Available online at www.centmapress.org

INTERNATIONAL JOURNAL ON FOOD SYSTEM DYNAMICS

Int. J. Food System Dynamics 15 (1), 2024, 10-28

DOI: https://dx.doi.org/10.18461/ijfsd.v15i1.I2x

Urban food consumption temporal patterns using power law scaling

Jason West

Bureau of Meteorology, Melbourne, VIC, Australia.
jason.west@bom.gov.au

Received May 2023, accepted December 2023, available online January 2024

ABSTRACT

We apply a variant of power law scaling to differentiate consumption patterns across major food categories in growing urban environments relative to rural environments. Using data from China over a 36-year period, we empirically demonstrate that there is a systematic dependence of urban food consumption on city population size. We derive a general function of food consumption based on the rate of urbanization that behaves with quantitative regularity manifest by urban efficiency gains. In urban areas, meat consumption increases by 80 percent while grain consumption declines by 16 percent with each doubling of population.

Keywords: *Power law; scaling; food consumption; urbanization.*

1 Introduction

The majority of the world's population now live in cities (Crane and Kinzig, 2005). The trend towards urbanization in both developed and developing regions is interconnected with economic development as well as substantial changes in social organization, land use and patterns of human behaviour (Bettencourt et al., 2007). In 2015, more than 70 per cent of the population in developed countries lived in cities while in developing countries this has recently accelerated towards 50 per cent. Importantly, cities occupy only 0.3 per cent of the total land area, representing roughly 3 per cent of arable land. By 2030, expectations are that the urban population of developing countries will double to over 4 billion people (United Nations, 2017). Over the same period, rural populations are expected to decline at a similar rate, representing a one-for-one switch from rural to urban residency. This shift is expected to markedly alter food consumption patterns. However, the differences in food consumption dynamics between urbanised and rural areas represents a major challenge in understanding and predicting the future demand for food.

The eating patterns of individuals are known to vary according to socioeconomic status with rural populations known to experience higher levels of socioeconomic disadvantage. However, little is known about the consumption pattern differences between urban and rural areas and to what extent such patterns differ based on the structure of the environment in which people live.

The importance of population size as a major determinant of the intensity of social and economic activity in urban areas has been examined in research that applies scaling analysis to understand the behaviours of a diverse set of macro-indicators (Wensing, et al., 2023; Remans, 2020). Urban development exhibits interesting and predictable levels of scaling across many metrics, both physical and intangible, and scale in a similar way across the wide variety of urban systems. Urban scaling analysis has been shown to reveal how general properties of city behaviours can exhibit growth that is slower relative to city size (sublinear) through economies of scale, or they grow faster than city size (superlinear) through increasing returns to scale (Bettencourt et al., 2020). These results are somewhat surprising since cities are complex adaptive systems aligned to differing spatial-temporal scales and exhibit emergent dynamics that are generally contingent on historical factors.

At a very small scale, Deaton and Paxson (1998) uncovered empirical evidence to show that with total household expenditure per capita held constant, expenditure per head on food declines with the number of individuals in a household. The effect is similar across geographies including developed countries such as the US and UK, as well as developing areas in Pakistan and southern Africa.

It is well understood that food consumption and diets evolve over time, being influenced by many factors and complex interactions. Income, prices, individual preferences and beliefs, cultural traditions, as well as geographical, environmental, social, and economic factors all combine to shape dietary consumption patterns. But understanding food consumption patterns as a complex interplay between exogenous factors using total consumption data or other similar measures such as food balance sheets ignore the powerful influence of urban development itself.

Emergent dynamics through urban development can be used to explore consumption patterns between food types using power law scaling that show very similar consumption patterns across all urban areas, independent of location, size, or culture.

In this study, we derive a general function of food consumption related to the rate of urbanisation that behaves with quantitative regularity. Using differentiated rural and urban consumption data from China over a 36-year period, we present empirical evidence showing that food consumption patterns are, on average, scaling functions of urban size that are quantitatively consistent, both spatially and temporally. We further show the contrast between rural and urban food consumption, manifest by urban efficiency gains, also displays quantifiable scaling relationships. This approach serves as a useful proxy in place of more complex methods to derive consumption forecasts in developing regions.

2 Urban scaling

At a national level, scaling analysis quantifies how measurable aggregate characteristics respond to a change in the size of a given system. Scaling refers to a broad set of properties governing the behaviour of complex systems that exhibit nonlinear relations in the form of power laws to describe certain attributes of their internal subsystems. This can be manifest through a combination of spatial distribution and temporal development. Urban systems have been examined to uncover processes that give rise to such regularities (Axtell, 2001). The application of scaling analysis is based on a relatively simple response function demonstrating a regular and systematic behaviour regardless of size. This implies that some nested generic factor constrains the system as it develops and grows.

Well-documented analyses of the effects of urban scaling concern the differences in urban conglomeration sizes of cities. The scaling effect has been defined in different ways, either by statistical laws like Zipf's rank-size rule (Zipf, 1949), or using central place theory (Openshaw and Veneris, 2003). Systematic relationships between population size, urban densities, traffic volumes, and other phenomena have been uncovered in urban areas. Similar patterns have been observed despite the socio-economic differences between regions (Angel et al., 2005). Specific production functions have been successfully derived using scaling as a basis to capture economic activity of urban systems to model economic output (Bettencourt et al., 2010).

While growth characteristics related to the volume of roads, gas stations, patent applications, wealth, crime, GDP, etc. have been examined against the growth of urban areas (Bettencourt, et al., 2007; 2010), little is known about the effect of urban agglomeration on food and fibre consumption patterns. In particular, the different dynamics of food and fibre consumption between urban and rural areas provides an alternative approach to forecast consumption patterns.

2.1 Urban and rural dynamics in China

Rapid economic growth in China has stimulated a fast rate of urban expansion as well as increased rural household income and consumption expenditure. In 1979, China initiated a range of rural reforms aimed to transform agricultural production from being centrally planning towards a market-based system. The reforms have had significant effects on agricultural production and productivity as well as rural household food demand (Fan et al., 1994; Halbrendt et al., 1994; Bloem and de Pee, 2017). Growth in rural household income coupled with diminished consumption of grains and low-quality vegetables has led to an increase in meat consumption along with higher-quality vegetables.

Over the 15-year period from 1992–2007 average household consumption per capita increased by a factor of 2.19. This is comprised of an increase of 1.61-fold for urban households and 1.32-fold for rural households (USDA, 2011). The composition of consumption over the same period has also changed substantially. For instance, Engel's coefficient, defined as the expenditure on food as a proportion of total consumption expenditure, decreased by 17.2 percent (from 53.0 percent to 35.8 percent) for urban households and by 14.6 percent (from 57.6 percent to 43.0 percent) for rural households. While dietary habits have changed in some regions, the availability of Western foods has not been extensive in China as in other regions.

Figure 1 depicts the change in animal-based protein and vegetable diets for inhabitants of Industrialised, Transition and Developing countries from 1967-2017. The proportional split between each category for Transition countries (located mainly in central Asia and Eastern Europe) and Industrialised countries has been relatively similar over the past two decades. China, as a country in transition over this period, displays a consumption pathway that mimics the dynamics of Industrialised countries in the sense that the aggregate proportion of food consumption is similar. In fact, China, by far, constitutes the largest component of the Transition country data. This suggests that overall dietary habits and total per capita consumption for China is broadly representative of the changing dynamics of food consumption.

To ascertain the dynamics of food consumption patterns in China with greater confidence, we examine how actual consumption patterns have changed from recent economic analyses. Jiang and Davis (2007) examined rural household food consumption behaviour in China using household data from Jilin Province. Data are classified into four main food groups - grains, vegetables, animal products and other foods. A household food demand system, incorporating four household characteristics, is estimated using a linear approximate almost ideal demand system (LA-AIDS) model (Deaton and Muellbauer, 1980), assuming a three-stage budgeting procedure. They estimated expenditure elasticities for a range of food groups (with a particular focus on animal products) and found that the inclusion of household characteristics did not have a statistically significant impact on the elasticity values in any of the three stages of the budgeting process. Future growth in household demand for grains (such as rice and wheat) grew in line with per capita income, while even greater growth was observed in the consumption of animal products.

Cui and Dibley (2012) found that intake of energy, fat and vegetable protein is greatest in rural areas and subsequently decreases with urbanisation. This decrease is attributable to lower consumption of cereals, which, in rural areas, are by far the principal source of calories, protein, and the fats. Conversely, animal protein intake increases with urbanisation through the consumption of meat, fish, milk, and eggs. Fat intake also increases due to the higher consumption of domestically produced or imported vegetable oils and some animal fats.

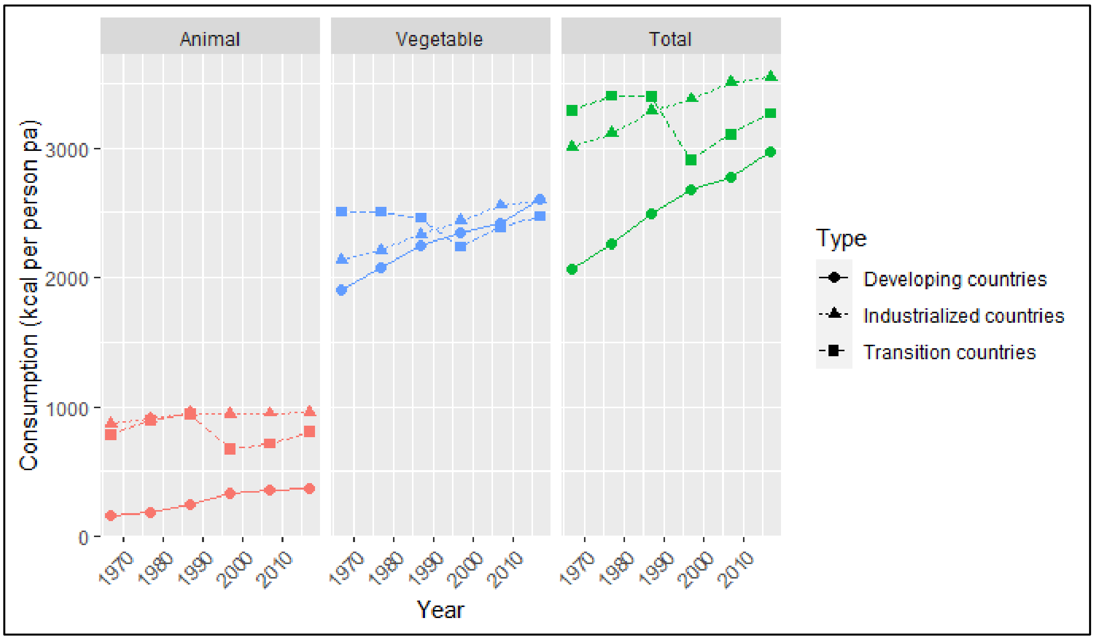

Figure 1. Vegetable and animal sources of energy in the diets of inhabitants in Industrialised, Developing and Transition countries (kcal per capita per day). *Source:* Bruinsma, (2003); FAO (2017).

Figure 2 compares rural and urban animal product consumption over the period 2000-2010. Rural inhabitants consume half the amount of animal products than urban inhabitants. Beef consumption is increasing but the magnitude remains small in both rural areas (0.6kg per capita annually) and urban areas (2.4kg per capita annually), compared with the OECD annual average beef consumption of 14.5kg per capita (OECD, 2019). Poultry, pork, eggs, and dairy are by far the dominant sources of consumption in both urban and rural areas, with volumes being substantially higher in urban areas.

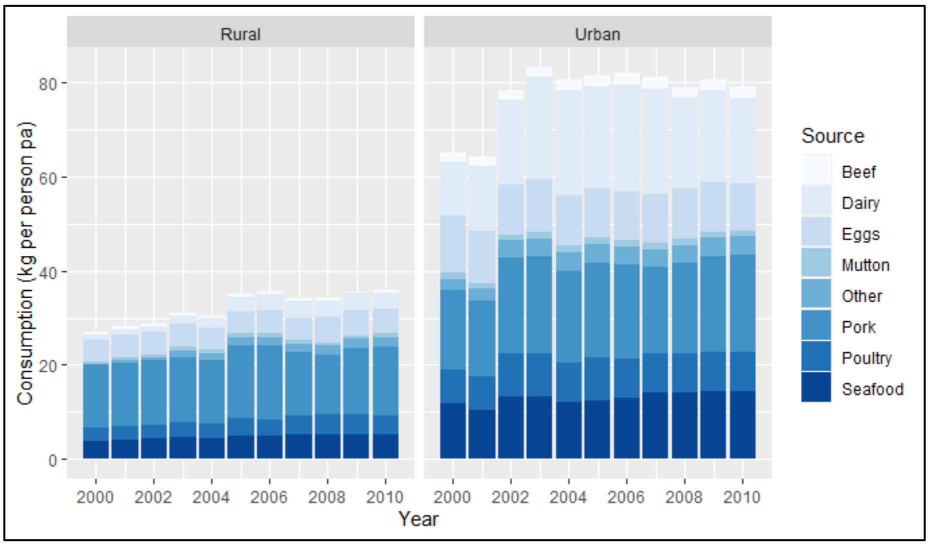

Figure 2. Rural vs urban consumption of animal products, China 2000-2010 (kg per capita).
Source: China State Statistical Bureau.

Other forecasts of food consumption patterns use almost ideal demand systems based on population and per capita GDP growth rate projections. Mottaleb et al (2018) found that both rural and urban households are likely to consume more grains and fish, while urban consumption of rice is likely to decline.

Prior attempts to forecast urban food consumption are based on bottom-up predictions that leverage the complex intersection of population growth, household budgets, food preferences, demand elasticity and food availability. The purpose of this analysis is to offer a parsimonious top-down alternative based on generalities in scaling laws that quantify urban growth characteristics caused by scale efficiencies. Observations in urban food demand can be easily compared with rural food demand upon the same quantitative basis.

3 Methodology

Our analysis concerns the relationship between food consumption differences in urban and rural areas, as a function of population. Specifically, we wish to examine whether there is a general average trend for the increase of the consumption of food types with urban population size. We use the term 'average' to represent many types of cities containing different characteristics.

Using population, $N(t)$ as the measure of city size at time t, temporal power law scaling takes the form

$$Y(t) = A_i Y_0 N(t)^{\beta}, \tag{1}$$

where Y can denote a material resources or measure of activity, Y_0 is a normalization constant, β is the scaling exponent (conceptually equivalent to an elasticity parameter), and most fundamentally, the factor A_i is city-specific but independent of time. The exponent β reflects general dynamical rules at play across the urban system. A common feature of scaling is scale invariance, which corresponds to the relationship formalised in equation (1).

In the general case, we assume a very simple functional relation between metropolitan population $N_{i,t}$ and food consumption $P_{i,t}$

$$P_{i,t} = A_i P_0 N_{i,t}^{\beta}, \tag{2}$$

where A_i is, again, city-specific but independent of time, P_0 is a normalisation constant independent of $P_{i,t}$ or $N_{i,t}$, and *i* indexes the metropolitan area at time *t* (in years). The exponent β determines the (power-law) scaling relationship between food or fibre consumption and population. Taking the natural logarithm of equation (2) and assuming the presence of i.i.d. Gaussian noise, we derive the basic equation[1]

$$\ln(P_{i,t}) = \ln(A_i) + \ln(P_0) + \beta \ln(N_{i,t}) + \varepsilon_{i,t}. \tag{3}$$

A similar formulation was derived using raw forms of resources and energy in a general sense for other scalable features. We estimate β using food data consumption differentiated by urban and rural location over the period 1978-2022 and an Ordinary Least Squares (OLS) estimation procedure with a correction for heteroscedasticity.

The main consideration from the formulation in Equation (3) is whether the transversal (spatial) scaling relationship for a city is also reflected in its longitudinal (temporal) scaling. That is, can changes to the population size of a city as related to urban metrics like economic output and infrastructure be related to the evolution of individual cities through time? Ribeiro et al., (2020) found that longitudinal scaling exponents are city-specific and distributed around an average value that approaches the transversal scaling exponent for cities with a sufficiently high growth rate.

To reconcile the spatial and temporal scaling aspects of the above formulation, some simplifying assumptions are required, outlined by Bettencourt et al., (2020). First, scaling residuals must be time-independent or vanishingly small. That is, time dependence of the cross-sectional scaling exponent β should not impact on the population scale dependence A. Second, the cross-sectional exponent β must be time independent. That is, $\beta(t) = \beta$ for $\forall\ t \in \{1, \ldots, T\}$. Third, the growth rates for the scaling factor A_i and city population $N_{i,t}$ are time independent. Fourth, the growth rate of the factor A_i (intensive growth) is zero, while population growth $N_{i,t}$ remains non-vanishing. Bettencourt et al., (2020) shows that the cross-sectional and temporal exponents coincide when the second, third, and fourth conditions above are met. That is, there is no intensive growth of the quantity of interest, the scaling exponent is independent of time, and the scaling residuals are either vanishingly small or independent of time. Our model accounts for these assumptions and assesses the output sensitivity to each.

[1] Transforming food and fibre consumption data by using the natural logarithmic function has the effect of changing the distribution into a normal distribution. This is verified both visually (inspecting the histograms) and by performing the Wilks-Shapiro test (for individual periods and across all periods for all areas).

4 Data

We obtained annual food consumption data from China's State Statistical Bureau (SSB) based on household surveys of mainland China's consumption trends in urban and rural areas. The accuracy and consistency of both urban and rural food consumption survey data is remarkable. An urban area is classified as an urban administrative unit (UAU) in China while a rural area is any place that is not urban. Food consumption is available in terms of quantity only as purchased by consumers for consumption at home. Rural food consumption data also includes food produced and consumed by the household in farm areas.

Food consumption data does not include away-from-home consumption. The data may therefore underestimate consumption patterns of certain foods, such as the increase in consumption of western-style fast foods. Comparative data was also obtained from the United States Department of Agriculture (USDA), the Food and Agricultural Policy Research Institute (FAPRI), the Food and Agriculture Organization (FAO) of the United Nations, and the Organisation for Economic Co-operation and Development (OECD).

Figure 3 illustrates the growth and decline of urban and rural populations respectively. While the rate of growth of China’s urban population is slowing, it is still positive relative to the negative rate of growth in the rural population.

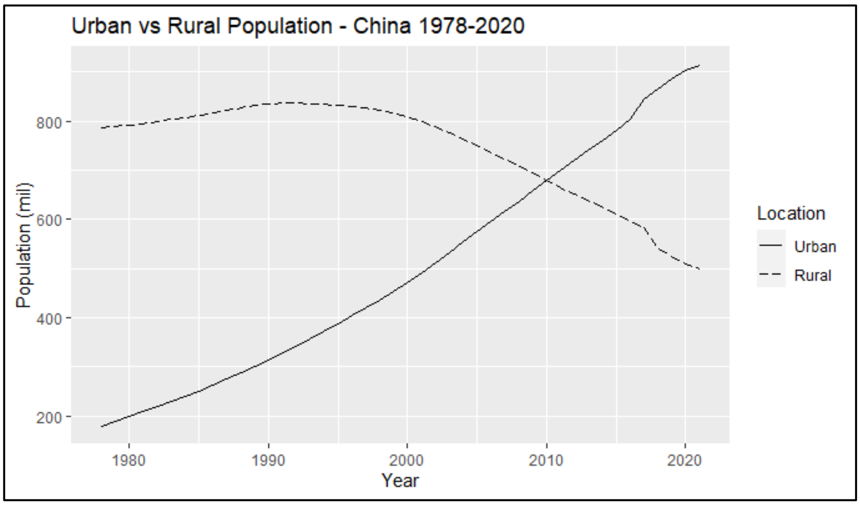

Figure 3. Urban vs. rural population estimates, China 1978-2020. *Source:* FAO (2021).

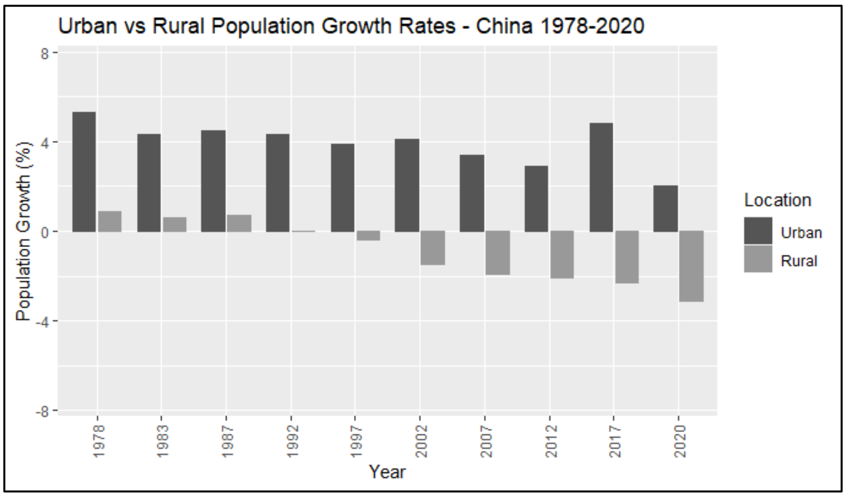

Figure 4. Urban vs. rural year-on-year population growth rate, China 1978-2020. *Source:* FAO (2021).

Data obtained from the FAO on the mean intakes of energy and nutrients found only slight differences between China’s urban and rural consumers. The mean daily energy intake ranged from 2400 to 2890 kcal (10-12.3 MJ) which decreases in older age groups. For both urban and rural consumers, protein intake ranged from 60-83 g/day and comprised roughly 10.0–11.5 percent of daily energy intake. Fat intake was low in both groups and ranged from 10.9–15.2 percent. Carbohydrate intake was high (74–79 percent) in both groups.

Overall, carbohydrates comprised 75 percent of energy intake, proteins comprised 10.5 percent and fat intake 12.5 percent (FAO, 2021). As highlighted in Figure 2 the main difference between urban and rural populations relate to the *types* of food consumed rather than major differences in calorific intake overall.

In contrast, for industrialized countries, carbohydrate intake seldom exceeds 55 percent (Lytle et al.,, 1993, Howat et al.,, 1994, Hujbregts et al.,, 1995), and values exceeding 60 percent are regarded as outliers. The extremely low-fat intake also differs markedly from the fat intake in industrialized countries, where the mean intake value can commonly exceed 35 percent.

While there are some differences in underlying food consumption between China, as a Transition country, and Industrialised countries, it is important to note that the staple food consumption patterns of Chinese urban and rural inhabitants do not appear to be limited by differences in per capita wealth.

5 Results

5.1 Model outputs

A summary of the OLS regression results modelled using Equation (3) is provided at Table 1. The presence of heteroscedasticity in the results does not induce bias in the coefficient estimates but it can make them less precise. The use of the log transformation in Equation (3) was sufficient to account for heteroscedasticity in the raw values.

There is strong statistical evidence for power law scaling on population growth explaining the relative consumption of grain, vegetables, beef/mutton, egg, fish, and oil for both urban and rural areas. The small sample size in fibres (wool and cotton) however offers limited evidence for power law scaling in population growth as a reliable factor. There is also a strong possibility of poor data quality in the food consumption statistics that were collected in rural areas during the early years of the data collection activity which may be affecting the reliability of some of the results for rural areas.

Table 1.
Urban versus rural scaling exponents for food and fibre categories, China 1978-2014.

Y	β	SE	95% CI	Adj-R^2	Observations
Grain					
Urban	0.439*	0.073	[0.274, 0.604]	0.802	33
Rural	2.912*	0.096	[2.700, 3.123]	0.987	35
Vegetables					
Urban	0.816*	0.051	[0.701, 0.931]	0.966	33
Rural	2.215*	0.365	[1.412, 3.018]	0.770	35
Beef & mutton					
Urban	1.474*	0.058	[1.341, 1.606]	0.986	32
Rural	1.262	0.803	[0.506, 3.031]	0.183	35
Eggs					
Urban	1.327*	0.092	[1.118, 1.535]	0.958	33
Rural	1.716*	0.533	[0.487, 2.944]	0.565	35
Wool & cotton					
Urban	0.562	0.288	[-0.681, 1.804]	0.654	18
Rural	28.920	4.979	[16.737, 41.103]	0.849	18
Fish					
Urban	1.808*	0.046	[1.703, 1.913]	0.994	33
Rural	2.091*	0.586	[0.741, 3.442]	0.615	35
Oil					
Urban	1.443*	0.0386	[1.356, 1.530]	0.994	33
Rural	0.049	0.285	[-0.705, 0.607]	0.004	35

* indicates statistical significance at the 5 percent level.

The results show that overall, the direct consumption of grains and vegetables is declining while the consumption of animal products is increasing in both rural and urban areas. But the key difference lies in how the consumption levels of each are manifest. Clearly, higher-quality and nutrient-dense food categories are scaling super-linearly (i.e., $\beta > 1$) in urban areas while grains, vegetables, and fibre are scaling sub-linearly (i.e., $\beta < 1$). The link between the super-linear scaling strength and shifts in dietary preference is directly related to urban expansion.

A visual representation of the relevant statistics reveals the strength of this approach. When plotted on a logarithmic chart the power law scaling is represented by the exponent β for each food category. Predictions of further growth in consumption can then be simply obtained for urban population growth estimates.

Foods exhibiting clear super-linear behaviours are the high-protein and nutrition-dense categories including beef and mutton, eggs, fish, and oil (Figures 7a, 8a, 9a, and 10a). The empirical estimates of consumption growth in 'higher-quality' foods reflect shifts in urban agglomeration, increasing by city size where productivity and wealth are higher. These exponents cluster in a similar way to other phenomena like innovation (through patents and R&D spending), economic opportunities, and pace of life found in Bettencourt et al., (2007), Bettencourt, Lobo and Strumsky, (2007) and Bettencourt et al., (2010). This finding is quantitatively consistent with the much studied "Zipf's law" (Gabaix, 1999) for the rank-size distribution of urban populations.

First, consider the differences in non-animal food consumption between rural and urban areas. Grain consumption in urban areas is increasing sub-linearly. The slope $\beta = 0.439$ [95% CI 0.274, 0.604] indicates that for every unit increase in the metropolitan population, grain consumption increases by roughly 0.44 units. Grain consumption remains high among rural inhabitants. But as rural populations decline the corresponding decline in grain consumption is substantial (Figure 5b).

The consumption of vegetables in rural areas follows a similar pattern to grains (Figure 6b). As rural incomes further improve, although not at the same super-linear rate as urban incomes, the trend is for further reductions in grain and vegetable consumption substituted by an increase in the consumption of animal products. Urban consumption of vegetables scales sub-linearly at $\beta = 0.816$ [95% CI 0.701, 0.931].

The annual consumption of meat in rural areas (20kg per capita) is markedly lower than urban areas (33kg per capita) but is increasing (Figure 7b). However, the rate of growth in meat consumption in rural areas will not match the expected super-linear growth rate in the consumption of animal products in urban areas $\beta = 1.474$ [95% CI 1.341, 1.606] (Figure 7a).

There are only minor differences in average calorific value consumption between rural (lower income) and urban (higher income) consumers. However, in terms of consumption behaviours, higher income households consume more nutrient-dense food, particularly animal products, and oil. As the super-linear growth of individual wealth, GDP, and food choices in urban areas continues, the pattern of consumption of animal products also occurs at a super-linear rate. The consumption of animal-derived foods in urban areas increases at a rate greater than the rate of growth in urban agglomeration, while the consumption of grains, vegetables, and natural fibres declines.

Beef consumption by high income households is roughly 50 percent higher than lower income households. Beef consumption rates are higher for individuals earning high incomes. High income individuals in both urban and rural areas consume similar volumes of beef. But for the population at large, as the urban population increases at a super-linear rate (and with it, growth in wealth, etc.), beef consumption follows a similar trajectory. The urban consumption trajectories for eggs, fish and oil follow a similar pattern.

When confining our analysis of rural food consumption, the empirical data offers a somewhat confusing picture. As rural populations decline, the consumption of high-quality foods continues to grow, but not at the same super-linear rate observed in urban areas. The data shows that the rural consumption of beef and mutton, fish, eggs, and oil will increase at a linear rate as the rural population declines. Although rural incomes are increasing, they are not increasing at the same rate as urban incomes so the growth in high-quality food has remained modest.

The relatively low explanatory power in rural food consumption is due to several factors, including lower incomes, more limited availability of certain foods (e.g., beef), and cultural preferences. The proximity of the population to the source of each food category is a key aspect not explicitly accounted for in the data. For instance, the major wheat-consuming provinces located in China's north counter those in China's south where rice is predominantly grown. Differences in meat consumption are also expected with the consumption of beef and mutton in the north, pork in the south and poultry meats and eggs in central and eastern China being predominant, as well as seafood consumption being more concentrated in coastal areas. Dairy products are confined to rural areas with ethnic minorities who count dairy produce as a major component of their diet, or to high-income households elsewhere in rural areas.

While there is evidence of convergence in food tastes across China's rural provinces over the period of analysis, the rate of convergence has been slow. This is likely to increase with improved transport networks across the country and refrigerated transportation becomes more widely available. Food preferences will also change with increased incomes and availability, generated through continued urban agglomeration.

It is well-known that food consumption varies with income. An early study by Fan et al., (1994) estimated price elasticities for the major food categories, which have remained largely steady over the study period (Zhou, Tian, and Malcolm, 2008). The price elasticity of grains ranged between -0.455 (wheat) and -0.547 (rice), meat (-0.604) and vegetables (-0.472). Consumption of meat is thus roughly 30 percent more sensitive to changes in price relative to wheat and vegetables. Importantly, they also found the expenditure elasticity for grain is relatively inelastic, indicating that grains remain necessary foods while some expenditure elasticity was observed in meat and vegetables, indicating that they are 'luxury' goods. Cross-price elasticities having positive signs, which indicates most food categories are substitutes for each other. These elasticities reinforce the findings of sublinear and super-linear rates of growth for rural and urban food consumption respectively in that preferences are motivated by availability due to scale efficiencies in addition to increased wealth. More recent analyses of urban and rural consumption patterns also support these findings (Gil, 2022a; Gil, 2022b; Miller et al., 2022).

Our analysis does not implicitly suggest there is a causal relation between urban scaling and urban consumption. Rather, the scaling identity reveals a systematic relationship between urban population size and food consumption patterns. Causality stems from the ways in which consumption patterns across larger agglomerations affects how individual consumption habits interact with each other.

To ensure the model does not violate the assumptions used to reconcile spatial with temporal scaling, we assess the results subject to the following criteria. First, we find there is no intensive growth among the food consumption rates in the above analysis. The results demonstrate that the coefficients for each scaling factor β are not excessive and do not stray dramatically from scaling factors measured for other urban variables. Second, the scaling exponent is shown to be time independent, with each scaling factor for the food categories measured being linear with most observations falling within the 95% confidence interval for each category. Finally, the scaling residuals are both small and time independent, as demonstrated in the regression results presented in Table 1 and Figures 5a to 10b.

5.2 Growth predictions

A major question from this relates to how each of these dynamics may impact the consumption of food with further urban growth. Food consumption growth responses will need to be increasingly efficient to ensure that super-linear growth dynamics reflect income growth. Under this circumstance, cities must become increasingly efficient in the production and distribution of foods that exhibit super-linear demand, otherwise they will be substituted by sublinear food products in line with expenditure elasticities of individuals.

Figure 11a. China's largest 22 cities, 2022.

Figure 11b. China's largest 22 cities, 2050.

While China remains less urbanised than other developed nations (58 percent), the trend towards urbanisation is relentless. Forecast population growth will slow dramatically, annual urban population growth will continue at around 1.8 percent (United Nations, 2017). At this pace, the major urban areas in China will double in population in the next 24 years. To extrapolate, the expectations using Zipf's law for China's largest cities will amount to several cities of a colossal size, with food consumption rates per capita over 30 percent larger than those same cities today. Figure 11a depicts China's largest 22 cities, with the size of each marker indicating relative population size. In 2022, each of these cities has more than 5 million inhabitants. Figure 11b depicts the expected size of the 22 largest cities by 2050 assuming a slowing growth rate (United Nations, 2017).

Figure 12 supported by Table 2 provides a summary of the expected growth in aggregate consumption of food categories in urban and rural areas, modelled using the projected population growth rates. Negative growth in rural food consumption will be more than offset by positive urban consumption growth in all categories apart from grain, which is expected to continue to decline in aggregate. For instance, urban consumption of meat, fish, and oil is predicted to more than double by 2050, which equates to an additional 130 million, 75 million, and 32 million tonnes respectively.

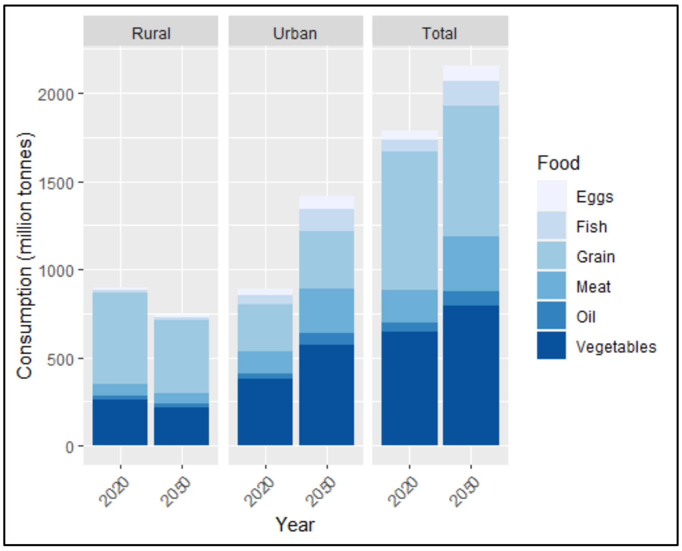

Figure 12. Predicted differences in food consumption by category between urban and rural locations using scaling methodology, China 2020 to 2050.

Urban population growth is predicted to amplify food consumption effects, especially where availability of food categories is unconstrained. The transformational change in China's urban systems may also severely exacerbate rural inequalities by further amplifying the impacts of consumption patterns. The dynamics of urban expansion will require ever more efficient means of food distribution through urban areas, which may be limited unless substantial adaptations occur in line with the assumptions of the dynamics defined by super-linear growth in Equation (9).

Table 2.
Projected growth in urban and rural food consumption categories using scaling exponents to 2050, China.

	Urban			Rural			Total	
	Growth	**2020**	**2050**	**Growth**	**2020**	**2050**	**2020**	**2050**
Grain	24%	265.50	329.22	-20%	515.75	412.60	781.25	741.82
Vegetables	50%	381.64	572.46	-16%	260.19	218.56	641.83	791.02
Meat	108%	121.56	252.84	-4%	64.75	62.16	186.31	315.00
Eggs	94%	37.14	72.05	-4%	16.75	16.08	53.89	88.13
Fish	146%	50.79	124.94	-14%	15.29	13.15	66.07	138.08
Oil	105%	30.36	62.24	-20%	25.15	20.12	55.51	82.36

While this study represents general insights into the effect of scaling through urban agglomeration, more research is needed to track empirical observations of food consumption, especially where availability constraints relate to substitution. More precise quantification of the urban scaling of food consumption will permit a better understanding of the effects on the demand for resources, food distribution network efficiencies, and environmental impacts.

6 Conclusion

Power law scaling has been used to project the growth of socio-economic factors in cities as a function of population. Food consumption in urban systems obey a measurable degree of scaling related to population size. This is due to the competing characteristics governing the rates of innovation, wealth, patterns of consumption and human behaviour, as well as economic efficiency properties governing urban infrastructure. This occurs despite the complexity and diversity of human behaviour in urban areas relative to rural areas. Our observations of the temporal consumption processes associated with the social dimension of urban behaviour indicate a degree of universality of consumption patterns across urban areas, with a large divergence in the consumption of higher-quality foods relative to rural areas. In urban areas, we find that meat consumption increases by 70-80 percent while grain and vegetable consumption declines by 16 percent with each doubling of the population. There is no implicit suggestion of a causal relation between urban scaling and urban consumption; rather, the scaling approach reveals a systematic relationship between urban population size and food consumption patterns. The scaling of wealth creation may dictate affordability and desirability, but without the efficiencies achieved through scale, urban food consumption would remain constrained.

The size of China's population along with the divergence in food consumption between urban and rural areas provides challenges ahead for China's food markets. Super-linear growth in urban income along with network scale efficiencies is predicted to generate super-linear growth in the consumption of animal products at the expense of grains and vegetables. The declining rural population and subsequently linear income dynamics is predicted to result in a similarly linear decline in the consumption of animal products, although super-linear declines in grains and vegetables are also expected. Similar dynamics could be assumed for large countries undergoing similar urban growth transition patterns including India, Brazil, Nigeria, and Indonesia.

References

Angel, S., Sheppard, C. S., Civco, D. L., Buckley, P., Chabaeva, A., Gitlin, L. Kraley, A., Parent, J., Perlin, M. (2005). *The Dynamics of Global Urban Expansion*. The World Bank, Washington D.C. http://www.citiesalliance.org/publications/homepagefeatures/feb-06/urban-expansion.html.

Axtell, R.L. (2001). Zipf Distribution of U.S. firm sizes. *Science* 293 5536, pp. 1818-1820. DOI: 10.1126/science.1062081.

Bettencourt, L.M.A., Lobo, J., Helbing D., Kühnert, C., West, G. (2007). Growth, innovation, scaling and the pace of life in cities. *Proceedings of the National Academy of Sciences of the United States of America* 10417: 7301-7306. https://doi.org/10.1073/pnas.0610172104 .

Bettencourt L.M.A., Lobo J., Strumsky, D. (2007). Invention in the city: increasing returns to patenting as a scaling function of metropolitan size. *Resources Policy,* **36**: 107-120. https://doi.org/10.1016/j.respol.2006.09.026.

Bettencourt, L.M.A., Lobo, J., Strumsky D., West G.B. (2010). Urban scaling and its deviations: revealing the structure of wealth, innovation and crime across cities. *PLoS ONE,* **511**: e13541. doi:10.1371/journal.pone.0013541.

Bettencourt L.M.A., Yang, V., Chuqiao Lobo, J., Kempes, C.P., Rybski, D., Hamilton, M.J. (2020). The interpretation of urban scaling analysis in time. *Journal of the Royal Society Interface,* **17**: 1720190846-20190846. https://doi.org/10.1098/rsif.2019.0846.

Bloem, S., de Pee, S. (2017). Developing approaches to achieve adequate nutrition among urban populations requires an understanding of urban development. *Global Food Security,* **12**: 80-88. https://doi.org/10.1016/j.gfs.2016.09.001 .

Bruinsma, J. (2003). *World agriculture: towards 2015/2030. An FAO perspective*. Rome, Food and Agriculture Organization of the United Nations/London, Earthscan.

Crane, P., Kinzig, A. (2005). Nature in the metropolis. *Science* 3085726, pp. 1225. DOI: 10.1126/science.1114165.

Cui, Z., Dibley, M.J. (2012). Trends in dietary energy, fat, carbohydrate and protein intake in Chinese children and adolescents from 1991 to 2009. *The British Journal of Nutrition,* **1087**: 1292-1299. doi: 10.1017/S0007114511006891.

Deaton, A., Muellbauer, J. (1980). An almost ideal demand system. *American Economic Review,* **70**: 312-336. https://www.jstor.org/stable/1805222 .

Deaton, A., Paxson, C. (1998). Economies of scale, household size, and the demand for food. *Journal of Political Economy,* **1065**, pp. 897-930. https://doi.org/10.1086/250035 .

Fan, S., Cramer, G., Wailes, E. (1994). Food demand in rural China: evidence from rural household survey. *Agricultural Economics,* **11**: 61-69. https://doi.org/10.1016/0169-5150(94)90017-5 .

FAO (2021). FAOSTAT. Food and Agriculture Organization of the United Nations, Rome, Italy. <Available at https://www.fao.org/faostat/en/#data>.

Gabaix, X. (1999). Zipf's law for cities: an explanation. *The Quarterly Journal of Economics,* **1143**: 739-767. https://doi.org/10.1162/003355399556133 .

Gil, J. (2022a). Agriculture expenditure and food security in West Africa. *Nature Food,* **31**: 811. https://doi.org/10.1038/s43016-022-00625-5 .

Gil, J. (2022b). Food consumption by the African poor. *Nature Food,* **39**: 676. https://doi.org/10.1038/s43016-022-00607-7 .

Halbrendt, C., Gempesaw, C., Dolk-Etz, D., Tuan, F. (1994). Rural Chinese food consumption: the case of Guangdong. *American Journal of Agricultural Economics,* **764**: 794-799. https://doi.org/10.2307/1243740.

Howat, P.M, Mohan, R., Champaigne, C., Monlezun, C., Wozniak, P., Bray, G.A. (1994). Validity and reliability of reported dietary data. *Journal of the American Dietary Association,* **2**: 169-173. DOI: 10.1016/0002-8223(94)90242-9.

Hujbregts, P.P.C.W, Feskene, E.J.M., Kromhout, D. (1995). Dietary patterns and cardiovascular risk factors in elderly men. The Zutphen elderly study. *International Journal of Epidemiology,* **24**: 313-320. DOI: 10.1093/ije/24.2.313.

Jiang B., Davis, J. (2007). Household food demand in rural China. *Applied Economics,* **393**: 373-380. DOI: 10.1080/00036840500428013.

Lytle, L.A, Nichaman, M.Z., Orbazanek, E., Glovsky, E., Montgomery, D., Nicklas, T., Zive, M. Feldman, H. (1993). Validation of 24-hour recalls assisted by food records in third grade children. *Journal of the American Dietary Association,* **93**: 1431-1436. https://doi.org/10.1016/0002-8223(93)92247-U .

Miller, V., Webb, P., Cudhea, F. et al., (2022). Global dietary quality in 185 countries from 1990 to 2018 show wide differences by nation, age, education, and urbanicity. *Nature Food,* **3**: 694-702. https://doi.org/10.1038/s43016-022-00594-9 .

Mottaleb, K.A., Rahut, D.B., Kruseman, G., Erenstein, O. (2018). Evolving food consumption patterns of rural and urban households in developing countries: A Bangladesh case. *British Food Journal,* **1202**: 392-408. https://doi.org/10.1108/BFJ-12-2016-0620.

OECD (2019). *Meat consumption indicator*. doi: 10.1787/fa290fd0-en Accessed on 14 June 2019.

Openshaw, S., Veneris Y. (2003). Numerical experiments with central place theory and spatial interaction modelling. *Environ Plan A,* **358**: 1389-1403. https://doi.org/10.1068/a35295b .

Remans, R. (2020). The changing nature of our food systems. *Nature Food,* **1**: 21. https://doi.org/10.1038/s43016-019-0015-z .

Ribeiro, F.L., Meirelles, J., Netto, V.M., Neto, C.R., Baronchelli, A. (2020) Correction: On the relation between transversal and longitudinal scaling in cities. *PLoS ONE,* **1510**: e0240758. https://doi.org/10.1371/journal.pone.0240758 .

SSBa State Statistical Bureau, China Statistical Yearbook various issues China Statistical Press, Beijing. Accessed 12/06/2018 <http://www.stats.gov.cn/english/Statisticaldata/AnnualData/>.

SSBb, Yearbook of Rural Household Surveys in China various issues State Statistical Bureau of China, Beijing. Accessed 12/06/2018 <http://www.stats.gov.cn/english/Statisticaldata/AnnualData/>.

SSBc, Statistical Yearbook of Price and Urban Income and Expenditure in China various issues State Statistical Bureau of China, Beijing. Accessed 12/06/2018 <http://www.stats.gov.cn/english/Statisticaldata/AnnualData/>.

United Nations, Department of Economic and Social Affairs, Population Division (2017). *World Population Prospects: The 2017 Revision*. DVD Edition.

USDA-ERS International Agricultural Projections Data, Economic Research Service, United States Department of Agriculture, viewed 18 September, (2011), http://www.ers.usda.gov/data/internationalbaseline/sutabs11.htm.

Wensing, J., Cremades, R., van Leeuwen, E. (2023). Cities can steer circular food systems at scale. *Nature Food,* **41**: 4-4. https://doi.org/10.1038/s43016-022-00682-w.

Zeng, Q., He, Z., Wang, Y. (2022). The Direct and Structure Effect of Income on Nutrition Demand of Chinese Rural Residents. *International Journal of Environmental Research and Public Health,* **19**: 13388. https://doi.org/10.3390/ijerph192013388 .

Zhou, Z., Tian, W., Malcolm, B. (2008). Supply and demand estimates for feed grains in China. *Agricultural Economics,* **39**: 111-122. https://doi.org/10.1111/j.1574-0862.2008.00319.x .

Zipf G.K. (1949). *Human Behavior and the Principle of Least Effort*. Cambridge, Massachusetts: Addison-Wesley.

Appendix

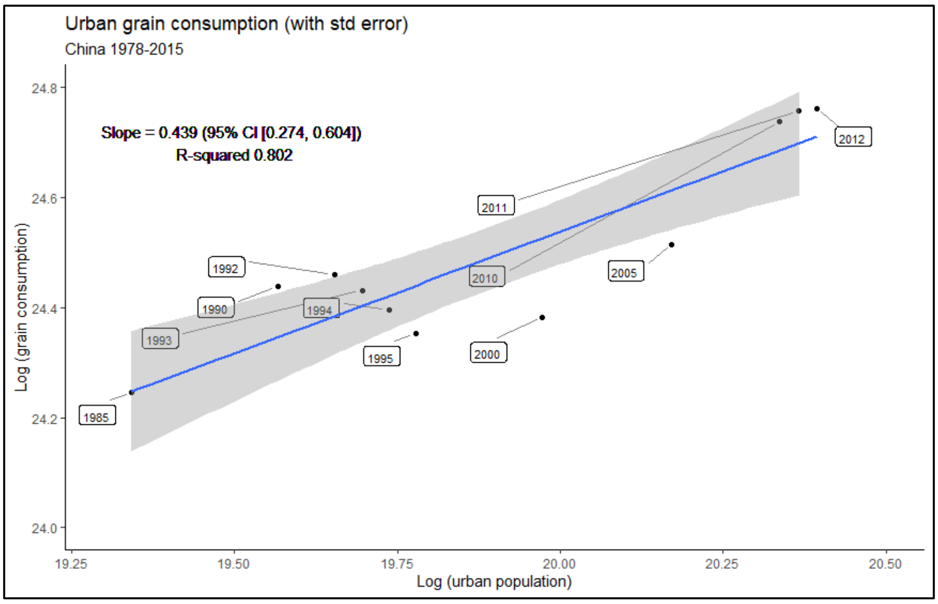

Figure 5a. Urban grain consumption relative to population, China 1978-2015.

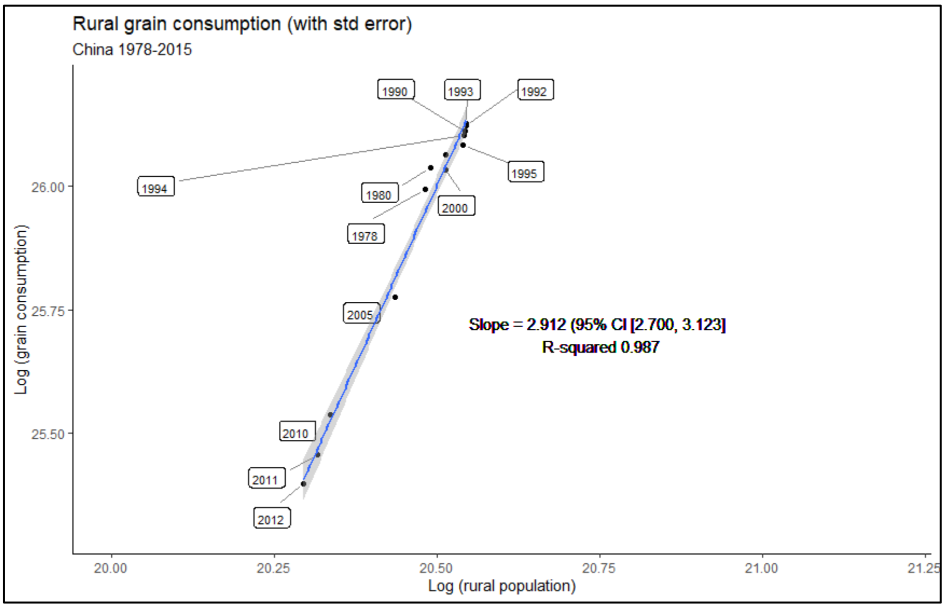

Figure 5b. Rural grain consumption relative to population, China 1978-2015.

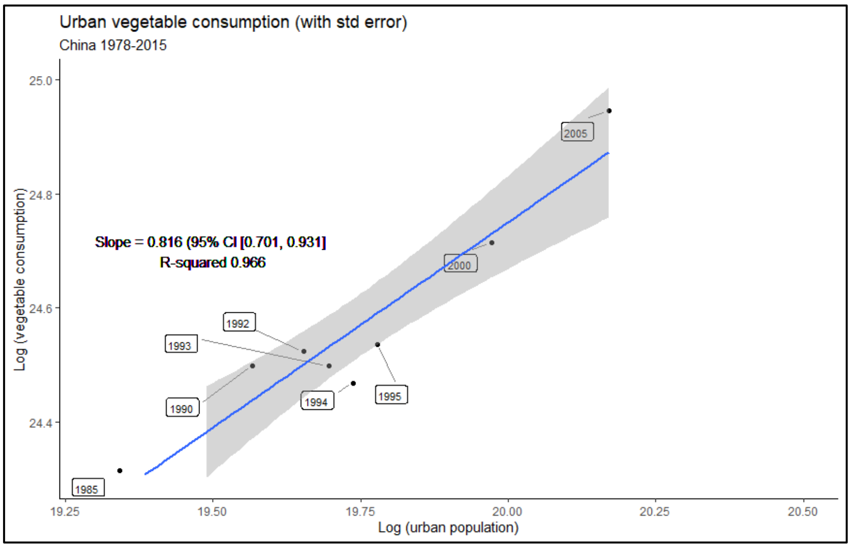

Figure 6a. Urban vegetable consumption relative to population, China 1978-2015.

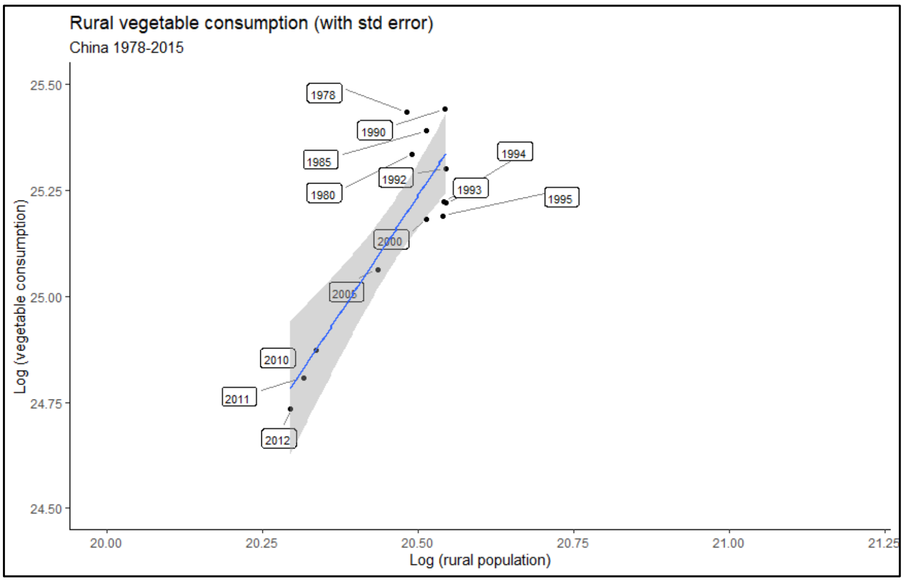

Figure 6b. Rural vegetable consumption relative to population, China 1978-2015.

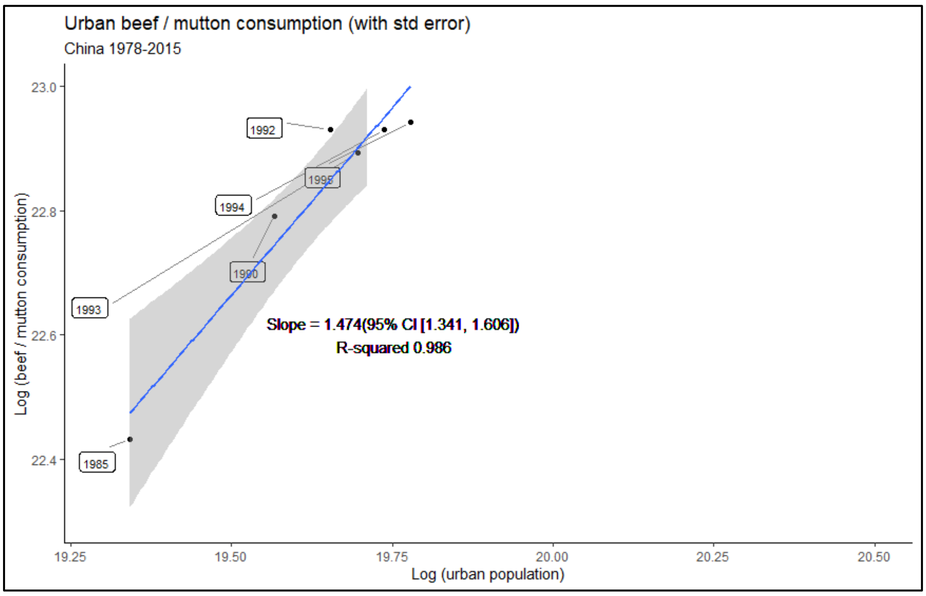

Figure 7a. Urban beef and mutton consumption relative to population, China 1978-2015.

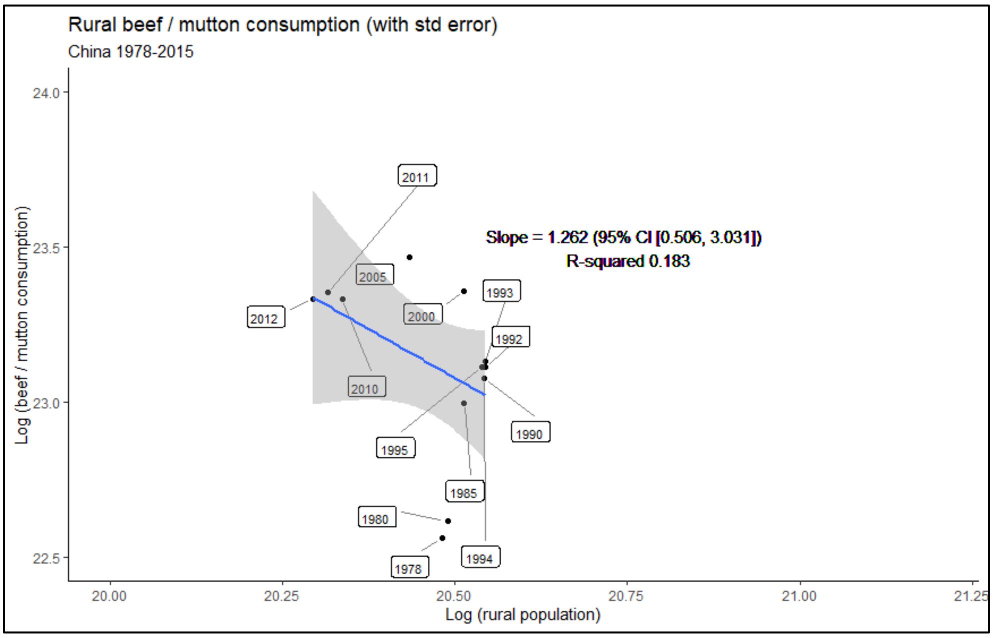

Figure 7b. Rural beef and mutton consumption relative to population, China 1978-2015.

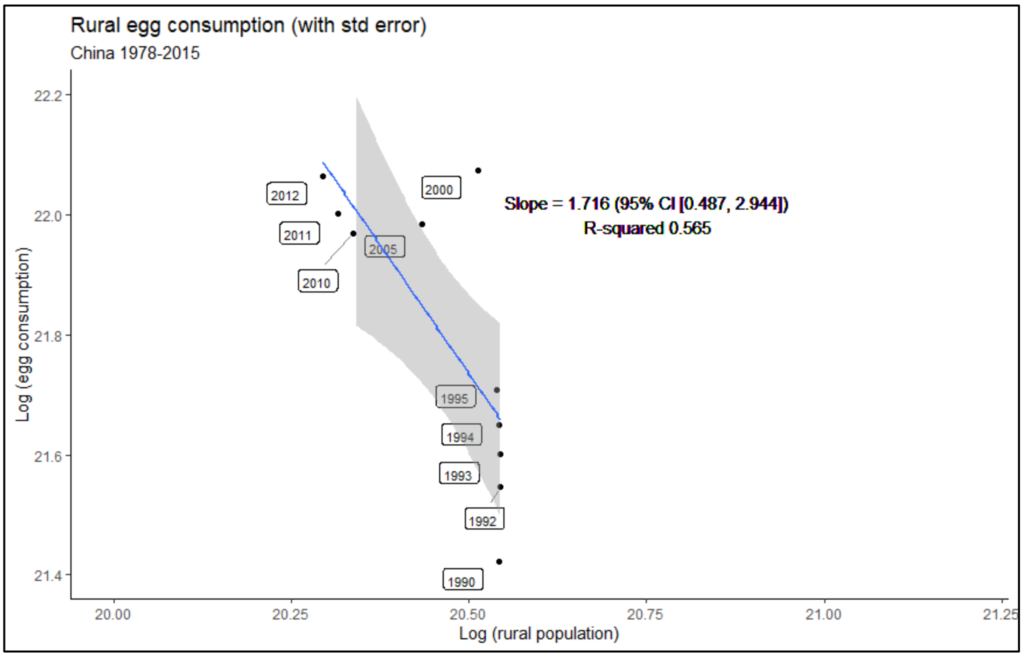

Figure 8a. Urban egg consumption relative to population, China 1978-2015.

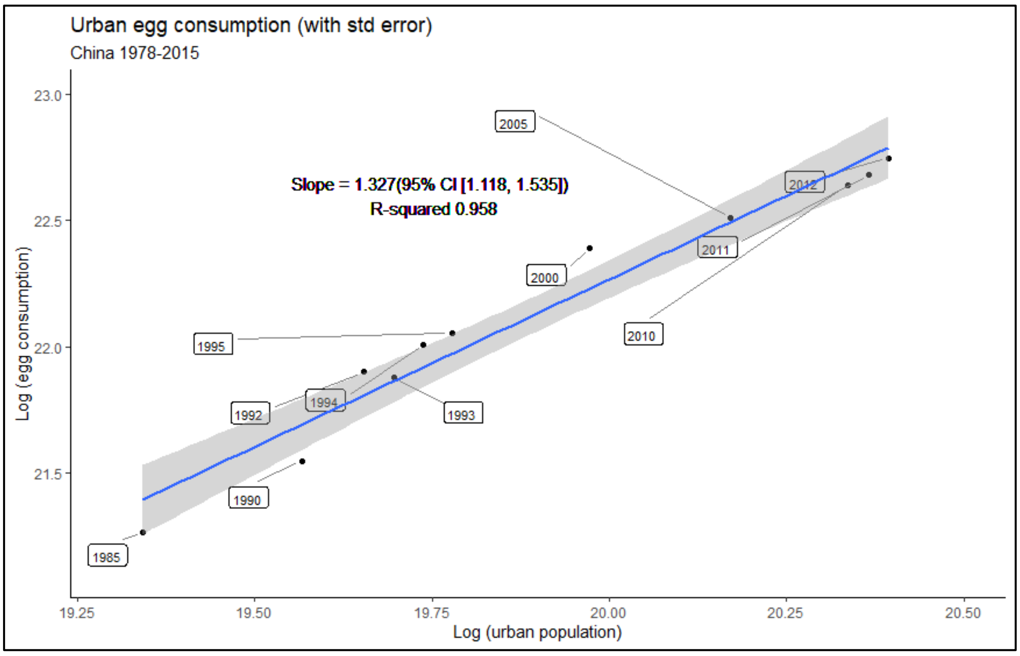

Figure 8b. Rural egg consumption relative to population, China 1978-2015.

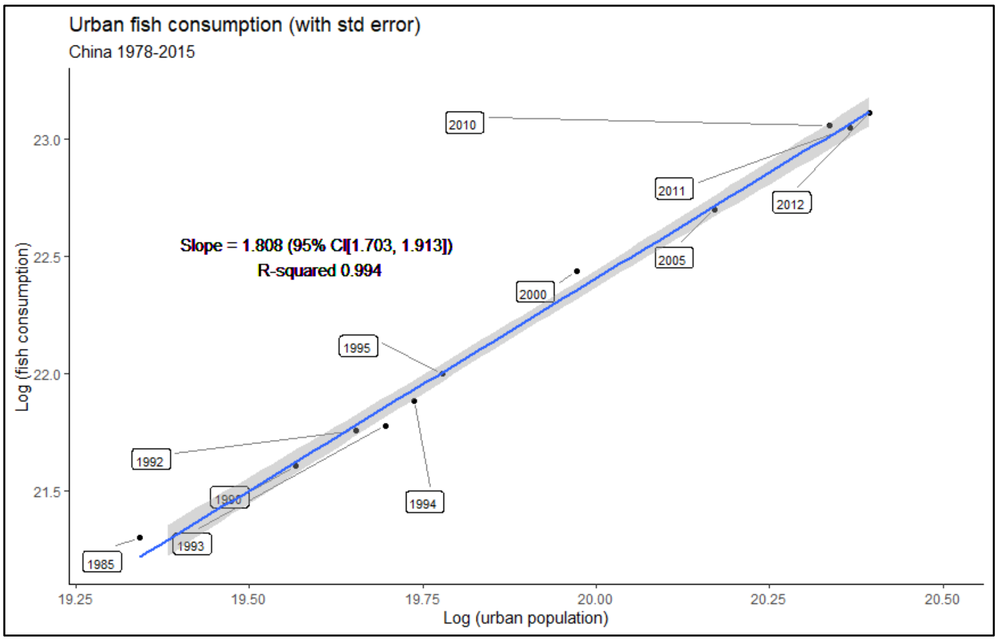

Figure 9a. Urban fish consumption relative to population, China 1978-2015.

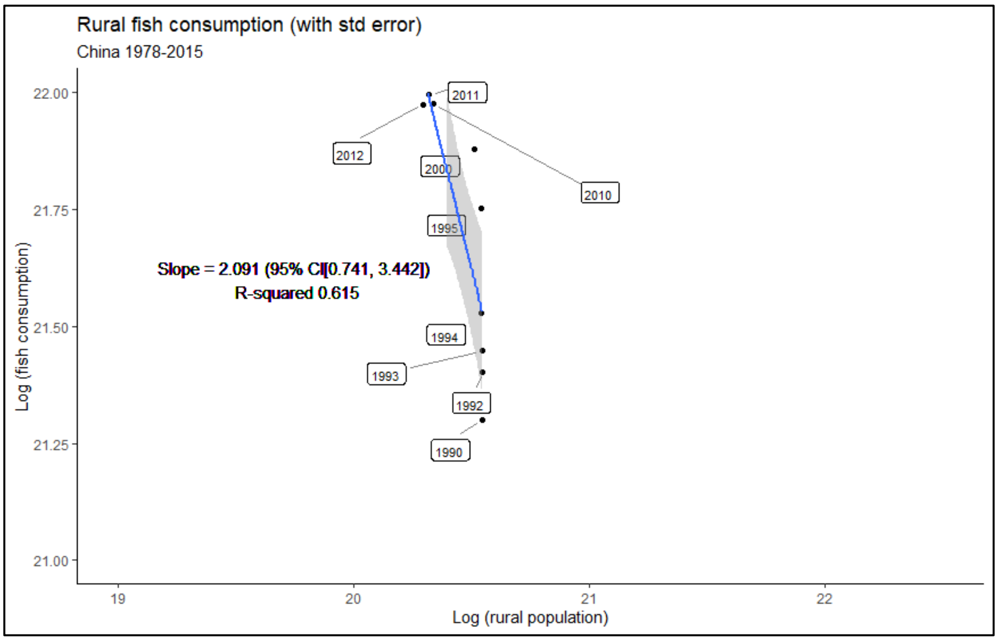

Figure 9b. Rural fish consumption relative to population, China 1978-2015.

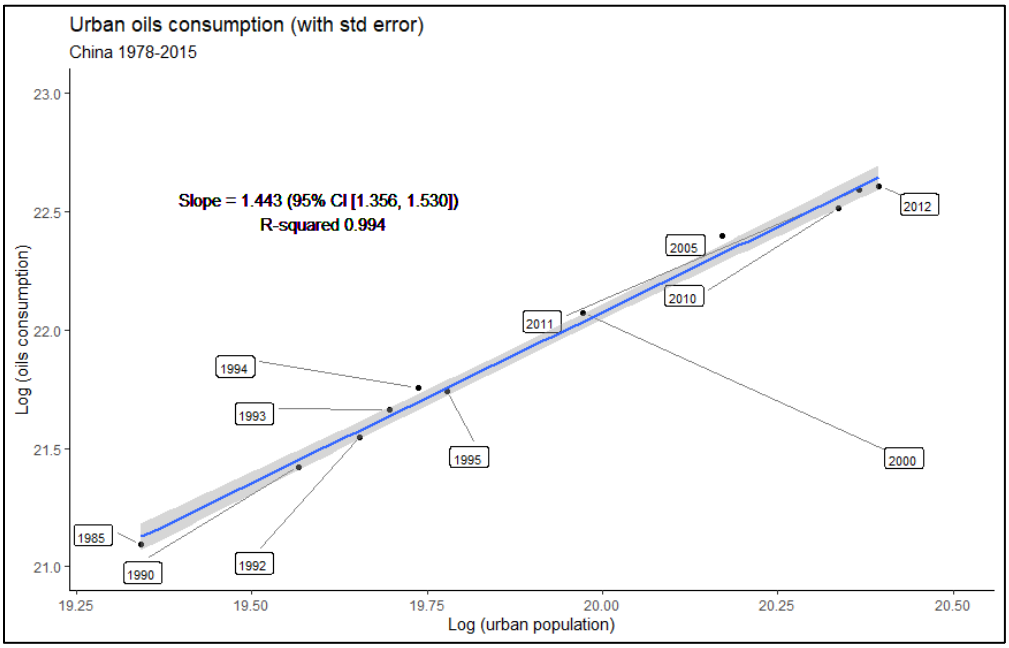

Figure 10a. Urban oils consumption relative to population, China 1978-2015.

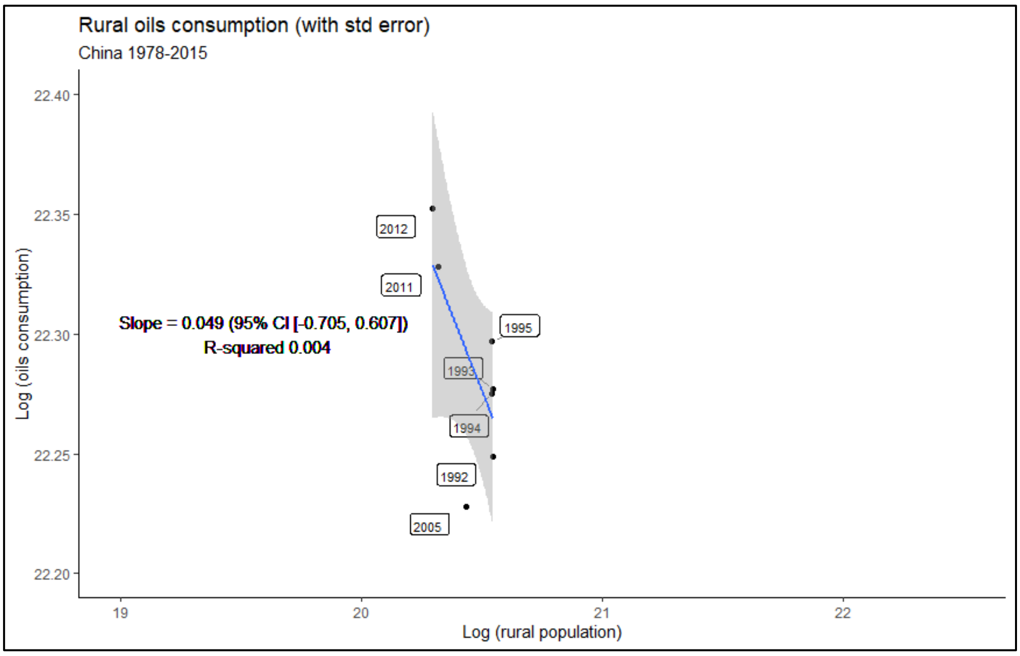

Figure 10b. Rural oils consumption relative to population, China 1978-2015.