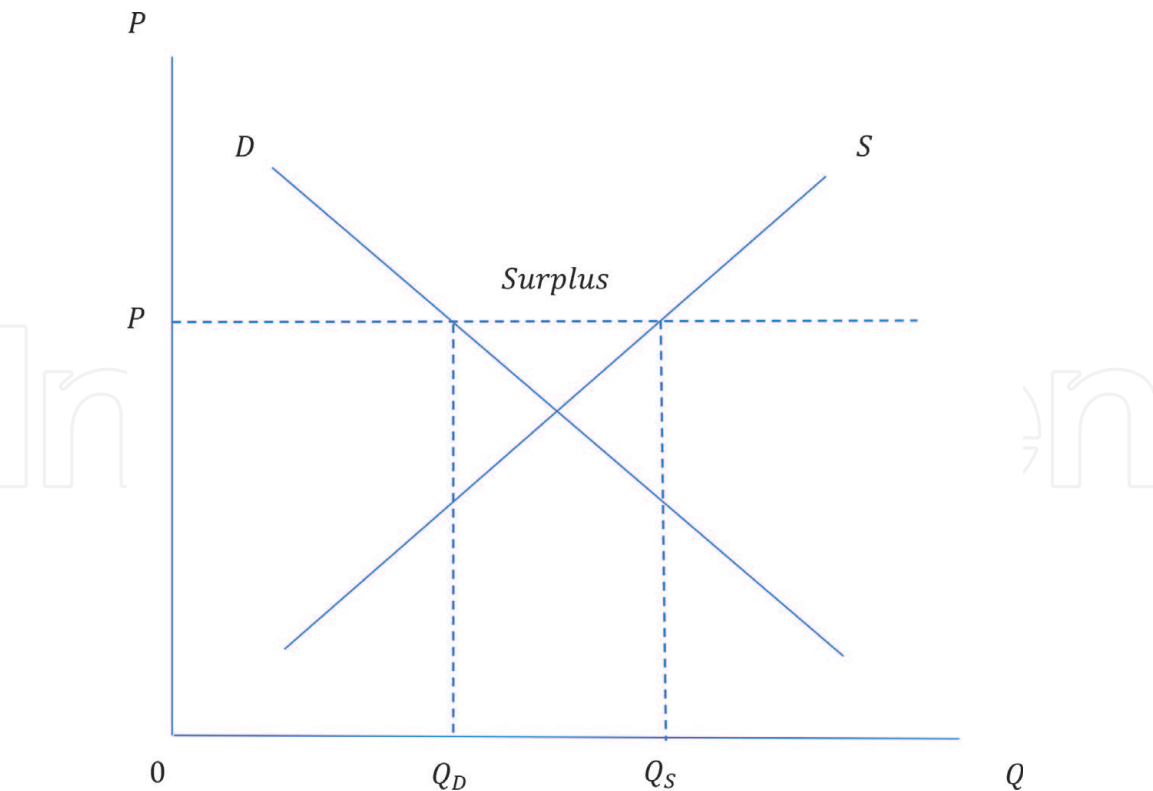
Figure 3.
The Market with Oversupply of Food.

consumption match and no goods will be left unsold. However, as shown in
Figure 3, if the price of goods deviates from its equilibrium, supply and demand of
goods do not match, and some goods are not sold.

Figure 4 illustrates a food shortage situation in poor countries.[20] Unlike in
Figure 3, the supply curve in **Figure 4** becomes vertical at a certain quantity (Q_S).
This shows supplier's limit of cereal production capacity. Due to the limited pro-
duction capacity in poor countries, once the supply reaches its limit, the quantity
does not increase regardless of the price. Moreover, in this situation, the price of the
goods deviates downward from its equilibrium. The discrepancy between supply
and demand becomes the shortage.

In theory, eliminating oversupply of food and the assurance of food security in
developing countries is mutually achievable. For example, transferring food surplus
from developed countries to developing countries to combat the shortages would
provide a solution to both problems.

5. Measures to ensure world food security

As discussed in Sections 3 and 4, there are the challenges to ensuring world food
security both in food supply and consumption. On the supply side, the main reason
for food insecurity is the lack of capital and training of human resources in devel-
oping countries. However, due to lack of funds, increasing capital and training
human resources are hardly be achieved. Therefore, loans and assistance from
international organisations and developed countries are required. Additionally,
investment projects (i.e. foreign direct investment) are also effective in raising
funds for developing countries. Furthermore, to gain an understanding of the

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[20] Here, in order to focus on the issue of food security in developing countries, we ignored food loss in
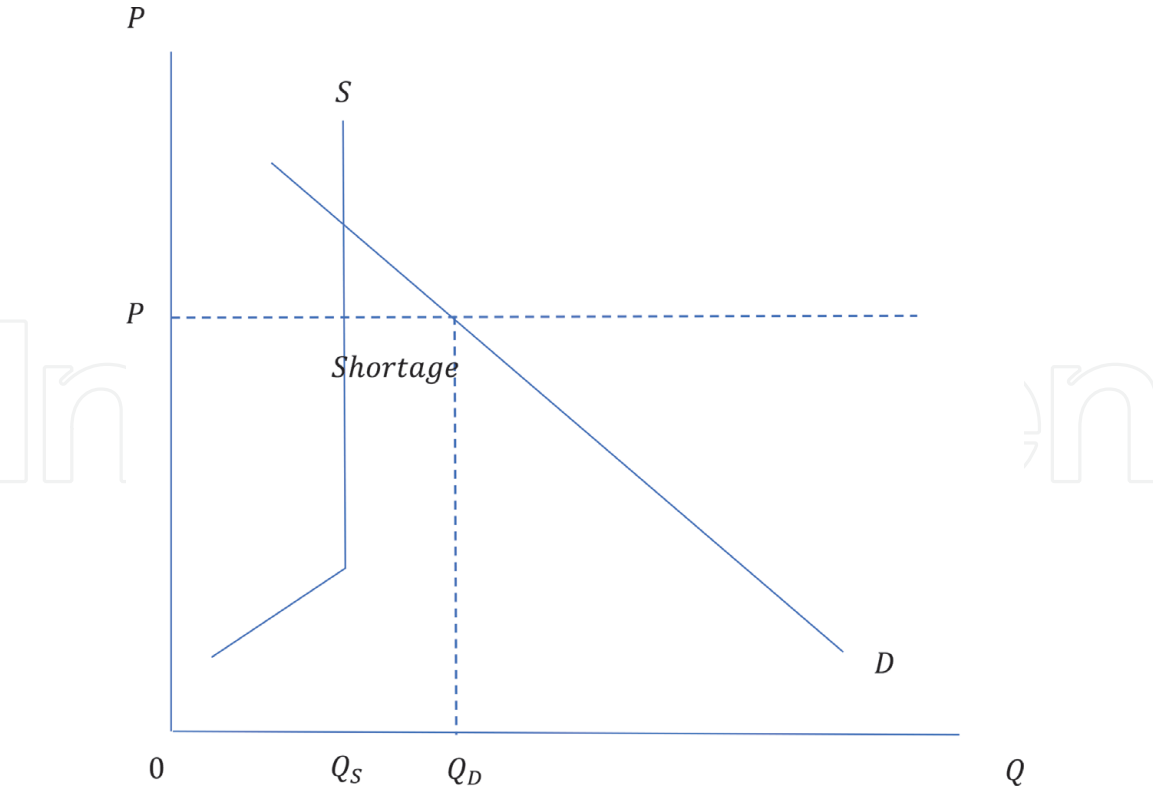the developing countries.

Figure 4.
The Market with Shortage of Food.

outcome of such investments is larger in developing countries than in developed countries will be important[21].

There are other points that need improvement. First, improvement in seed breeding is effective for sustainable agricultural production [5]. Second, in many cases, as compared to farmers with large operations, smallholder farmers are disadvantaged in accessing market; therefore, farming should be re-invented as an attractive local business opportunity for smallholder families [6]. Third, in the agri-food system, a few large international firms dominate the market share, and smallholders mainly trade on local short-supply chains [7]. Fourth, in recent years, production and consumption of rice in many parts of Asia has been steadily declining, whereas the opposite is true in Africa [8]. Fifth, due to economic development, the demand for maize to feed livestock has increased [9]. Six, the problem of food self-sufficiency does not apply only to developing countries. In Japan, due to the ageing population and the lack of young people willing to engage in agriculture, the self-sufficiency rate is low [10]. As a result, Japan imports a substantial amount of food from abroad (i.e. China) to cover their shortages [10].

Stabilisation of markets to protect suppliers from macroeconomic shocks is also important. For example, in 2020, the global economy was greatly affected by the spread of COVID-19. Because the main transmission route of COVID-19 is droplets from infected people, people stopped eating out. In Japan, food manufacturing and service businesses were severely damaged by people's restraints and many food manufacturers and restaurants went bankrupt [11]. This was mainly because in

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[21] This is because countries with small capital grow faster by capital investment than countries with large capital. However, on the other hand, we cannot ignore that investment in developing countries often involves higher risk than that in developing countries.

Japan many restaurants are small and medium-sized enterprises that lack corporate strength to withstand severe economic adversities [12]. As a result, a significant amount of ingredients that were to be delivered to restaurants went left unsold. In addition, a sharp drop in the demand for restaurant food has spurred the overstock of food, leading to the collapse of the prices of some foods. If the situation does not improve, farmers will not be able to make sufficient profits and will be forced out of business. This will lead to a decline in food production capacity and will worsen food insecurity.

In addition, inflation and instability of agricultural prices will put pressure mainly on the world's low-income group of people and an increase in labour productivity will be necessary to overcome the problem [13]. The effect of extreme weather is also a major issue for cereal production. Weather extremes in the United States in 2012 caused a sharp increase in the world maize price, and the poor countries with high maize import dependency were the most seriously affected [14].

On the consumption side, the main challenge is to reduce food loss in the developed countries. One measure to correct such market failure is government intervention in the market to internalise negative externalities. Additionally, transferring food surpluses from developed countries to developing countries to combat food shortages may improve the situation. Food banks are one of the potential measures for recycling food within a country [15]. If such food banks could be internationalised, food security in developed countries may be ensured in a way that is close to our idea. However, there are many difficulties with this potential solution. For example, some foods do not last long and are not suitable for long-distance transportation. Moreover, as discussed before, due to regional variances in food culture, some foods may be hard to replenish.[22] Many countries also impose tariffs on imported products because large amounts of imported food may adversely affect local farmers' businesses.

Additionally, food loss also occurs in developing countries, where food security is not ensured. The main cause of food loss here is lack of capital for storage; therefore, as in the supply side discussion, increasing capital through investment and assistance is the effective measure[23].

In this section, we examined measures to improve food security. Although the authors' proposed methods have the potential to improve food security, there are many challenges. In order to achieve these improvements, in addition to international efforts (i.e. international organisations and governments), changing the mindset of each economic entity (i.e. supplier and consumer) will be necessary.

6. Conclusion

Cereals are essential for human nutrition. However, the ever-increasing world population makes it difficult to maintain food security. It is necessary to consider various factors related to production and consumption of cereals to ensure food security. This study considers the food security issues for cereals in terms of both supply and consumption.

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[22] South Asia, where rice is the staple food, is one of the most densely populated regions and the second poorest region in the world [16]. In order to guarantee its food security, self-sufficiency is important [16].

[23] Installation of evaporative coolers can be considered as one of the realistic measures to reduce food loss and waste [15].

On the supply side, we proposed that cereal food security can be improved by increasing production capacity in developing countries. The optimal condition of our theoretical model specifies that, as compared to the case of developed countries, farmers in developing countries should more actively utilise capital resources. However, reality largely differs from theory. As shown by the data, the use of farming machinery in developing countries is lower than in developing countries. Additionally, our regression result confirms that the production of cereals (i.e. wheat, rice and maize) in G20 countries surpasses that in the least developed countries. Furthermore, our empirical analysis also confirms that the type of cereals produced vary significantly regarding the region.

On the consumption side, we emphasised the problem of food loss. Although some countries in the world suffer from food insecurity, others discard large amounts of food. Reducing such waste can contribute to global food security. However, the causes of food loss differ between developing and developed countries. In the case of the former, the lack of capital means that food rots before it is consumed. In the case of the latter, foods are oversupplied to the market due to excessive competition between firms.

In order to mitigate these problems, we proposed the following measures. In order to increase production in developing countries, their capital resources need to increased; this requires significant investment and assistance. On the other hand, one way to prevent food loss in developed countries is to mitigate excessive competition among firms through government market intervention. It may also be effective to transport surplus food from developed countries to developing countries to fill shortages. However, there are many challenges to implementing these measures. To truly improve the global food situation, in addition to international efforts (i.e. international organisations and governments), each of us needs to change our consciousness.

Acknowledgements

Appendix

Country	Wheat		Rice		Maize		Tractors	Population
	Product	Domestic Supply	Product	Domestic Supply	Product	Domestic Supply		
Afghanistan	3613	6995	352	626	107	165	711	37171.92
Angola	3	1111	10	725	2765	2996		30809.79
Bangladesh	1099	6885	54416	56415	3288	4841		161376.7
Benin	0	186	459	2131	1510	1415		11485.04
Burkina Faso	0	277	161	523	1700	1616		19751.47
Cambodia	0	46	10647	10006	604	692		16249.79
Central Africa	0	5	11	11	90	86		4666.368
Chad	2	75	260	257	438	422		15477.73
Djibouti	0	339	144	241	0	4		958.923

Country	Wheat		Rice		Maize		Tractors	Population
	Product	**Domestic Supply**	**Product**	**Domestic Supply**	**Product**	**Domestic Supply**		
Ethiopia	4500	6394	54	441	8350	8255		109224.4
Gambia	0	84	2340	214	39	42		2280.094
Guinea	0	420	171	3527	819	806		12414.29
Haiti	0	278	183	735	260	288		11123.18
Laos	0	24	3585	3436	982	737		7061.507
Lesotho	9	59	258	19	100	292		2108.328
Liberia	0	73	4030	598	0	1		4818.973
Madagascar	6	365	112	4774	215	222		26262.31
Malawi	1	145	3168	118	2698	2736		18143.22
Mali	29	341	232	3027	3625	3226		19077.75
Mauritania	7	551	134	295	16	23		4403.313
Mozambique	21	691	27574	1101	1250	1315		29496
Myanmar	116	560	5152	26176	1984	1559	102750	53708.32
Nepal	1958	1961	102	5700	2473	2616		28095.71
Niger	5	66	120	309	30	60	375	22442.82
Rwanda	11	158	763	148	410	207		12301.97
Senegal	0	682	920	2051	264	645		15854.32
Sierra Leone	0	91	3	1595	23	25		7650.15
Sudan	595	2754	87	125	45	63		41801.53
Togo	0	144	145	222	887	905		7889.093
Uganda	23	647	246	374	2773	2500		42729.04
Tanzania	57	984	2220	2134	6273	5206		56313.44
Yemen	106	3650	0	781	43	687		28498.68
Zambia	114	160	43	56	2395	2859		17351.71

*Note: **Table 1** is provided by the author based on the data extracted from FAOSTAT. Product and domestic supply of wheat, rice and maize are in 1,000 tonnes. Population is in 1,000 people.*

Table 1.
Production of cereals, number of tractors and population in the world's least developed countries.

Country	Wheat		Rice		Maize		Tractors	Population
	Product	Domestic product	Product	Domestic product	Product	Domestic product		
Argentina	18539	5596	1368	753	43462	19237		44361.15
Australia	20941	8716	635	453	387	382		24898.15
Brazil	5422	12530	11749	12273	82288	64173		209469.3
Canada	32216	7940	0	533	13885	14215	733182	37074.56
China	131690	127248	214079	206919	257349	277032		1459378
France	35798	19521	73	659	12667	8428		64990.51
Germany	20264	16289	0	405	3344	6714	798700	83124.42
India	99700	95422	172580	142688	27820	23402		1352642
Indonesia	0	9868	83037	73805	30254	31380		267670.5
Italy	6933	11136	1512	699	6179	12034		60627.29
Japan	766	6700	9728	11232	0	15819		127202.2
Mexico	2943	6217	284	1352	27170	40514		126190.8
Korea	26	4663	5195	6688	78	10037		51171.71
Russia	72136	32416	1038	1175	11419	6447	439600	145734
Saudi Arabia	518	3667	0	1882	45	3160		33702.76
South Africa	1900	3593	3	1406	12510	10510		57792.52
Turkey	20000	19134	940	1359	5700	7071	1037383	82340.09
The UK	13555	16364	0	606	0	2067		67141.68
The US	51398	33837	10153	5504	364262	292878		327096.3

Note: **Table 2** is provided by the author based on the data extracted from FAOSTAT. Product and domestic supply of wheat, rice and maize are in 1,000 tonnes. Population is in 1,000 people.

Table 2.
Production of cereals, number of tractors and population in G20 countries.

	Wheat		Rice		Maize	
	The Least Developed Countries	G20 Countries	The Least Developed Countries	G20 Countries	The Least Developed Countries	G20 Countries
Observation	165	95	165	95	165	95
Mean	1056.667	22955.14	3775.121	24536.86	1343.521	42863.25
Standard Deviation	1862.218	30904.34	10106.54	54650.72	1704.479	83273.31
Minimum Value	5	2735	−42	375	1	346
Maximum Value	7617	127248	56415	206919	8255	343651

Note: Table 3 is provided by the author based on the data extracted from FAOSTAT. $Cereal_{cit}$ is in 1,000 tonnes.

Table 3.
Descriptive statistics for $Cereal_{cit}$.

Independent Variable	Dependent Variable $Cereal_{Wheat\ i\ t}$	Dependent Variable $Cereal_{Rice\ i\ t}$	Dependent Variable $Cereal_{Maize\ i\ t}$
	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient
G_{20i}	24978.12*** (0.000)	32732.82*** (0.001)	45346.42*** (0.000)
$Africa_i$	17217.26*** (0.002)	31947.7*** (0.001)	44958.31*** (0.000)
$America_i$	7068.021*** (0.001)	8418.469*** (0.001)	80329.6*** (0.000)
$Asia_i$	24711.49*** (0.000)	54529.34*** (0.000)	46233.9*** (0.000)
$Europe_i$	13487.44*** (0.000)	254.84*** (0.002)	7352.68*** (0.000)
Constant	−17861.62*** (0.003)	−32457.05*** (0.002)	−46880.16*** (0.000)
Number of Observations	260	260	260
Prob > F	0.000	0.000	0.000
R^2	0.312	0.309	0.247

*Note: This table shows estimation results for Eq. (10). P-values are presented in parentheses. The estimation is conducted with robust standard errors. Superscripts ***, ** and * indicate statistical significance at 1%, 5% and 10%, respectively.*

Table 4.
Estimation results of Eq. (10).

	Wheat		Rice		Maize	
	The Least Developed Countries	G20 Countries	The Least Developed Countries	G20 Countries	The Least Developed Countries	G20 Countries
Observation	165	95	165	95	165	95
Mean	0.0502536	0.1482661	0.1270291	0.0540263	0.0583697	0.20179
Standard Deviation	0.1062425	0.0939006	0.162305	0.0677363	0.0550903	0.2146537
Minimum Value	0.0010715	0.0291697	−0.0019442	0.0045624	0.0002075	0.0146632
Maximum Value	0.8501159	0.3557684	0.61645	0.2757308	0.2365934	1.063882

*Note: **Table 5** is provided by the author based on the data extracted from FAOSTAT.*

Table 5.
*Descriptive statistics for **Cereal Per Capita**$_{cit}$*

Independent Variable	Dependent Variable Cereal Per Capita$_{Wheat\ i\ t}$	Dependent Variable Cereal Per Capita$_{Rice\ i\ t}$	Dependent Variable Cereal Per Capita$_{Maize\ i\ t}$
	Estimated Coefficient	Estimated Coefficient	Estimated Coefficient
G_{20i}	0.0388*** (0.001)	−0.150*** (0.000)	0.132*** (0.000)
$Africa_i$	−0.225*** (0.000)	−0.090*** (0.002)	0.177*** (0.000)
$America_i$	−0.211*** (0.000)	−0.014 (0.103)	0.399*** (0.000)
$Asia_i$	−0.209*** (0.000)	0.123*** (0.000)	0.132*** (0.000)
$Europe_i$	−0.066*** (0.000)	−0.011*** (0.000)	0.087*** (0.000)
Constant	0.270*** (0.000)	0.169*** (0.000)	−0.119*** (0.000)
Number of Observations	260	260	260
Prob > F	0.000	0.000	0.000
R^2	0.340	0.403	0.530

Note: This table shows estimation results for Eq. (11). P-values are presented in the parentheses. The estimation is conducted with robust standard errors. Superscripts ***, ** and * indicate statistical significance at 1%, 5% and 10%, respectively.

Table 6.
Estimation results of Eq. (11).

The Least Developed Countries				G20			
	Wheat	Rice	Maize		Wheat	Rice	Maize
Afghanistan	542	25	16	Argentina	316	53	633
Angola	0	0	307	Australia	209	6	2
Bangladesh	238	3104	250	Brazil	247	1181	8321
Benin	0	115	378	China	2901	8624	11806
Chad	0	10	36	France	326	3	112

The Least Developed Countries				G20		
Ethiopia	168	3	252	India	5987	4654	2785
Madagascar	0	403	10	Italy	49	34	11
Malawi	0	5	529	Japan	163	190	4
Mali	21	127	218	Mexico	197	53	4571
Mauritania	22	7	1	Korea	23	481	205
Mozambique	1	5	75	Russia	433	21	115
Myanmar	24	861	90	Saudi Arabia	35	0	92
Nepal	195	486	248	South Africa	85	0	569
Niger	0	4	1	Turkey	2133	30	202
Rwanda	0	3	49	The US	2334	398	17864
Senegal	6	30	33				
Sierra Leone	0	120	1				
Sudan	48	2	4				
Uganda	20	5	175				
Tanzania	3	30	738				
Zambia	3	2	72				

Note: Table 7 is provided by the author based on the data extracted from FAOSTAT. Food loss of wheat, rice and maize in the least developed and G20 countries are in 1,000 tonnes.

Table 7.
The amount of food loss in the least developed and G20 countries.

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