THE CONSEQUENCES OF AN INDUSTRIAL FOOD SYSTEM: A CROSS-NATIONAL EXAMINATION OF THE ROLE OF MECHANIZATION IN THE RISING OBESITY EPIDEMIC

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Abstract: Research suggests that physical inactivity, trends toward increasing urbanization, and changes in the agriculture employment sector, can strongly inform us about the causes of obesity in modern society. However, they fail to link the rise of obesity in today's society to changes in the modern processes of food production, and particularly, to the broader trend toward mechanized agriculture that characterizes the current food production system, across both poorer and affluent nations. This paper employs structural equation modeling to test both the direct and indirect effects of causal factors to the increasing prevalence of obesity across nations. Findings indicate that the mechanization of agriculture is an important underlying factor in explaining cross-national trends in overweight males and females. It directly contributes to declines in employment in the agriculture sector, which leads to increased urbanization and physical inactivity, which are interrelated and acting as driving forces in the growing obesity epidemic. Integrative models provide a holistic view of the world's food system and the potential implications for how factors of globalization spur obesity in populations worldwide.

Introduction

The prevalence of obesity and overweight in humans is a problem that spans across the entire globe. The extent of this problem has reached such high percentages that it is considered by many to be an epidemic (Popkin & Doak 1998; Loureiro & Nayga 2005; WHO 2014). In 2008, over 1.8 billion adults over the age of 20 were overweight. Of these, over 200 million men and almost 300 million women were obese (WHO 2014). The common health consequences of overweight and obesity include cardiovascular diseases such as heart disease and stroke, which were the leading cause of death in 2008, and diabetes (WHO 2014).

The World Health Organization defines overweight and obesity as abnormal or excessive fat accumulation that may impair health (WHO 2014). A person who has a body mass index (BMI) of 25 or higher is considered overweight, while a person with a BMI of 30 or higher is considered obese (WHO 2014). Being obese is closely related to being overweight; for the purpose of this paper I will use the single term of obesity when discussing the causes of the obesity epidemic, unless I am referring to data or research where the difference between obesity and being overweight is relevant.

Obesity is caused by energy imbalances between calories consumed and calories spent (WHO 2014). In general, women tend to have more stored body fat than males and are therefore more likely to be obese (Sobal 2001). Literature points to shifts in diet as one of the major causes for the rising obesity epidemic. These shifts characterize a move toward high calorie intake and are accompanied by less physical activity among people in both the developed and under-developed world. Studies have shown that under any condition, the energy imbalance that causes obesity is determined by the interaction between diet and physical activity, never one or the other in isolation (Hill & Peters 1998; French, Story & Jeffery 2001; Loureiro & Nayga 2005).

Obesity affects both developed and developing nations. In fact, in some lower-income and developing countries, levels of obesity are as high or higher than levels reported for developed nations (Popkin & Doak 1998; WHO 2013). On a global scale, we are experiencing a general shift toward obesity, not only centered in a few high-income countries. There have been rapid increases in obesity in lower- and middle-income developing countries (WHO 2013). This rate of change in obesity rates is higher than in higher-income countries (Popkin & Larsen 2004). It has been reported that from 1998 to 2008 the prevalence of obesity has risen from 2.3 percent to 19.3 percent in several developing countries (Misra & Khurana 2008). It is expected that between 1990 and 2020, mortality from cardiovascular disease in developing countries will increase by 120 percent for women and 137 percent for men. This is substantially greater than from developed countries: 29 and 48 percent respectively (Misra & Khurana 2008). Literature suggests that the major causes of the increasing scope and prevalence of obesity including changes in diet and physical activity, are often influenced by urbanization, the adoption of a Western diet, education, and income level (Popkin & Larsen 2004; Loureiro & Nayga 2005; Ball & Crawford 2004).

While these patterns in physical inactivity, diet, and urbanization are important, I contend that they are facilitated by larger trends and changes in the structure of agricultural production worldwide. The mechanization of agriculture has affected not only the farm itself, but also the surrounding community (Harper 2001). For instance, mechanization has decreased the need for hard labor and lessened the need for sharing of labor (Harper 2001). Such changes emerge from trends that are global in nature, and heavily promoted by the industrialization of agriculture (McMichael 2012). World powers have encouraged developing and less developed nations to industrialize agriculture by adopting mechanized processes that spur increased production. Such processes become increasingly important to developed nations as they import agricultural products from other countries, or move their production facilities to nations where labor costs are lower and environmental standards are much weaker (McMichael 2012; Roberts and Thanos 2003). While trade and relocation may improve the economies of developing countries, some evidence suggest that it also corresponds to increases in the prevalence of obesity among children and adults (Misra & Khurana 2010).

Thus, the global pressures that spur adoption of commercialized agricultural practices worldwide may contribute to the direct and indirect causes of global obesity prevalence. I am interested in exploring the problem of obesity in the broader context of these changes in food production processes, specifically, by looking at the role of mechanized agriculture. Industrialization of the world's food systems undoubtedly causes significant social and economic changes that can be seen through shifts in agricultural sector employment, migration from rural to urban areas, and ensuing changes in diet and exercise.

This paper will argue that mechanized agriculture plays an important underlying role in the obesity epidemic due to its impact on agricultural employment, urbanization, and levels of physical activity. Although changes in employment, increasing urbanization, and a decline in physical activity have all been identified as causes of the contemporary obesity epidemic, the interrelationships between these variables and the underlying factor of the mechanization of agriculture have not been empirically assessed. I aim to analyze the complex association between the mechanization of agriculture, employment in the agricultural sector, urbanization, and physical inactivity by exploring the degree in which the independent variables influence each other, and ultimately, obesity prevalence.

Background

Physical Activity and the Rise of Obesity

The relationship between physical activity and obesity is directly correlated. Because obesity is caused by energy imbalances between calories consumed and calories spent, we can attribute some of these imbalances to decreases in physical activity, as physical activity is the way in which humans expend calories. Because a person's weight is the result of calories spent subtracted from caloric intake, a decline in physical activity without a commensurate decline in calorie intake can directly increase a person's weight (WHO 2014; CDC 2012).

Many studies attribute the decline in levels of physical activity to the worldwide shift toward much less physically demanding occupations (WHO 2014). This trend is reflected in the employment decline in the agriculture sector, the increase in employment in industry and services, and also in the specific type of work within most forms of occupational employment (Popkin & Doak 1998). Some research shows that countries with high agricultural productivity, measured by the value of output per worker in the agricultural sector, are less likely to suffer from obesity (Loureiro & Nayga 2005). The shift in activity is also represented by the increasing use of transportation to get to work or school, technology in homes, and rising passive leisure time (Popkin & Doak 1998).

Urban environments tend to discourage physical activity as residents may rely heavily on public transportation and are likely to take employment opportunities that are much more sedentary in nature. This may be due to advancement in technology and transportation that decrease the need for physical activity in daily life, or to the heightened use of computers, televisions, and electronic games that increase the time adults and children spend sitting (Hill and Peters 1998; Owen & Sparling 2010). Residents commuting to urban centers may be more likely to own a motorized vehicle, increasing their chances of being obese if they spend many hours traveling to work each week. In China, the odds of being obese are 80 percent higher for those who own a motorized vehicle compared to those who do not (Bell & Popkin 2002).

Some shifts in physical activity can be attributed to the modernization of societies across the globe. Modernization involves shifts in modes of economic production for whole societies, which have substantial impacts on how human populations expend energy (Ehrhardt-Martinez 1998). There are three sectors that describe the economic production process: primary, secondary, and tertiary. Primary production extracts raw materials from the environment in agriculture, hunting and fishing, gathering, timbering, etc., and traditionally relies on the use of muscles of humans and animals to extract and harvest resources (Sobal 2001). Secondary production converts raw materials into manufactured products, and typically draws energy from fossil fuels and concentrates people in cities (Sobal 2001). Tertiary production provides services to consumers, where people offer attention, advice, and experience, and is not as dependent on physical energy sources as primary and secondary production (Sobal 2001). As whole societies shift from reliance on primary to secondary to tertiary modes of economic production through the modernization process, the energy expended by most people in the population decreases dramatically (Sobal 2001).

Amidst these trends moving from primary to tertiary production, some jobs within the primary sector are also trending towards less physical activity, where workers are similarly engaged in minimal physical activity for long periods of time. In the agricultural sector, employment changes due to mechanization explain why some specific occupations have workers who become increasingly inactive (Harper 2001). The mechanization of agriculture directly contributes to declines in physical activity because the use of more capital-intensive technologies, such as tractors, decreases the need for human labor on farms, pushing these people toward other modes of employment or unemployment (Harper 2001; McMichael 2012). Even for the farmers who remain working on the farm, tractors take away the need for as much manual labor as well as labor sharing. As the agricultural landscape changes to more per capita, intensified food production, more farmers move off of their farms and often into urban areas.

Diet's Contribution to Obesity

The increased intake of energy-dense foods that are high in fat has been contributing to rising obesity rates worldwide (WHO 2014). This informs the other half of the energy balance model: a high fat diet often results in more calories consumed then expended. High caloric diets are becoming even more common amongst less-developed and developing countries, ironically experiencing the double burden of both under-nutrition and obesity (McMichael 2012; WHO 2014). Children may be especially at risk as they are vulnerable to inadequate nutrition while simultaneously exposed to high-fat energy-dense foods that often cost less than nutritious, fresh foods (WHO 2014). In developing countries, diet-related problems are associated with the rapid adoption of a Western-style diet where economically possible (Fairweather-Tait 2003). A diet consists of high-fat, high-sugar, high-salt, energy-dense foods that may be highly packaged, of large proportions, and more convenient than whole foods prepared in the home (Ulijascek & Lofink 2006; WHO 2014; Fairweather-Tait 2003). The U.S. can be used as an example of the dietary dynamics of high-income countries, where the food landscape consists of increased daily caloric intake, foods that are energy-dense and nutrient poor such as fast food, salty snacks, more meals consumed outside the home and of large proportions, and fruit and vegetable consumption below recommended levels (Popkin & Larsen 2004). The adoption of a Western-style diet in recent decades in other nations has been associated with lifestyle changes that make consumers increasingly reliant on processed foods and fast food outlets (Fairweather-Tait 2003).

Major dietary shifts across the globe are often encompassed by and referred to as the "nutrition transition." As suggested, this nutrition transition relates globalization, urbanization, and Westernization to changing food environments across the globe. The globalization of food brings wealthy consumers greater access to more diverse and healthy foods, and at the same time delivers more refined food durables to the poor (Weis 2007). Globalization also fosters a dietary convergence between the wealthy and the poor in the form of junk food: soft drinks, packaged snacks and 'convenience foods' that are high in fat, sweeteners, artificial flavors and coloring (Weis 2007). The adoption of a Western diet in conjunction with this dietary convergence represents an overall shift in diet toward increased consumption of energy-dense food as well as declines in physical activity (Ulijaszek & Lofink 2006). It may also lead to an increased consumption of animal fat. Since the agricultural revolution, the animal protein content of the diet has increased dramatically in industrialized countries (Fairweather-Tait 2003). Animal food intake per capita per day tends to be higher among residents of urban areas than those of rural areas (Popkin & Larsen 2004). Increased animal protein intake often leads to increased total energy intake. Many studies show that total energy intake was higher in subjects who consumed diets high in fat than in subjects who consumed lower fat diets (Hill & Peters 1998). Body fat storage also occurs at a greater rate when excess energy comes from fat than when it comes from carbohydrates or protein (Hill & Peters 1998).

The consumption of caloric sweeteners, such as sugar, high-fructose corn syrup, dextrose, and fructose has increased largely in recent decades. In 2000, 306 kilocalories were consumed per person per day, which was a third higher than in 1962 (Popkin & Larsen 2004). Studies show that all measures of caloric sweetener increase significantly as gross national product per capita of the country and urbanization increase (Popkin & Larsen 2004). In less urbanized areas, the proportion of energy consumed from sweeteners increases largely as income increases. In more urbanized areas, this proportion is much higher at lower income levels and decreases as income rises (Popkin & Larsen 2004).

Many environmental factors drive consumer behavior and dietary choice such as food cost, advertisements, availability, satiability, and preference. Consumers may be more likely to experience the nutrition transition and adopt a Western-style diet if they relocate to an urban area (Popkin & Doak 1998).

Urbanization

Some of the most important factors responsible for urban dietary patterns are improved transportation and food distribution systems, greater penetration of commercial food sector marketing practices, increased heterogeneity of diet, employment patterns less compatible with home food production and consumption, changes in household composition and structure, and differences in disease patterns and health care availability (Popkin 1993). Movement from rural to urban areas and international migration largely affect dietary changes, although the causes and details of these dietary changes are poorly understood (Popkin 1993). Urban residents may have less time to prepare meals at home, they may be living by themselves, and they are likely to have many more options of convenience food readily available.

Exponential growth in urban populations affects diet based on trends including increased consumption of: processed foods high in fat and sugar, animal products, and food prepared outside the home. This environment fosters obesity prevalence by providing convenient, inexpensive, highly palatable, and energy-dense foods in combination with a more sedentary lifestyle (Hill & Peters 1998). To explain this technically: this environment promotes high energy intake and low energy expenditure (Hill & Peters 1998). Literature suggests that as per capita incomes rise, consumers tend to diversify their diets; meaning that they demand higher-value livestock products, fruit and vegetables, and relatively fewer food staples (Hazell & Wood 2008). Urbanization heightens these patterns while placing a high premium on market access, especially for perishable products (Hazell & Wood 2008).

The simple fact that more people are moving to the city exacerbates the problem: today, over 50 percent of the world population is living in cities. However, this does not mean that rural areas are immune to obesity: increased mechanization of farm activity leads to reduced physical activity at the same time that more food, but not necessarily a better variety of foods, becomes available.

Mechanized agriculture has allowed for food production to become increasingly efficient. Increased capital has enabled countries across the globe to adopt industrial practices of food production, enabling them to currently produce more food than the recommended daily amount per person. According to the Food and Agriculture Organization, global food production reached 2,600 kilocalories per capita and is expected to reach 3,000 kilocalories per capita by 2030 (Caballero 2007).

Changes in Agriculture Sector Employment

Previous research has shown that the mechanization of agriculture has led to a decline in agricultural sector employment (Harper 2001). The efficiency spurred by the industrialization of food production made human labor more expensive relative to land and capital, which decreased the amount of people needed in the agriculture sector. Because of this, employment in agriculture declines, the value in agriculture declines, and agriculture as a percentage of the economy declines, yet we are producing more food than ever before. Historically, agriculture has declined in importance compared to commercial and industrial activities, and commercial agriculture has replaced subsistence agriculture (McMichael 2008). Changes in agriculture sector employment have led to the increasingly sedentary nature of alternative employment opportunities, which leads to a decline in physical activity worldwide (WHO 2014). In the agricultural sector, as societies adopted capital-intensive machinery such as tractors, people were employed to drive the tractors rather than plow or weed the land by hand (Harper 2001). This resulted in declines in the amount of human labor needed on farms as well as the physical activity required of farmers, contributing to the increasingly sedentary lifestyle for workers, whether they remained in the agriculture sector or were employed elsewhere. For men, this often means moving into urban areas, where they are even more likely to adopt a less physically active lifestyle (McMichael 2012). Women may remain in the rural area in order to care for the children, while the men migrate toward the city in order to find more lucrative business opportunities (McMichael 2012).

Globally, there has been a major shift in the structure of employment, with adults moving away from physically demanding forms of employment such as agriculture, toward more capital-intensive and knowledge-based employment (Popkin & Doak 1998). The figure below shows shifts in the distribution of occupations for lower-income countries:

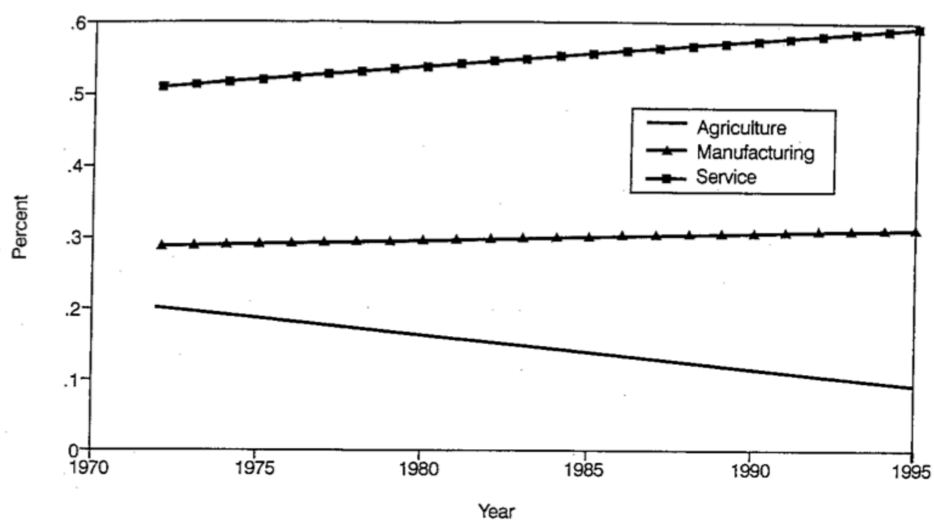


Figure 2. Shifts in the distribution of occupations for lower-income countries, 1972–1993.

(Popkin & Doak 1998)

Early colonialism spurred the fragmentation of agriculture, as land in less-developed countries was confiscated by colonial powers and men migrated to work on European estates (McMichael 2008). Small farms in the global south were seen as "underutilized," and were said to be better employed by conversion to commercial agriculture (McMichael 2008). Even today, small farms often lose their ability to compete and get overtaken by larger, more industrialized farms. This spurs an exodus of agriculture sector works, and the adoption of more capital-intensive technologies, such as tractors. What results is a system of food production consisting of farms that are larger, more commercial, and more specialized in higher-value products (Hazell & Wood 2008). Small farms disappear, or adapt toward specializing in a high-value product. Simultaneously, opportunities for farmers to leave the agriculture sector or diversify their incomes increase with economic growth and development (Hazell & Wood 2008). Economic growth and development in core nations has redistributed jobs to lower-wage regions where transnational corporations enhance profitability and Northern consumers gain access to low-cost products produced overseas (McMichael 2008). These economic and geopolitical factors directly explain why farmers worldwide have increasingly moved away from employment in agriculture, the majority gaining opportunities in less physically demanding jobs and moving from rural to urban areas. The changing nature of the employment sector, whether the increasingly sedentary nature of work, the adoption of an urban lifestyle, or both, that have led to declines in physical activity among adults worldwide.

Predictions

Current literature suggests that the relationships between obesity and physical inactivity, changes in the agriculture employment sector, and trends toward increasing urbanization can strongly inform us about the causes of obesity in modern society. However, they fail to link the rise of obesity across nations to changes in the modern processes of food production, and particularly, to the broader trend toward mechanized agriculture, involving the use of capital intensive equipment. This is an important gap in the existing literature because each of these causes of obesity has strong theoretical connections to the rise of mechanized agriculture.

I seek to demonstrate that the use of tractors across nations can be an important determinant for obesity, as tractors likely have indirect effects on other factors known to influence comparative trends in obesity, such as employment changes, urbanization, and physical inactivity. Specifically, I predict that the increased use of tractors across nations will lead to a decline in employment in the agriculture sector, which will then lead to increased urbanization. I predict that for males in particular, urbanization will lead to an increase in physical inactivity (as males are more likely to seek alternative employment in cities than females). This in turn will lead to increased obesity rates. I will also control for other important direct and underlying factors such as diet, schooling, and GDP per capita.

Methods

Sample

The sample includes 188 countries. This represents all countries for which data on overweight males and females was provided. For a complete list of nations included in the sample, see Table 1.

Countries that were included in the analyses may yield missing data points for certain variables. However, the level of missing data on remaining cases is relatively low and there does not appear to be a pattern to the missing values that would cause bias in the results. Utilizing the strengths of the structural equation modeling (SEM) technique, I use full maximum likelihood missing value routine. This is not an imputation procedure, but rather, the likelihood for the entire sample is found by summing the likelihoods for each case using whatever information each case has available. Therefore, each country in the sample contributes the maximum amount of information possible to the estimation. These estimates are consistent and efficient under the condition that missing data is missing at random. In SEM, each path or relationship between two variables represents one regression. A country may not be included in one path if data is missing, but it may be used in the calculation of a different path between two other variables.

Table 1: Nations Included in the Sample (N = 188)

Afghanistan	Djibouti	Lebanon	San Marino
Albania	Dominica	Lesotho	Sao Tome and Principe
Algeria	Dominican Republic	Liberia	Saudi Arabia
Andorra	Ecuador	Libya	Senegal
Angola	Egypt, Arab Rep.	Lithuania	Seychelles
Antigua and Barbuda	El Salvador	Luxembourg	Sierra Leone
Argentina	Equatorial Guinea	Macedonia, FYR	Singapore
Armenia	Eritrea	Madagascar	Slovak Republic
Australia	Estonia	Malawi	Slovenia
Austria	Ethiopia	Malaysia	Solomon Islands
Azerbaijan	Fiji	Maldives	Somalia
Bahamas, The	Finland	Mali	South Africa
Bahrain	France	Malta	Spain
Bangladesh	Gabon	Marshall Islands	Sri Lanka
Barbados	Gambia, The	Mauritania	St. Kitts and Nevis
Belarus	Georgia	Mauritius	St. Lucia
Belgium	Germany	Mexico	St. Vincent and the Grenadines
Belize	Ghana	Micronesia, Fed. Sts.	Sudan
Benin	Greece	Moldova	Suriname
Bhutan	Grenada	Monaco	Swaziland
Bolivia	Guatemala	Mongolia	Sweden
Bosnia and Herzegovina	Guinea	Morocco	Switzerland
Botswana	Guinea-Bissau	Mozambique	Syrian Arab Republic
Brazil	Guyana	Myanmar	Tajikistan
Brunei Darussalam	Haiti	Namibia	Tanzania
Bulgaria	Honduras	Nepal	Thailand
Burkina Faso	Hungary	Netherlands	Timor-Leste
Burundi	Iceland	New Zealand	Togo
Cambodia	India	Nicaragua	Tonga
Cameroon	Indonesia	Niger	Trinidad and Tobago
Canada	Iran, Islamic Rep.	Nigeria	Tunisia
Cape Verde	Iraq	Norway	Turkey
Central African Republic	Ireland	Oman	Turkmenistan
Chad	Israel	Pakistan	Tuvalu
Chile	Italy	Palau	Uganda
China	Jamaica	Panama	Ukraine
Colombia	Japan	Papua New Guinea	United Arab Emirates
Comoros	Jordan	Paraguay	United Kingdom
Congo, Dem. Rep.	Kazakhstan	Peru	United States
Congo, Rep.	Kenya	Philippines	Uruguay
Costa Rica	Kiribati	Poland	Uzbekistan
Cote d'Ivoire	Korea, Dem. Rep.	Portugal	Vanuatu
Croatia	Korea, Rep.	Qatar	Venezuela, RB
Cuba	Kuwait	Romania	Vietnam
Cyprus	Kyrgyz Republic	Russian Federation	Yemen, Rep.
Czech Republic	Lao PDR	Rwanda	Zambia

Analytic Strategy

I employ structural equation modeling (SEM) using the statistical software package AMOS. This allows for the measurement of both direct and indirect effects between the chosen variables in order to more accurately test my complex hypotheses. A traditional regression model would not have been able to account for the complex causal chain that links tractors to obesity rates. The SEM technique allows me to test for indirect and mediating effects and thus represents the best statistical approach for this line of research. My research design employs time ordering to help adhere to conditions of causality, where the dependent variable is measured in time after the independent variables. The key dependent variables (overweight rates) are measured in the year 2010, and the predictors are measured in the year 2008.

Dependent Variable

The key dependent variables in my analysis are *percent overweight males* and *percent overweight females*, measured for the year 2010. The overweight prevalence variable was constructed using data of confirmed overweight percentages and total population level from the World Bank. The prevalence of overweight is measured by the percentage of adults over the age of 15 whose weight for height is more than two standard deviations above the median for the international reference population of the corresponding age as established by the WHO's standards (World Bank 2014). This variable is gender-specific.

Independent Variables

In order to explore the relationship between the mechanization of agriculture and obesity, I include six interconnected variables that help determine increasing prevalence of overweight males and females. I employ the variable *tractors* in order to represent the mechanization of agriculture. This variable refers to the number of wheel and crawler tractors (excluding garden tractors) in use in agriculture per 100 square kilometers of arable land at the end of the calendar year 2008, or during the first quarter of 2009. Arable land includes land defined by the FAO as land under temporary crops, temporary meadows for mowing or pasture, land under market or kitchen gardens, and land temporarily fallow (World Bank 2014). I chose to include this variable to capture the mechanization of agriculture across the countries. The implementation and use of tractors directly contributes to the decline of employment in the agriculture sector as well as obesity prevalence. Relevant literature attributes the drastic worldwide shift in the industrialization of the agricultural production system to the implementation of tractors. I preformed a log-transformation on this variable to reduce the influence of extreme outliers.

Another key independent variable employed in the model is *employment in agriculture*, measured in 2008. Employees are people who work for a public or private employer and receive remuneration in wages, salary, commission, tips, piece rates, or pay in kind. Agriculture corresponds to agriculture, hunting, forestry, and fishing. I chose to include this variable because I would expect employment in the agriculture sector to decrease with the increased use of tractors.

I also include *percent urban,* which refers to people living in urban areas as defined by national statistical offices, is calculated using World Bank population estimates and urban ratios from the United Nations World Urbanization Prospects. I included this variable in my model because changes in employment may facilitate increased urbanization, and current literature largely attributes urban population growth to shifts in diet and inactivity, leading to the growing obesity epidemic.

Thus another key indicator is, *physical inactivity*, defined as the percentage of the population attaining less than 30 minutes of moderate activity five times per week, or less than 20 minutes of vigorous activity three times per week, or the equivalent (World Health Organization 2014). This variable was estimated based on self-reported physical activity as captured by the Global Physical Activity Questionnaire, the International Physical Activity Questionnaire, or a similar questionnaire containing activity at work/in the household, for transport, and during leisure time. Physical inactivity, or insufficient levels of physical activity are determinants of rising obesity prevalence because weight gain is caused by an imbalance of energy intake. As people become increasingly inactive, they are expending less energy and therefore gaining weight, thus I control for it in my analysis. This variable is gender specific and measured in the year 2008.

I have chosen to include *animal fat supply* in my model to account for dietary changes that are often pointed to as a causal factor to the obesity epidemic. This variable reflects the amount of animal fat in food, expressed in grams per day, available for each individual in the given population during the year 2008. It represents the average supply available for the population as a whole and does not necessarily indicate what is actually consumed by individuals. It is impossible due to data limitations to estimate the exact consumption levels. The animal fat supply variable gives us an idea of the amount of animal fat consumed by a given population, which can be used as another way to look at shifts in dietary changes worldwide. I performed a log-transformation on this variable to account for the influence of extreme outliers.

I have also controlled for both *GDP per capita* and *secondary school enrollment* in my model to account for the influence of economic development and modernization. I measure GDP per capita using Purchasing Power Parity (PPP) rates. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products (World Bank 2014). Data are in current international dollars. I performed a log-transformation on this variable to account for the influence of extreme outliers. The total secondary school enrollment rate represents the ratio of children in the official secondary school age who are enrolled in secondary school to the population of the official secondary school age children. These two variables are often used as key determinants of economic development in cross-national studies.

Results

Table 2 shows the correlation matrix of all variables used in this analysis and includes the mean, standard deviation, minimum, and maximum. These offer a preliminary test for multicollinearity among central indicators.

Table 2: Univariate Statistics and Correlation Matrix

	1	2	3	4	5	6	7	8	9	10
1. Percent Overweight Male 2010	1.0000									
2. Percent Overweight Female 2010	0.5901	1.0000								
3. Physical Inactivity Male 2008	0.3728	0.2615	1.0000							
4. Physical Inactivity Female 2008	0.2281	0.2376	0.8281	1.0000						
5. Animal Fat Supply 2008 (ln)	0.4903	0.0056	0.2437	0.0434	1.0000					
6. Percent Urban 2008	0.5965	0.1768	0.3966	0.1903	0.3799	1.0000				
7. Employment in Agriculture 2008	-0.7133	-0.2753	-0.3912	-0.1708	-0.7121	-0.7163	1.0000			
8. Tractors 2008 (ln)	0.5250	0.1051	0.4498	0.3646	0.6779	0.4016	-0.7621	1.0000		
9. Secondary School Enrollment 2008	0.5348	-0.0257	0.3824	0.2103	0.6880	0.5906	-0.8476	0.8395	1.0000	
10. GDP (ln) 2008	0.6811	0.2496	0.5302	0.3310	0.7075	0.6401	-0.8951	0.8344	0.8583	1.0000
Mean	43.7581	50.3929	31.4084	38.4529	1.7268	55.1954	19.5748	5.3640	78.4865	8.7636
Standard Deviation	20.4921	18.5080	15.4410	17.7560	0.9189	23.3806	18.7286	1.7636	27.5164	1.2894
Minimum	3.5016	3.7052	2.7000	6.6000	0.0953	10.1352	0.3000	0.4391	11.5338	5.7747
Maximum	93.0598	92.1116	70.7000	76.2000	3.8088	100.0000	76.5000	8.6821	126.7423	11.1868

Values are rounded to the nearest millionth

The high magnitude of the relationships among variables demonstrates that many of the predictor variables are highly correlated. Although this cannot confirm the existence of multicollinearity solely based on correlations among variables, the strength of the relationships suggests a high probability that multicollinearity is an issue for the data. For example, animal fat supply and percent overweight male (0.4903) have a strong, positive relationship, based on the idea that a relationship of 1.000 indicates a perfectly correlated relationship between variables. This evidence of highly correlated variables further warrants the use of SEM analytical method given its ability to provide more flexible assumptions and create mediating relationships that allow for the unbiased interpretation of coefficient estimates for models with interconnected independent variables.

The correlation between key variables tractors and percent overweight male (0.5250) starts to provide some evidence that there is a causal relationship between my key independent variable and the dependent variable. The mean value for percent overweight female is higher than the mean value for percent overweight male at 50.3929. This may be due to the genetic differences among males and females and the fact that females have inherently more body fat than males. Higher levels of physical inactivity among females may also contribute to their elevated overweight percent.

Figures 2 and 3 provide the graphical representation of my SEM results for the obesity for males and females, respectively. When using SEM, it is important to confirm that the model fit is appropriate before interpreting the pathway coefficients between indicators. The fit for the model as a whole is confirmed by the chi-square test, which for Model 1 for male overweight yields a significance level of .126. When using SEM, we want this value to be non-significant because the null hypothesis predicts that the model is a good fit for the data. In this case, we do not want to reject the null hypothesis. Here, the chi-square test is non-significant and we can fail to reject the null hypothesis with a chi-square statistic of 22.543 and degrees of freedom at 16. Further model fit statistics also suggest that this is a good fitting model. For example, the Root Mean Squared Error of Approximation (RMSEA) is less than .05 at .047. The incremental fit index (IFI), Tucker-Louis index (TLI), and comparative fit index (CFI) are generally required to be to be as close to 1 as possible, and in my model the estimates for these measures respectively are: .993, .983, and .992.

The fit for Model 2 for females as a whole is confirmed by the chi-square test, which yields a significance level of .247. This value is non-significant; therefore we do not reject the null hypothesis. The chi-square test is non-significant and we can fail to reject the null hypothesis with a chi-square statistic of 19.420 and degrees of freedom at 16. Further model fit statistics suggest that this is also a good fitting model. For example, the Root Mean Squared Error of Approximation (RMSEA) is less than .05 at .034. The incremental fit index (IFI), Tucker-Louis index (TLI), and comparative fit index (CFI) are generally required to be to be as close to 1 as possible, and in my model the estimates for these measures respectively are: .996, .990, and .996. It is clear that both the male and female models are good fits for the data, which allows me to further interpret the findings and pathways shown in the graphs.

Figure 1: ***Structural Equation Model*** **for Percent Overweight Male**

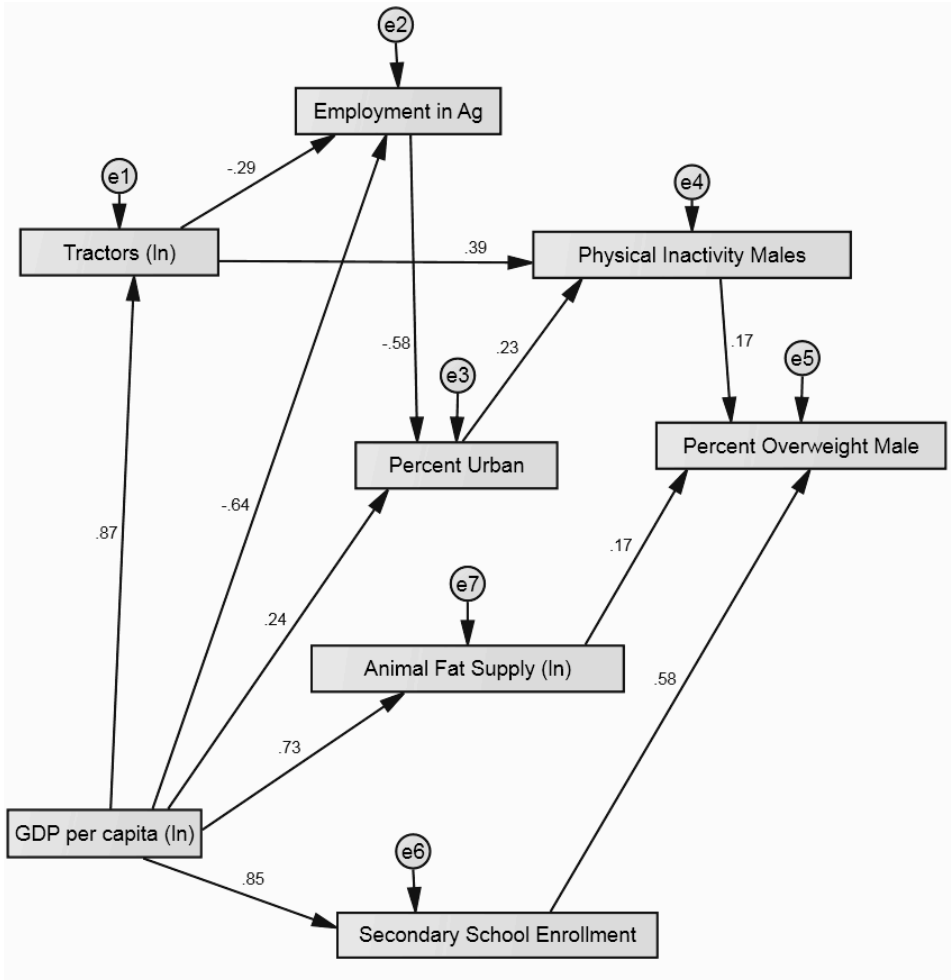
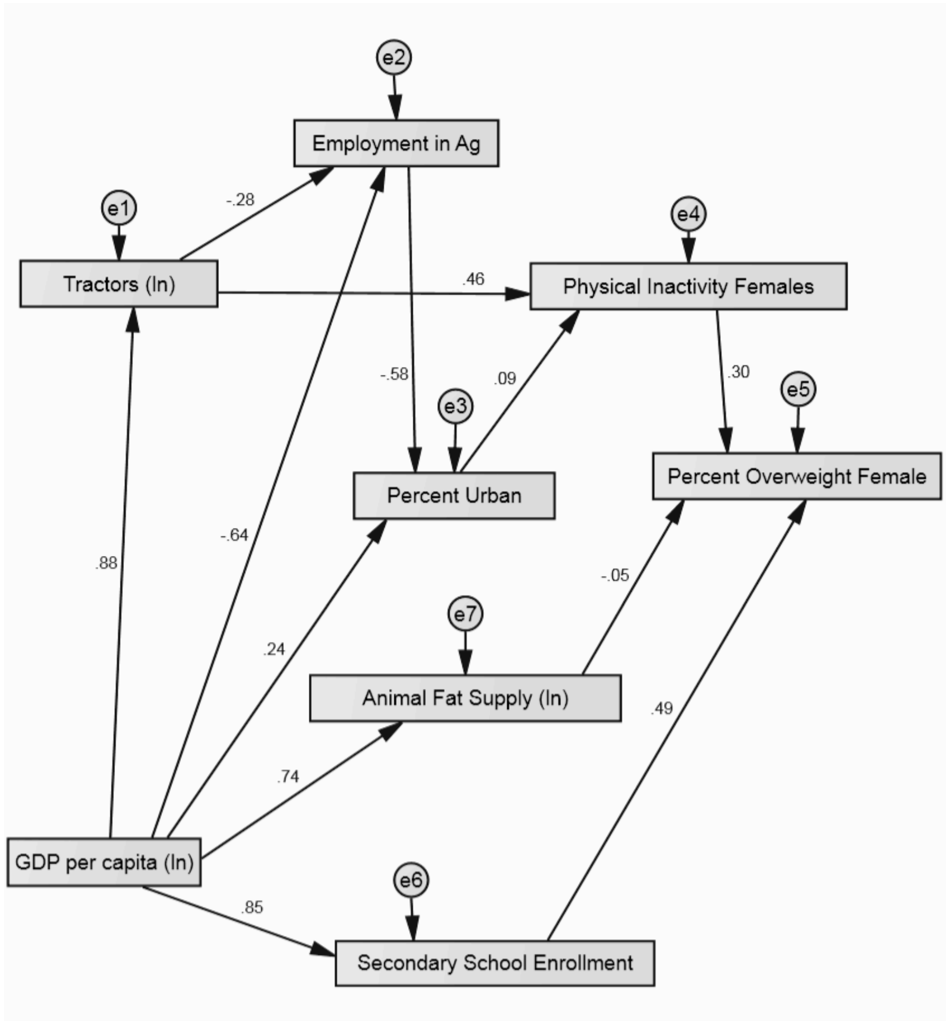


Figure 1 demonstrates that as predicted, GDP is positively associated with tractors (.87) across nations. In turn, tractors is negatively associated with employment in agriculture (-.29), which then has a negative influence on percent urban (-.58). This means that economic development increases industrialization of agriculture, which in turn lowers employment in agriculture and increases the urbanization rate across nations. Both tractors (.39) and percent urban (.23) are positively associated with physical inactivity among males, where nations with increased industrialization in agriculture and increased urban populations tend to have reduced levels of physical activity in males.

Physical inactivity in males then leads to increased rates of obesity (.30). This set of findings confirms my key hypothesis.

I also find that GDP per capita, or level of economic development, plays an important indirect role in a number of additional relevant factors. For example, I find that GDP per capita is strongly associated (.73) with animal fat supply, which is then positively associated with percent overweight male (.17). GDP per capita is also strongly associated with secondary school enrollment (.85), which is positively associated with percent overweight male (.58). Increases in economic development also increase rates of urbanization (.24) and lower employment in agriculture (-.64), independent of the effect of tractors.

Figure 2: ***Structural Equation Model*** **for Percent Overweight Female**



The coefficients present in Figure 1 and Figure 2 are standardized regression coefficients. We can use the size of the number to estimate the magnitude of the relationship.

Figure 2 represents the model for females, where all pathways presented are statistically significant except animal fat supply to percent overweight female and percent urban to physical inactivity. As predicted, GDP is positively associated with tractors (.88), and tractors is negatively associated with employment in agriculture (-.28), which in turn has a negative influence on percent urban (-.58). Economic development influences the mechanization of agriculture, which lowers employment in agriculture and increases the rate of urbanization. Although percent urban does not have a significant relationship with physical inactivity among females, physical inactivity is still positively associated with percent overweight female (.30). This may be because few females are migrating to urban areas, but physical inactivity still influences percent overweight female as the mechanization of agriculture may foster a more sedentary lifestyle among females as well as males, even if they are not the ones migrating to cities. This confirms my hypothesis that urbanization may be a key determinant of physical inactivity in males more so than females.

I also find that GDP per capita, or level of economic development, plays an important role in a number of factors in this model, as it did in the model predicting overweight males. For example, GDP per capita is strongly associated with animal fat supply (.74), although animal fat supply is not significantly associated with overweight females (-.05). This may because animal fat may be more likely to be consumed by the males in the household who have more social and economic power, especially in less-developed countries (e.g. McMichael 2012). As in the previous model, GDP per capita is also strongly associated with secondary school enrollment (.85), which is positively associated with percent overweight female (.49). Increases in economic development also increase percent urban (.24) and lower employment in agriculture (-.64), autonomous of the effect of tractors.

While there is consistency in the overall relevance of tractors and the structure of many relationships across the models, there are also important differences between the male and female models. Tractors and physical inactivity seem to have a slighter stronger association for females rather than males, while the association between tractors and changes in employment in agriculture is very similar in both models. This may be because in less-developed countries, women are more greatly affected by changes in the agricultural sector as they traditionally are the ones responsible for growing food in less-developed nations (e.g. McMichael 2012; Roberts and Thanos 2003). This suggests that if women stay behind to take care of their family, they may still be less physically active because they are no longer doing manual labor every day working in agricultural.

Animal fat supply does not seem to have a strong significance in the female model, which may be because if there is animal fat available in households in less-developed countries, it often goes to the men and not the women due to patriarchal social norms. In developed countries, it may be more common for men to consume more animal fat than women due to cultural norms about eating meat which imply than men should eat more meat-based diets. Percent urban is not strongly associated with physical inactivity among women, most likely because women are not the ones moving to urban areas in less-developed nations because of these changes in the agricultural sector. They may stay behind to take care of the family while men move to the cities to find work, once employment opportunities in agriculture decline. As both males and females become less physically active, possibilities for becoming overweight increase.

Discussion

When looking at both the male and the female model for percent overweight, it becomes clear that the mechanization of agriculture—as measured by the variable *tractors*—is an important underlying factor in explaining cross-national trends in overweight males and females. The relationship between tractors and obesity is mediated by many different causal factors identified in prior research. However, the model that I have developed reveals a new and more overarching relationship of the effects of the industrialization of the food system as a whole on the rising obesity epidemic. The mechanization of agriculture has greatly transformed our food system, as well as other aspects of society; the combination of which causes increased cases of overweight adults across both affluent and developing nations.

Tractors have lessened the need for human labor in the agricultural sector and they have made it much easier to produce more food at lower costs. As employment in the agriculture sector declines, previous employees search for work elsewhere, often by moving to urban areas, and often become less physically active. This especially affects men, who are moving to urban areas more so than women (McMichael 2012). The adoption of a more urban lifestyle promotes decreases in physical activity, which tends to affect males more than females. Urban employment opportunities tend to be much more sedentary, and transportation to these jobs includes trains, buses, and cars.

Conclusion

The increasing global obesity epidemic poses substantial threats to the health of the global population, as well as threats to economic growth and development. The U.S. economy is already experiencing the effects of obesity in increasing costs to the health care system, which are expected to rise drastically in the coming decades. The medical care costs attributed to obesity totaled $147 billion in 2008 in the United States alone (CDC 2012). Undoubtedly, similar trends of rising obesity across less-developed nations will put significant strain on their economies and health care systems which are already ill-equipped to deal with costly and chronic conditions that result from obesity.

Some progress has been made to alleviate this growing epidemic; yet developing and less-developed countries appear to be only increasing in the prevalence of obesity as globalization continues to modernize the food system, as well as introduce more Western, high-fat diets. The technological advancements in agriculture have ensured food security for many nations by producing increasing amounts of kilocalories per acre of land. This increase in food production may be contributing to the problem of obesity even as it alleviates food insecurity, however, as much of the food produced by capital-intensive farms is used in processed and convenience foods, as well as for raising meat (Roberts and Thanos 2003). Transnational agencies have long encouraged the industrialization of agriculture as a means to develop, arguing that poor nations can increase economic growth by exporting more primary sector products to core markets (Roberts and Thanos 2003). However, the mechanization of agriculture is clearly having unintended consequences that could impair health and stifle development over the long term. Additionally, as affluence increases and populations grow in developing nations, more and more people will be demanding foods that reflect a more Western diet (McMichael 2012). Both changes in diet and increased industrialization in agriculture stem from larger patterns in globalization.

We need to address the food system as a whole in order to better address the threat of rising obesity worldwide. The mechanization of agriculture has allowed for increased production of food, yet it has also destroyed humans' relationship with the food that they consume, transformed labor relations, and facilitated lifestyles that are more sedentary. Proximate causes of obesity include physical inactivity, dietary changes, and urbanization, but there is a greater force driving these causal indicators, and this force is mechanization of agriculture.

The goal of this paper was to explore not only this larger context, but also the interconnections between the factors contributing to obesity. The complex interrelationships evidenced demonstrate that there is no single cause of increased obesity, but rather this demographic shift results from the system of food production and consumption as a whole. An area that can be altered is the food production industry itself. If industries were made more aware of the impacts of their practices, or took steps to ensure the healthfulness of their food, consumers would be less able to suffer from the consequences of unhealthy food. Promoting smaller-scale, organic farms may connect more people with the food production practices and help combat some of the harmful impacts of the industrialized food system. This re-localization of agriculture may be successful in helping to combat increasing rates of obesity.

It is important to acknowledge the limitations of this research. My research was limited in some instances by the availability and scope of the data. For example, the variable animal fat supply, is not an ideal measure, in this case providing only a crude operationalization of changes in diet. Also, urbanization rates do not necessarily reflect rural-to-urban migrants. Thus, while some measures are not ideal, it is important to acknowledge in the context of comparative research that while there at times may be sacrifices in terms of the refinement of certain measures, it is still important to draw on what data is available to be able to assess large-scale changes in a macro-comparative context.

This research also points to other needed areas of inquiry. Future studies could focus more on these patterns specifically in developing countries. Reviewed literature points to China as extremely burdened by changes in the agricultural sector and the effects of adopting a more Western diet. It would be interesting to explore the cultural impacts that adopting this diet has on a society and the health of their citizens, especially as more developing countries develop. It would also be interesting to explore the more direct effects of global development policies that promote industrialization in agriculture on the rising obesity epidemic, in order to put this work into even broader context. Observing trends over time or making distinctions across different types of regions may be another avenue of further study.

The rising percentage of obesity across the globe has been explored more in recent literature. Because this is still a relatively new area of study, it warrants more research and the use of different and more integrative approaches. My goal was to draw attention to the mechanization of the food system as an overarching driving force in the increasing obesity epidemic. While the industrialization of agriculture has allowed more food to be produced globally, it is also facilitating changes to the labor force with declines in physical activity, that potentially have many negative health consequences that go beyond obesity. Addressing issues of obesity and resulting health risks will represent key challenges for all nations in the coming decades.

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