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A city and national metric measuring isolation from the global market for food security assessment

Molly E. Brown [a,*], Kirk C. Silver [b], Krishnan Rajagopalan [c]

[a] Biospheric Sciences Laboratory, Code 618, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[b] College of the Environment and Life Sciences, 106 Coastal Institute – MESM, University of Rhode Island, Kingston, RI 02881, USA
[c] Mathematics Department, 121 Blake Road, U.S. Naval Academy, Annapolis, MD 21402, USA

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A B S T R A C T

The World Bank has invested in infrastructure in developing countries for decades. This investment aims to reduce the isolation of markets, reducing both seasonality and variability in food availability and food prices. Here we combine city market price data, global distance to port, and country infrastructure data to create a new Isolation Index for countries and cities around the world. Our index quantifies the isolation of a city from the global market. We demonstrate that an index built at the country level can be applied at a sub-national level to quantify city isolation. In doing so, we offer policy makers with an alternative metric to assess food insecurity. We compare our isolation index with other indices and economic data found in the literature. We show that our Index measures economic isolation regardless of economic stability using correlation and analysis.

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Introduction

Global commodity prices have seen enormous variability and change in the past five years (Trostle, Marti, Rosen, & Westcott, 2011, p. 29). These changes have driven significant anxiety among policy makers and low-income consumers around the world, fearing the impact of changing food prices on the ability of the poorest people to access adequate food. Higher global commodity prices will affect food security when countries or regions import food from the global marketplace and the higher cost of this food subsequently affects local food prices (Darnton-Hill & Cogill, 2009; Ravallion, 1991, p. 34; Thompson, 1983). The degree to which changes in the international commodity market affect local prices depends on the market's isolation from the world market (Brown et al., 2012).

Many of the least developed countries are isolated from the international market by some degree (Brown et al., 2012). In poor agricultural countries, economic isolation restricts development while at the same time protects farmers and consumers from international price fluctuations. Reduced access to imported food increases the cost of food during periods of drought when local production is reduced. Isolation also serves as a substantial barrier for farmers to sell their goods outside of their local region (Aker, Klein, O'Connell, & Yang, 2010). Built infrastructure has long been recognized as an important element to development and strengthening of local markets (Briceño-Garmendia, Estache, & Shafik, 2004).

The cost of transporting goods from a port to a market is associated with different degrees of cost-efficiency per distance traveled. Adequate infrastructure (roads, rail, law enforcement, etc.) is critical for ensuring reasonable transaction costs for low value, high bulk goods such as grain. Variations in the quality of transport infrastructure by country and the impact of improvements in infrastructure on food markets have not been systematically evaluated (Briceño-Garmendia et al., 2004).

In less developed regions of the world, such as Africa, problems with transportation infrastructure are compounded with issues of broader economic development. Despite rapid growth in the region's economy in the past decade, Africa's share in world trade has been falling since the 1980s (UNCTAD, 2003, p. 24). The proportion of the economy in manufacturing has fallen from 15% in 1990 to 10% in 2008. This trend is particularly strong in West Africa, where the proportion of economy in the manufacturing sector fell from 13 to 5 percent during the same period (UNCTAD, 2012, p. 161). Trade in the manufacturing sector provided revenue that was used to support and maintain transportation infrastructure. Reductions in manufacturing seen in Africa since 1990 may have a significant impact on the ability of the individual countries to support their transportation infrastructure, and reduce their

* Corresponding author.
E-mail address: molly.brown@nasa.gov (M.E. Brown).

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ability to reach development targets laid out in the Millennium Development Goals (MDGs) (Majid, 2004).

Population expansion during the past few decades has resulted in significant increases in the demand for food. This demand has been met largely from globally marketed cereal and food products because of their relatively low cost and ease of use. The inability of most countries within Africa to grow enough food to feed its people is often due to population growth, low and stagnating agricultural productivity, policy distortions, weak institutions, and poor infrastructure. In addition, food import dependency is closely related to a country's income (Rakotoarisoa, Iafrate, & Paschali, 2011, p. 89). Trade is an excellent buffer for domestic fluctuations in food supply because there is adequate food for all at the global scale. Food security crises are caused by the inability to move adequate food across borders from surplus to deficit areas. Movement of goods may be hindered by political, economic, or physical barriers that isolate the deficit region. Isolation further inhibits agricultural production through restriction of infiltration of new technology, improved plant varieties, and other agricultural inputs. Isolation due to inadequate infrastructure is a critical barrier to achieving food security in many regions.

The overarching objective of this paper is to create a metric that enables the comparison of the differences in built transportation infrastructure across all economies. To reach this objective, we first derive a country-level isolation metric from universally available data that measures the economic vitality and connectedness of each country with the international market. Then we measure the distance between a country's primary port and its capital city, or other community of interest. We use this distance metric for each city and scale it using the country-level metric for each country through which the goods must travel. Although the specifics around pairing a given city with a particular port and measuring distance can be modified, our method is powerful in the logical process used to arrive at city isolation. Finally, we compare the resulting metric to existing measures of economic activity and food security to explore its usefulness and originality.

Isolation and its definition

The type of isolation we aim to quantify is a measure of accessibility. The question we wish to answer is depending on a city's location, how connected is it with the market for globally traded commodities? This assumes that economic measures and the stability afforded by local government are not factors. As such, the index is primarily a measure of strength of infrastructure. Economic contributors are not included so as to empower the index in its application to understanding trade and market isolation. We did not want differences in economic activity to be captured in the explanatory variables. In addition, measures of societal stability were too subjective to incorporate quantitatively in the Isolation Index we present here. The lack of consistency would weaken the index's ability to be applied globally. We recognize the importance of economic factors and societal stability in assessing isolation, but they are excluded to reduce subjectivity and allow the use of the Isolation Index with these economic indices in later analysis. There are many other metrics of isolation that do include these parameters (see Table 2 for examples). Our contribution is in the development of a comparable, international isolation metric that can be applied to a city or nation that excludes these considerations.

Central to the development of an Isolation Index is acknowledging the importance of maritime trade. It is the most commonly used means of international trade as approximately 80% of the world's trade is conducted by sea (Vego, 2008). Considering this, it is crucial to pair inland cities with specific major, industrialized ports that are likely to be employed to import bulk commodities.

Table 1
Inputs to the isolation metric.

Explanatory variable $j \in P$	Description	Input (x_{ij})	Source
Geographic area (ga_i)	Sum of all land and water areas in square kilometers	None	CIA
Airports (ar_i)	Total number of airports or airfields recognizable from air	ar_i/ga_i	CIA
Airports paved (ap_i)	Total number of airports with paved runways	ap_i/ga_i	CIA
Airports infrastructure (ai_i)	Percent airports paved of total	ap_i/ar_i	CIA
Roads (ro_i)	Total length of road network in kilometers	ro_i/ga_i	Nationmaster
Roads paved (rp_i)	Total length of paved roads of network in kilometers	rp_i/ga_i	Nationmaster
Roads infrastructure (ri_i)	Percent roads paved of total	rp_i/ro_i	Nationmaster
Railways (rl_i)	Total length of rail network in kilometers	rl_i/ga_i	International Union of Railways
Ports (pt_i)	Number of major coastal and inland ports	pt_i/ga_i	CIA
Coastline (co_i)	Total length of land boundary touching sea in kilometers	co_i/ga_i	CIA
Inland water (iw_i)	Total area of all inland water bodies in square kilometers	iw_i/ga_i	CIA

Thus, we consider a city's isolation to be a measure of its accessibility from its associated port. The issue then becomes how to quantify this accessibility. Relying upon distance alone is not sufficient. Travel time and transport efficiency rely too heavily upon regional infrastructure strength to base accessibility upon distance alone (World Bank, 2012).

Index development

There are two widely accepted paths that may be used to develop an index: a network-flow optimization model (Magle, Theobald, & Crooks, 2009) and a statistical approach (Briguglio, 1995). Magle et al. (2009) implement a network optimization model in an effort to quantify the level of isolation amongst prairie dog populations in the Denver, CO area. Nodes of the model indicate location of prairie dog populations with the connecting arcs weighted by the presumed relative difficulty of traveling along such a path. Because the authors were able to directly measure the difficulty of travel using clearly defined methodology and comparable datasets, the metric is effective at measuring the isolation of one community from another (Magle, Theobald, & Crooks, 2009). Although this approach would meet the objective of creating an index that quantifies transport convenience across diverse areas of the world, there is simply not enough specific, comparable infrastructure quality information and travel time data to construct accurate models for our purposes.

We use a statistical approach to measure isolation using freely available economic factors as explanatory variables, adapting Briguglio's (1995) method to index the vulnerability of small islands. His technique of standardizing the variables is of particular interest to us because the author addresses multiple factors with different units and produces a single, meaningful number that can be comparable across economies and locations. The author's primary concern is that the method be simple and thus easily replicated. We adopt a similar approach to Briguglio and also employ methods from the Konjunkturforschungsstelle, or KOF Index of Globalization, in weighting the explanatory variables of the index (Dreher, 2006). Dreher (2006) weighs variables in such a way

Table 2
Metrics to which we compared the country isolation index. Table shows the description of the metric, reference, period over which the data is viable, and resolution of the data.

Metric	Source	Year	Description and temporal span of data used	Countries in index/total countries
National Food Price Index for food insecure countries	Brown et al., 2012	2012	Standard deviation of country price metric 2001–2010	35/136
Percent of income spent on food	Meade, 2011	2010	Percent of income spent on food and beverages	67/136
WMO Percent of children underweight	Onis et al., 2004	1998–2011	Percent of underweight children, both sexes, from nutrition surveys, most recent years	114/136
Per capita food supply (kg/capita/yr)	FAO, 2012	2009	Amount of food produced in country	127/136
Aggregated cereal yields	FAO, 2012	2010	Total aggregated cereal yields	130/136
Time to export goods	The World Bank, 2012	2011	2010–2011	130/136
Time to import goods	The World Bank, 2012	2011	2010–2011	130/136
Vulnerability index	Briguglio, 1995	1995	Natural disaster data 1970–1990	82/136
Accessibility	Nelson, 2008	2008	Population data, 2000; road/railway networks/national borders, 1997; navigable rivers, 1980s; land class, 2000; urban areas, 2004.	136/136
Port efficiency index	Clark et al., 2004	2002	1998–2000	42/136

as to maximize the variance in the final indices. We employ the statistical methods found in the Briguglio (1995) and Dreher (2006) in this study.

Producing national factors of isolation requires compounding the collected infrastructure, geographic, and population data for each country into a single, meaningful number. This process yields the challenges of reconciling data that come in different units and determining how to weight the relative importance of each variable. It is important to note that the ultimate goal of this metric is to quantify the relative isolation of localities; absolute values of isolation are of interest. We are thus seeking to determine how isolated "City A" is compared to the isolation of "City B," rather than the standalone isolation value of any particular location.

Briguglio's (1995) methods were adapted to accomplish the first challenge of standardizing data with different units. Briguglio normalizes a given set of data by ranking each entry form (0–1) based upon its quantity in comparison with the rest of the pool (Briguglio, 1995).

For the sake of explanation, consider total distance of roads in countries A, B, C. The country with the greatest distance of roads (without loss of generality, A) would receive a 1 in this section. The country with the least distance of roads (without loss of generality, C) would receive a 0 in this section. Country B would receive a number between 0 and 1, proportional to the distance of roads it has relative to A and C. In this manner, the countries' relative values are of the utmost importance. Our efforts necessitated countries with higher levels of isolation to have higher index values. As such, we modified Briguglio's method so that higher valued data entries corresponded to lower normalized values.

Dreher's (2006) method was applied toward the second challenge of determining the weighted value of each explanatory factor in its contribution to the final index values. As stated earlier, our purpose was to produce a metric that provided relative meaning. Dreher's method involved a principal component analysis, which solved the optimization problem to maximize the variance in the final indices. Such a method is most applicable in producing index values designed to show relative levels of isolation because maximizing the variance in the final values makes relationships more discernible.

Existing metrics of trade and infrastructure

Because we are interested in quantifying the impact of poor infrastructure and non-travelable roads on economic integration, we compare our index to a number of measures of integration and food security situations. The first is the country-level food price index presented in Brown et al. (2012) from 44 countries around the world. This paper provides country-level information on local food price variability that incorporates locally produced and consumed commodities. We also compare the Isolation index to commonly used country-level metrics of food insecurity that are independent of trade. These are percent of income spent on food, per capita food supply, agricultural yields, and the percent of children who are underweight. These metrics are widely used to estimate how vulnerable a country is to short-term food production deficits due to drought, extreme weather, or other shock (Maxwell & Frankenberger, 1992). Underweight children suffer long-term consequences from lack of adequate nutrition during their first years of life. This metric is easy to calculate and is comparable across cultures and economies. Percent of income spent on food along with estimates of domestic food supply can both be used to estimate a country's vulnerability to domestic food production shocks. Poor infrastructure and lack of access to the international market can increase the likelihood of nutrition impacts during shocks.

Unlike these metrics of food security, isolation is more often considered in the economic arena. One commonly used metric of isolation is from the World Bank's Trading Across Borders project (World Bank, 2012). The World Bank's Economy Rankings include indices based on procedural requirements for importing and exporting a standardized cargo of goods. These parameters include documents required, time in system, and cost to export and import goods. The World Bank's database takes into account the entire trade procedure ranging from packing goods in warehouses to their departure from the port of exit. In that way, it is similar to our distance measurement and bundles time with cost to estimate the impact of infrastructure on market accessibility to the world economy. In order to be comparable across economies, this 'Time to Export' metric makes assumptions that the company has at least 60 employees, exports more than 10% of it sales, and the product in question is one of the economy's leading export or import products. It also assumes the movement of the goods in standard, 20-foot containers. These assumptions are less reasonable in small economies in landlocked, least developed countries with large informal sectors and few manufacturing organizations. This metric, however, nevertheless provides useful information on the time to import goods and time to export goods.

We also compare our Isolation Index to Briguglio's vulnerability index, which uses variables such as exposure to foreign economic conditions, remoteness and insularity, ratio of transport and freight costs to export proceeds, and disaster proneness (Briguglio, 1995). In addition, he adjusts his vulnerability index based on GDP per capita. The GDP per capita index is standardized using the same method as the vulnerability index (Briguglio, 1995) and is the same method we adapt.

The study published in Nelson (2008) aims to quantify accessibility around the world, where accessibility is defined as the travel time to the nearest city with a population of 50,000 using land or water based travel (Nelson, 2008). The final product, known as the first Global Accessibility Map (Holden, 2009), was made for the World Bank's World Development Report 2009 *Reshaping Economic Geography*. The project uses a cost–distance algorithm that ultimately creates an extremely detailed raster grid. The data sources that are used in the algorithm include places with populations of 50,000 people or more in the year 2000, road networks, railway networks, navigable rivers, major water bodies, shipping lanes, national borders, land cover classes, urban areas, elevation, and slope. The study assigns travel speeds to most of the factors. For example, an artificial surface land class is 2 min per kilometer, while travel speed in herbaceous cover is 36 min per kilometer. The resulting index is expressed in travel time compared to our unitless metric, which can be used to modify distance traveled from any point in a country.

The last metric we explore that also incorporates infrastructure without economic considerations is Clark, Dollar, and Micco (2004) Port Efficiency Index. Although it does not provide information for all countries, it uses data on port infrastructure, cargo handling restrictions, mandatory port services, clearance time, and crime to determine port efficiency of a country in a unitless index. One limitation of this metric is that many food security crises occur in nations without a major port or inland port and these areas are not covered by this metric (Clark et al., 2004). We seek a method to combine this information with information on distance to ports from rural regions in land-locked countries that have most often experienced food insecurity.

Methods

Country isolation index

Our national level Isolation Index takes into account many different variables. Once identified, these variables need to be normalized between countries so they are commensurate. Once each variable's relative contribution to a country's isolation is known, the maximum variance weight for each variable is calculated. Then we find each country's isolation value by taking the sum-product of the weightings with the normalized explanatory factors.

C set of countries with $i \in C$
P set of explanatory variables with $j \in P$

The above set notation will be used when referring to formulas. These variables are utilized within a table of countries in rows "i" with explanatory factors in columns "j". For instance, an item a_{ij} would have its origin in the "ith" row and "jth" column of this parent table.

It is necessary to normalize the explanatory variables because they need to be transformed into unitless and therefore comparable values before being utilized for the index. Thus we combine the explanatory factors (Table 1) with the following relationships:

x_{ij} = input value of j assigned to country i, $i \in C$ $j \in P$

We use the x_{ij} as part of the V_{ij} contribution of explanatory variable j to the isolation of country i, $i \in C$ $j \in P$

$$V_{ij} = \frac{(\text{Max } X_i - X_{ij})}{(\text{Max } X_i - \text{Min } X_i)}, \quad i \in C\ j \in P \tag{1}$$

This process normalizes the data by assigning a value V_{ij} for each explanatory variable per country with $0 \le V_{ij} \le 1$. A country that has a greater level of isolation with regards to explanatory variable j, relative to the pool of countries C, will have a greater V_{ij}. For instance, the country with the least concentration of highways per area will earn a value of one for the highway component of their isolation index while the country with the greatest concentration will earn no points for its highways.

This technique normalizes a set of data with varying units and is often seen in the form $(x - \mu/\sigma)$, where x is the sample, μ is the population mean, and σ is the population standard deviation (Johnson & Bhattacharyya, 2010). The version stated above (1) shifts and scales the data such that our values are all greater than or equal to zero. This scaling is particularly useful because we are interested in the *relative* isolation of the countries and their *relative* strengths of infrastructure (Briguglio, 1995).

Determining maximum variance weightings and isolation index values

After establishing relative contributions of each explanatory factor to a country's overall concentration, we must select weights for each component. Here we build an isolation index that is primarily prescriptive in nature that aims to find a way to assign relative values of countries isolations in order to discern relationships besides absolute values of isolation. With this in mind, we assign weights to each component of a country's isolation or connectivity level using roads, highways, ports, etc. in such a way that maximizes variance in the final values of isolation indices, according to methods outlined by Dreher (2006):

B_j = model coefficient corresponding to explanatory variable j, $j \in P$
Y_i = isolation index for country i, $i \in C$

$$Y_i = \sum(\text{over all j}) B_j * V_{ij}, \quad i \in C \tag{2}$$

Objective: Max Var Y_i.
Subject to: $\sum(\text{over all j}) B_j^2 b = 1$ length of explanatory weight vector equal to 1.

The equation listed above finds maximum variance weights for the explanatory variables. These maximum variance weights are elements of the first eigenvector of the data covariance matrix (Dasgupta, 2008).

For each country, we take the sum product of maximum variance weightings math formulation with the normalized values (Equation (1)) for each country's respective isolation contributors to produce the Isolation Index. The creation of this index enables us to change our conception of traveled distance within each country. The Isolation Indices are factors by which to scale distances in the countries and cities of interest. In a more isolated country, distances will be amplified, while distances will be condensed in well-connected nations.

Normalizing the final values

We normalize the values in this paper using simple equations for three reasons: 1) in order to perform *t*-tests the values must be in the same units to be compared for covariances; 2) normalizing the data makes visualization more intuitive and 3) makes comparisons easier to analyze The values are normalized 1–10 using the simple formula:

Where Y is the normalized value and x is the number in the list

$$Y(x) = 1 + \frac{(X - \text{MIN } x)^*(10 - 1)}{(\text{MAX } x - \text{MIN } x)} \quad (3)$$

City isolation index

In a given country, a city's isolation from the global market will be directly proportional to its distance away from that city's associated port. The country's isolation index will be used as the constant of proportionality. If a country is landlocked, a city's isolation within that country will be the sum-product of each country's Isolation Index with the distance traveled in that particular country to reach port (Equation (4)). We therefore had to calculate the distance between the port and the country border and then the border to the city of interest. When multiple countries were traversed, a distance within each country was calculated, the Isolation Index for each country was used, and the sum of all products was calculated for the final city metric.

I = city isolation
d_i = distance traveled in country i to reach port, $i \in C$

$$I = \sum(\text{over all } i)Y_i d_i \quad (4)$$

Equation (4) calculates the final city isolation levels.

We only used ports with container liner service and used coordinates from World Port Source to associate the nearest ports with cities according to Google Maps. If two ports were the same distance, the port with a shorter travel time was chosen. Google maps is useful for port selection, but is not appropriate as a tool to produce comprehensive travel time data between cities because it does not take into account poor road conditions or roadblocks due to police activity.

For the purpose of measuring straight-line distances, it was necessary to separate the lines into standalone datasets of approximately 30° latitudinal ranges because no single projection can provide completely accurate distance measurements between any two points on the globe. To account for this, we created custom Albers Equal Area projections, adjusting the parallels to appropriately match the standalone datasets. Albers was chosen because it has a reasonable latitude range of 30° and more importantly for our purposes, no east–west limitation. Eight to twelve paths from the centers and extreme corners of each latitudinal range were extracted for empirical accuracy testing. Each distance within a projection was compared with the true distance. The custom projections yielded an average difference of 1.15% from truth with an average standard deviation of 0.93.

The World Countries dataset from ESRI's Smart Data Compression (SDC) Feature Database was used for country boundaries. One problem with the analysis was that some paths crossed over water to reach the port, causing some lines to exit the country layer boundary. Where the path traveled through only one country, this issue was resolved by dividing the distance by the percentage that water made of the total distance, which calculated the full length of the route. However, this could not be accomplished when a line traveled through multiple countries because the percentage for each segment provided in the table only represented information about the total length. To account for this, we discarded any lines for which the percentage in each country did not sum to 95% or greater.

The segment distances for each country were then multiplied by the appropriate raw country isolation factor, found from Equation (2). Finally, the segment products for each line were summed, which constituted the final Isolation Index for each city of interest.

Evaluating the country isolation index

To assess the meaning of the derived country Isolation Indices, which are used to find individual city isolation, our national indices were tested against other nationally available economic metrics and food security statistics that are listed in Table 2. We calculated the coefficient of determination (r^2) between the Isolation Index and the metrics listed in Table 2 in order to determine the independence and relationship with known parameters. The primary data sources we compared against are national food price indices for cereals (Brown et al., 2012), percent of income spent on food (Meade, 2011), percent of children underweight (Onis, Blössner, Borghi, Frongillo, & Morris, 2004), per capita food supply and aggregated cereal yields from the FAO, time to export and import goods (World Bank, 2012), the Briguglio index (Briguglio, 1995), an accessibility index (Nelson, 2008) and a port efficiency index (Clark et al., 2002) (Table 2). We also explored the outliers and extreme values seen in both indices in the results section.

Results

Our national isolation factors illustrated in Fig. 1a show the expected trend of higher isolation when countries are landlocked and in less developed regions. Countries with large amounts of infrastructure relative to total area have low Isolation values while countries, such as those in Africa and South America, with large amount of territory and poor infrastructure have higher index values.

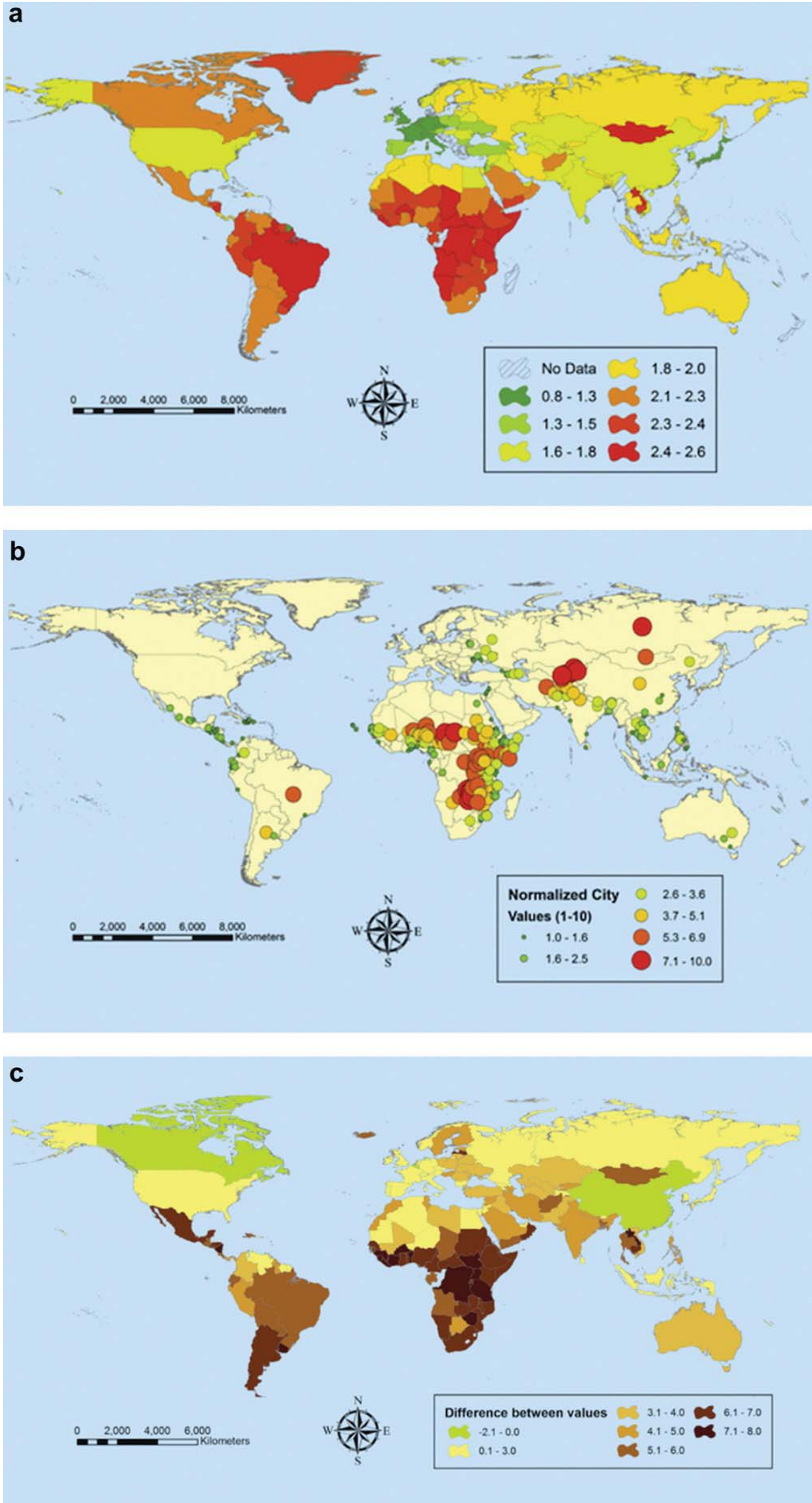
The Isolation Index permits the direct comparison of infrastructure in both developed and developing regions. The regions with the lowest isolation are small and extremely highly developed nations in Europe, with metrics are between 0 and 1.5. The United States, Russia, China and Australia all have large distances in their territory, as well as high levels of infrastructure and relatively dispersed populations. As a result, these countries all have similar isolation metrics of between 1 and 2. Lesser-developed countries with lower population densities and far less infrastructure have much higher index values, ranging from 2.1 through 2.6.

The city isolation factors illustrated in Fig. 1b show the expected trend of higher isolation when landlocked and located in countries with worse isolation scores. To illustrate how the city-level metric can be used, we applied it to cities where local food prices are regularly reported by the United Nations Global Information and Early Warning System (GIEWS) and US Agency for International Development's Famine Early Warning Systems Network. In these cities, food security monitoring is a critical activity and isolation from the international market has a significant effect both on the ability of local businesses and governments to import food, but also restricts the ability of local farmers to export to the international market.

The cities in Fig. 1b with high Isolation values are significantly more isolated from shipping terminals and other inexpensive ways of moving low-value goods. This will permit analysis with the variability of food prices. Interestingly, even if a city is in a country with poor infrastructure and ample coastline in comparison to geographic area, such as Nicaragua, it may have a low isolation value, indicating a lower isolation than in other regions with substantially higher infrastructure and development, but much larger distances to cover, such as Russia.

Comparison of country isolation indices with other metrics

Fig. 2 presents scatter plots of the relationships between our Isolation Index and other metrics listed in Table 2. The relationships vary from negative to positive and are uniformly fairly weak. Poor


a
No Data
0.8 - 1.3
1.3 - 1.5
1.6 - 1.8
1.8 - 2.0
2.1 - 2.3
2.3 - 2.4
2.4 - 2.6
0 2,000 4,000 6,000 8,000 Kilometers
N
W
E
S
b
Normalized City Values (1-10)
1.0 - 1.6
1.6 - 2.5
2.6 - 3.6
3.7 - 5.1
5.3 - 6.9
7.1 - 10.0
0 2,000 4,000 6,000 8,000 Kilometers
N
W
E
S
c
Difference between values
-2.1 - 0.0
0.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 6.0
6.1 - 7.0
7.1 - 8.0
0 2,000 4,000 6,000 Kilometers
N
W
E
S

relationships between our Isolation Index and these other metrics are expected because our metric brings new and relevant information to metrics typically used to evaluate food insecurity.

The relationship with cereal price variability is low, but this is to be expected because the countries with price variance reported in Brown et al. (2012) are all developing countries with food security problems and high levels of isolation. In addition, food prices have many sources of variance that are not related to levels of infrastructure. We do, however, see high variance coincide with high levels of isolation and a positive relationship between the two variables. Somalia, the country with the highest standard deviation of cereal prices during the past decade exemplifies this. It has a standard deviation value of 134 and its isolation metric was also high, with a normalized value of 0.94. The correlation between these two metrics was quite low because only food insecure countries were represented in this dataset. For example, all the countries except Cape Verde had isolation factors above the 50th percentile, which would skew correlations.

The relationship between the isolation metric and percent of income spent on food is positive, but weak. Countries with low levels of income spent on food generally had a low isolation metric, with the small European countries being clustered together. The United States has a fairly high isolation, at 1.75 (0.54 normalized), because of its large territory, but it has the lowest percent of income spent on food, at 6.7% in 2010. At the other end of the spectrum, the countries with the highest percent of income spent on food are Cameroon, Azerbaijan and Kenya. Of these, Cameroon and Kenya also have extremely high levels of isolation, with normalized values of 0.89 and 0.94. This shows the isolation metric is able to capture broad economic isolation, which is a factor in and perhaps a cause of poverty (Chaudhuri & Ravallion, 1994; Moser, 1998; Ravallion, 1988).

There is a very weak positive relationship between our isolation metric and the percent of children who are malnourished. Although these data are from national surveys conducted throughout the last decade having been produced for the Millenium Development Goals assessment, they are generally representative of the impact of differences in food security outcomes between nations. The five countries with the highest malnutrition rates, between 40 and 45%, are Timor-Leste, India, Yemen, Bangladesh, and Niger. Timor-Leste, Yemen, and Niger are all highly isolated, with normalized indices of 0.72, 0.90 and 0.85 respectively. India has a lower Isolation Index value of 0.56 and Bangladesh a metric of 0.62, which is understandable given their significant role in the international manufacturing sector and their relatively well developed ports and transportation systems.

The next two metrics, 2009 food supply and 2010 yield data, both from the UN Food and Agriculture Organization, show distinctly different relationships with our metric. The food supply metric, which is kilograms of food produced per capita per day, is poorly related with a slight negative relationship and wide dispersion of values. The 2010 yield data, however, have a stronger negative relationship to the isolation metric, including the outlier of Oman, which has extremely high yields due to its small, irrigated agriculture sector. Yield data reflect the transfer and utilization of technology and modern approaches to agricultural production and distribution of cereals after harvest, which increases yields as isolation declines.

The two metrics that report time to import and export also show positive relationships with our Isolation Metrics. The non-linear relationship that the plots show is interesting because it shows that as the time to export or import increases, the infrastructure components reflected in the Isolation Index do not continue to increase. The countries with over 80 days to export are Iraq and Tajikisan. Countries that take over 80 days to import goods are Iraq, Tajikistan, Uzbekistan and Chad. Of these, only Chad had an extremely high isolation metric of 0.98, with the others only moderate isolation indices of around 0.5. This indicates that these countries had non-physical causes of increased time to move goods such as paperwork, taxes, and other bureaucracy that are captured in these indices.

The comparisons of our Isolation Index to the Briguglio Vulnerability and the Nelson Accessibility Index show that our metric is only poorly related to the Vulnerability Index and only slightly better related to the Accessibility index. The Accessibility Index contains a dataset that is by far the most similar to our effort and incorporates many relevant and global variables. The main difference between our Index and the Accessibility map is that ours is more directly related to international trade and the global market. This is due to the fact that we have designed our metric to enable calculation of isolation from any port or city in neighboring countries instead of to the nearest city of 50,000. We report a Pearson correlation between the country-level Isolation Index and the Accessibility metric of 0.40. To visualize this comparison, a map of the difference between the country isolation index and accessibility is provided (Fig. 1c).

The largest differences between the two indices are in the least developed nations and in larger nations, such as Mexico and Argentina, with moderately sized economies, but significant challenges to transportation. Because our focus is on broader goods transportation and do not consider interior cities of 50,000 as our point of departure, these countries stand out as locations that we consider to be more isolated than the Accessibility Map.

Finally, we related our Index to the Port Efficiency Index. We show a fairly strong negative relationship between the Isolation Index and the Port Efficiency index, with a Pearson correlation of −0.45. This comparison resulted in a surprising outcome because it is the only case where the *p*-value (0.222) indicates that the covariance of the arrays does not statistically differ. In other words, the two datasets are highly comparable. This index only has values in countries with high efficiency industrial ports, however, so the metric cannot be used in interior, less developed countries that may experience food security crises, such as Niger or Tajikistan.

Comparison of city-level isolation metric with food price variability

Fig. 3 shows a comparison between the city-level metric and difference between the local sorghum, rice, wheat, and maize and global monthly prices for the same commodities. Rice and wheat are often imported from major agriculture regions, such as Thailand and the United States, to the cities being considered here. They are then routed through major ports and overland in order to reach local markets (von Braun, 1988; Reardon, 1993). When including all cities, the correlation between the price difference and the Isolation Metric is extremely low. When excluding cities that have an isolation metric value that is in the lower half, the metric is able to capture the impact of infrastructure on food price variance. When the city is not isolated, then the City Isolation Index has no explanatory value for food price variation. For rice, which is often imported from the international markets, cities with isolation factors over the 50th percentile are more likely to have a local price for rice that is over 40% of the international market price

Fig. 1. a. Map of country isolation index. Values range from 0 to 3 and are classified into seven Jenks natural breaks. b. Map of city isolation index. Values are normalized between 1 and 10 and classified into six Jenks natural breaks. c. Map of difference between the normalized average national accessibility index values subtracted from the normalized isolation index. Both indices were normalized from 1 to 10 for ease of comparison.

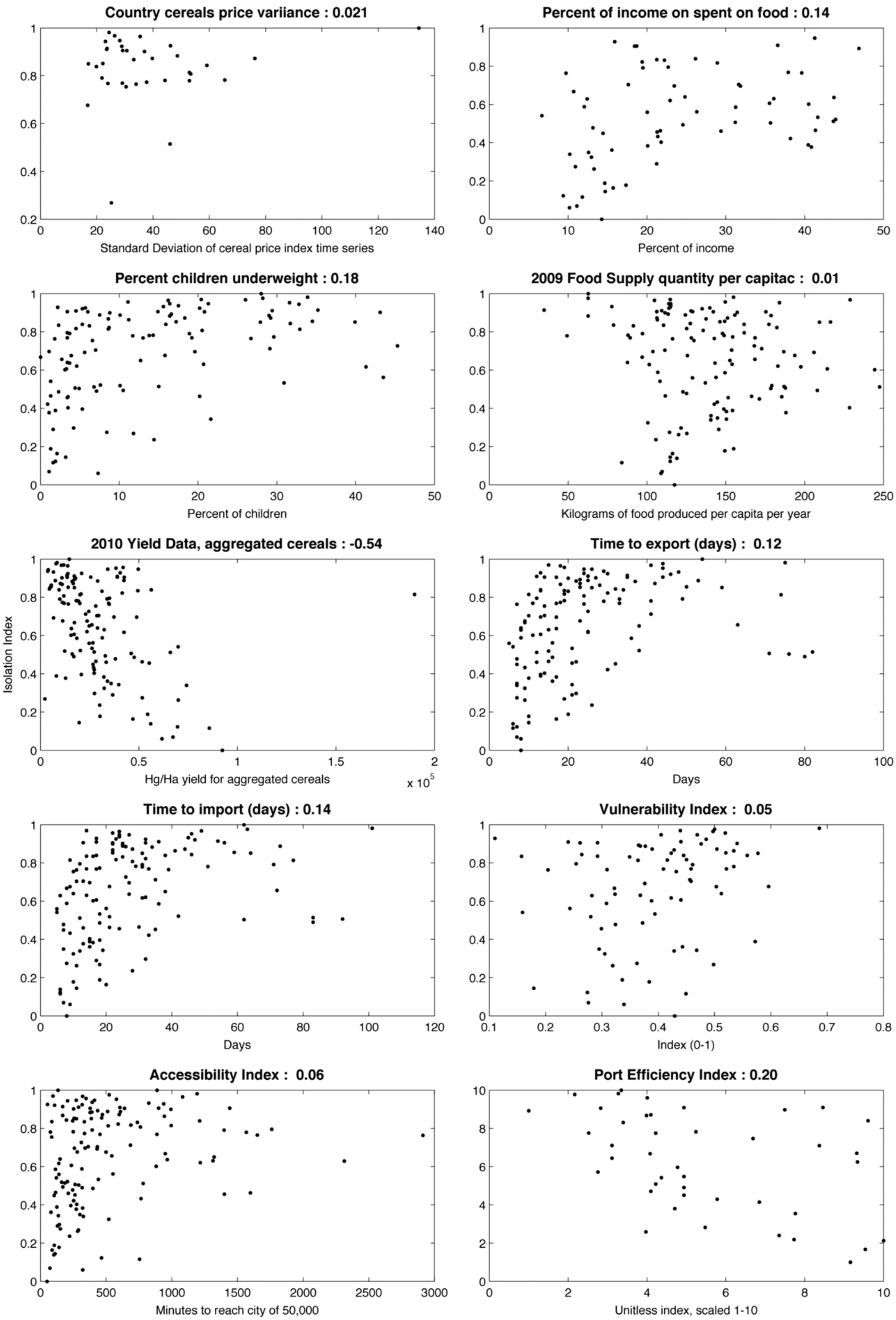


Fig. 2. Scatter plots showing all metrics presented in Table 2 with the isolation index. Correlation statistics are stated in the header for each graph.

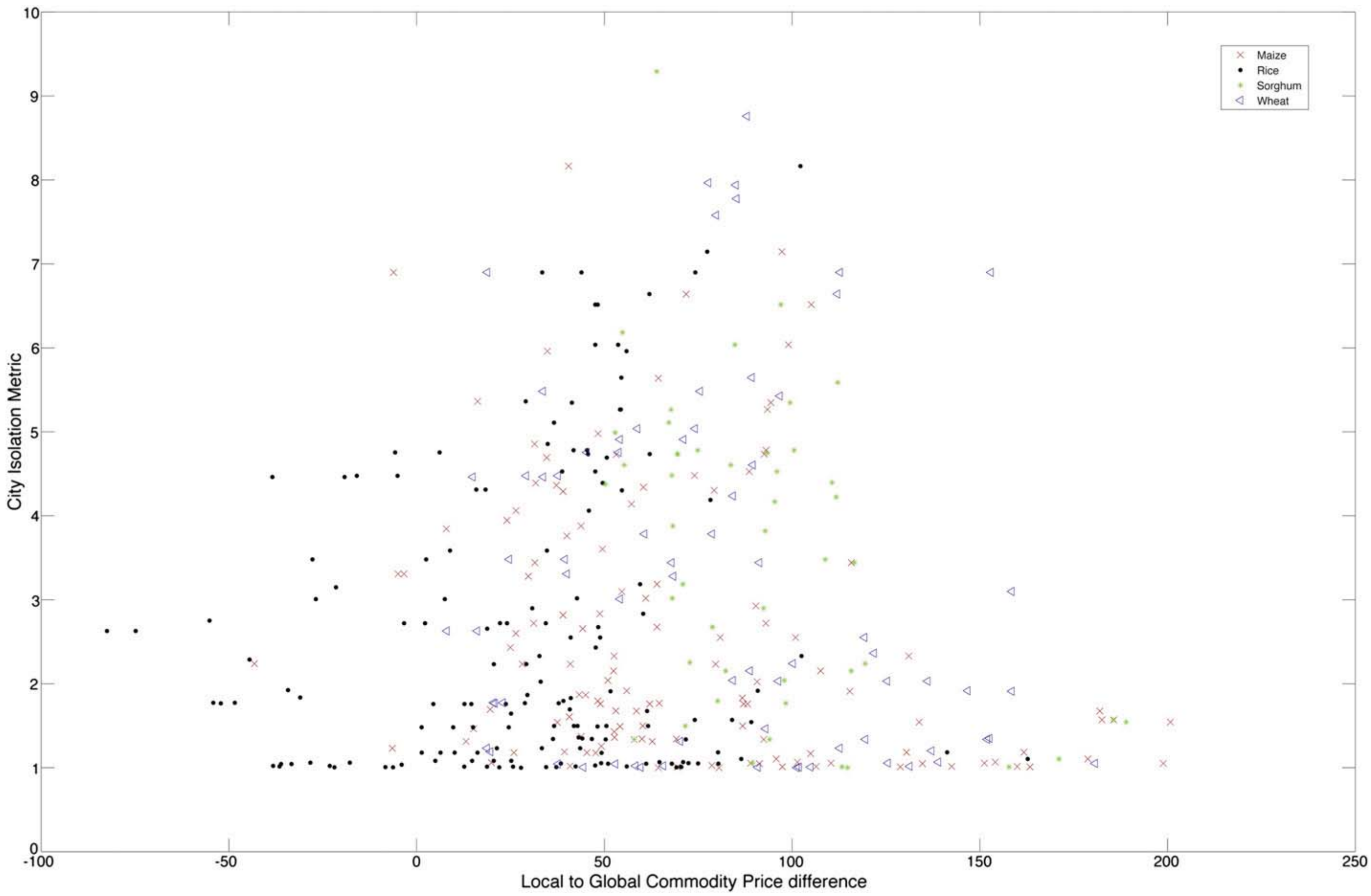


Fig. 3. Scatter plot between the isolation index and the percent difference between the local and global market monthly local retail rice, sorghum, wheat and maize prices for cities in the developing world from 2000 to 2010 in US Dollars per ton. Data from www.fao.org/giews/pricetool.

(correlation of 0.65). Price increases are likely due to high transaction costs, lack of reliable transportation, and low demand (Coulter & Poulton, 2001).

Discussion

Investment in infrastructure has many benefits, but evaluating the return on investment in different economies has often been difficult. As Canning and Bennathan (2000, p. 49) have noted, many benefits to improved infrastructure are accrued as externalities that are not directly measurable. Where there are few paved roads and little infrastructure, investment in transportation networks pays large rates of return (Canning & Bennathan, 2000, p. 49). These investments also diversify markets and enable movement of food from regions with surplus to those with deficits and high local food prices. These effects are difficult to quantify in many countries due to the paucity of observations of food prices and movements of goods across borders. By relating a measure of isolation to the difference between local prices and international prices, we estimate the impact of investment in infrastructure on the ability of cities to access food on the international market.

Differences in infrastructure across countries and regions cause significant differences in the cost of food. Prices of staple foods in food insecure regions are often more related to local and regional growing conditions, transaction costs for moving goods, time of year, policy barriers to trade, the absence of imported products, and the cost of energy than they are to global commodity prices (Brown et al., 2012). Regional differences in market integration between the international markets can be assessed more effectively using comparative metrics that allow the removal infrastructure-related differences from market assessments. The metric we provide here is an attempt to understand which cities are more isolated than others and where we could expect reduced ability to access food from the international markets during times of need.

The metric used national isolation factors that were calculated using various infrastructure data, which were modified according to distance traveled within a country. Any given city will be proportionally more isolated if it is farther away from the nearest port with container liner service. Briguglio (1995), however, noted that measuring remoteness by taking distances in kilometers may convey the wrong information for economic purposes. This was because the nearest commercial center may not be the one with which the country in question has its most important trade relations. We avoid the problem of the nearest commercial center because while calculating distances from cities to the closest outgoing port, our assumption is that the port will handle the majority of the associated city's trade. Other users of the Isolation Index can calculate the distance to the city through which their goods will travel regardless of its proximity. Then the user of the Index can multiply our country-level metric with the distance traveled within each country to estimate the different levels of isolation of each location. In this way, specialized knowledge of a region can be applied to this metric, enabling a more precise understanding of the isolation of a particular city. Our metric may be particularly useful if one wishes to place emphasis on infrastructure during analysis.

The closest metric to ours was the robust Nelson (2008) Accessibility data. One reason that our data was different from the Accessibility Index was that it uses specific factors to deal with the issue of varying ease of travel. Slope, elevation, and land class cover are among these factors. This can be seen in areas like central Africa, near the Democratic Republic of the Congo or Tanzania. Although our index attempts to take the difficulty of travel into account by using ratios of paved/unpaved roads, Nelson (2008) uses additional data, such as elevation, that may be a large factor in mountainous regions.

Accessibility to international food markets can have a positive impact on the ability of a country to extend its markets through increased competition, allows producers to exploit economies of scale and specialization, and allows greater dissemination of knowledge and technology (Canning & Bennathan, 2000, p. 49). These benefits are often excluded from cost–benefit analyses, but are critical contributors to more integrated food markets in the developing world. If farmers in isolated regions are to successfully expand production in regions with high population and very low yields, they will need to increase productivity in good years while expanding regional markets that can absorb the increased production (Funk & Brown, 2009; Hansen, 2002). Our metric allows the quantitative analysis of which countries and regions need more investment in infrastructure to improve food security and food production.

Conclusions

This study focuses on providing an independent metric of economic isolation that can be used in food security analyses that typically include economic measures. Considering how food security analyses often use food prices as a measure of food access, we are interested in developing a metric that is independent of economic statistics and can be applied to the city level. We have developed a national index that can be multiplied by the travel distance within each country from a city to a major port. We provide analysis of this new metric to existing metrics and finally to local imported rice prices in 47 economically and geographically diverse cities. Our metric specifically measures isolation from the global market, but can be used to compare any country or city around the world.

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