Cliodynamics: The Journal of Quantitative History and Cultural Evolution
UC Riverside

Title:
Wheat flour versus rice consumption and vascular diseases: Evidence from the China Study II data

Journal Issue:
Cliodynamics, 6(2)

Author:
Kock, Ned, Texas A&M International University

Publication Date:
2015

Permalink:
https://escholarship.org/uc/item/7hk1254d

Keywords:
China, The China–Cornell–Oxford Project, Wheat Flour Consumption, Rice Consumption, Vascular Diseases, Mortality, Path Analysis

Local Identifier:
irows_cliodynamics_27969

Abstract:
Why does wheat flour consumption appear to be significantly associated with vascular diseases? To answer this question we analyzed data on rice consumption, wheat flour consumption, total calorie consumption, and mortality from vascular diseases obtained from the China Study II dataset. This dataset covers the years of 1983, 1989 and 1993; with data related to biochemistry, diet, lifestyle, and mortality from various diseases in 69 counties in China. Our analyses point at a counterintuitive conclusion: it may not be wheat flour consumption that is the problem, but the culture associated with it, characterized by: decreased levels of physical activity, decreased exposure to sunlight, increased consumption of processed foods, and increased social isolation. Wheat flour consumption may act as a proxy for the extent to which this culture is expressed in a population. The more this culture is expressed, the greater is the prevalence of vascular diseases.

Supporting material:
Appendices A and B

Cliodynamics: The Journal of Quantitative History and Cultural Evolution

Wheat Flour Versus Rice Consumption and Vascular Diseases: Evidence from the China Study II Data

Ned Kock
Texas A&M International University

Abstract

Why does wheat flour consumption appear to be significantly associated with vascular diseases? To answer this question, we analyzed data on rice consumption, wheat flour consumption, total calorie consumption, and mortality from vascular diseases obtained from the China Study II dataset. This dataset covers the years of 1983, 1989 and 1993 and includes data related to biochemistry, diet, lifestyle, and mortality from various diseases in 69 counties in China. Our analyses point to a counterintuitive conclusion: it may not be wheat flour consumption that is the problem, but the culture associated with it, which is characterized by decreased levels of physical activity, decreased exposure to sunlight, increased consumption of processed foods, and increased social isolation. Wheat flour consumption may act as a proxy for the extent to which this culture is expressed in a population. The more this culture is expressed, the greater is the prevalence of vascular diseases.

Introduction

Recent years have seen the vilification of wheat flour as a food ingredient, particularly in health books aimed at non-technical readers, with its consumption being presented as a major cause of a variety of modern diseases, including vascular diseases (Davis, 2011; Taubes, 2008). The term "vascular diseases" is used here to refer to diseases that affect the heart and blood vessels, including ischemic heart disease, stroke, hypertensive heart disease, aortic aneurysms, cardiomyopathy, atrial fibrillation, and peripheral artery disease (Mendis et al., 2011).

A key hypothesis underlying this indictment of wheat flour is that foods made with it induce acute insulin elevations, thus promoting excess body fat gain when consumed regularly over a period of several years. Insulin is a hormone that tends to rise sharply in response to the intake of foods that, like those made with wheat flour, have high glycemic indices and, particularly, high glycemic loads (Barclay et

Corresponding author's e-mail: nedkock@tamiu.edu

Citation: Kock, Ned. 2015. Wheat flour versus rice consumption and vascular diseases: Evidence from the China Study II data. *Cliodynamics* 6: 130–146.

al., 2008; Cordain et al., 2003; Ludwig, 2002). Excess body fat gain then induces insulin resistance, which, in turn, increases the likelihood of vascular diseases (Apovian & Gokce, 2012; Poirier & Eckel, 2002; Rexrode et al., 1996; Sowers, 1998; Van Gaal et al., 2006).

However, one of the key problems with the above hypothesis comes from epidemiological evidence related to rice consumption and its health effects. Boiled rice also scores relatively high in terms of glycemic index and glycemic load, and its regular consumption is generally associated with a low prevalence of vascular diseases in China and Japan (Liu & Li, 2000; Matsuzaki, 1992). This dilemma leads to an important research question: *Why does wheat flour consumption appear to be significantly associated with vascular diseases?*

The importance of this research question comes from the fact that wheat flour products are widely consumed around the world, and that their broad availability and relatively low cost help mitigate global hunger (Singh, 2009). To answer this research question, we analyzed data on rice consumption, wheat flour consumption, total calorie consumption, and mortality from vascular diseases obtained from the China Study II dataset (Junshi et al., 2006). This is an extensive dataset that covers the years of 1983, 1989 and 1993 and includes data is related to biochemistry, diet, lifestyle, and mortality from various diseases in 69 counties in China.

Our investigation suggests that wheat flour consumption in China, and perhaps in many other countries, is accompanied by culturally-induced factors including decreased levels of physical activity, decreased exposure to sunlight, increased consumption of processed foods, and increased social isolation. We conclude that consumption of wheat flour *per se* may not be the problem and that evidence points to these culturally-induced factors correlated with wheat flour consumption playing a role in cardiovascular disease. Therefore, wheat flour consumption may be a proxy for the extent to which these culturally-induced factors are expressed in a population. The more they are expressed, the greater the prevalence of vascular diseases.

Research Background

There is strong evidence linking consumption of modern processed foods based on wheat flour and vascular diseases (Davis, 2011). The evidence refers primarily to modern foods made with refined wheat flour and not to more traditional whole-wheat products (Harris & Kris-Etherton, 2010; Smith & Tucker, 2011). Examples of foods based on refined wheat flour include white flour, white bread, hominy, and most types of pasta. Foods based on refined wheat flour are widely available in modern cities and widely consumed by urban populations.

Although the link between consumption of wheat flour and vascular diseases has a hypothetical connection to elevated insulin, boiled rice also scores relatively high in terms of glycemic index and glycemic load, but its consumption is generally associated with a low prevalence of vascular diseases in China and Japan (Liu & Li, 2000; Matsuzaki, 1992). However, obesity is a clear, major cause of vascular diseases, as determined by innumerable studies conducted over different periods of time and with a variety of participants (Apovian & Gokce, 2012; Poirier & Eckel, 2002; Rexrode et al., 1996; Sowers, 1998; Van Gaal et al., 2006). Total calorie consumption has been found to be associated with obesity in several studies (Rosenheck, 2008; Waxman & Stunkard, 1980), whereas other studies found no link between these two variables (Braitman et al., 1985). Wheat flour consumption may significantly influence total calorie consumption, thus causing obesity (Galal, 2002). Rice, however, appears to contribute significantly to total calorie consumption and yet not to be a major cause of obesity in countries such as China and Japan (Liu & Li, 2000; Matsuzaki, 1992).

The discussion above indicates the necessity of a path analysis (Kock, 2015; Kock & Gaskins, 2014; Wright, 1934) examining the relationships among rice consumption (*Rice*), wheat flour consumption (*Wheat*), total calorie consumption (*Calorie*), and mortality from vascular diseases (*MVasc*; Figure 1). Our goal is to try to understand why consumption of wheat flour, but not rice, appears to be significantly associated with vascular diseases.

The path analysis includes a possible correlation between rice consumption (*Rice*) and wheat flour consumption (*Wheat*) and allows us to explore the extent to which they are consumed together or separately. If they are consumed together, a positive correlation will be observed, and if they are consumed separately, we will see a negative correlation. In countries such as China and Japan, rice consumption is associated with adherence to traditional cultural practices in rural contexts, whereas consumption of products based on refined wheat flour is associated with urbanization and adoption of modern lifestyles (Liu & Li, 2000; Matsuzaki, 1992). This cultural divide would typically be reflected in a strong negative correlation between rice consumption (*Rice*) and wheat flour consumption (*Wheat*) in these countries. Next, the path analysis assesses rice (*Rice*) and wheat flour consumption (*Wheat*) in the context of total calorie consumption (*Calorie*).

Finally, the analysis allows us to assess the extent to which those hypothesized predictors influence mortality from disease (*MVasc*). Given that there is evidence that total calorie consumption is not associated with obesity (Braitman et al., 1985), and thus may not be associated with vascular diseases, it would be interesting if rice and wheat flour were nevertheless associated, positively or negatively, with vascular diseases. Counterintuitive results such as these would arguably help in our understanding of why wheat flour consumption appears to be significantly associated with vascular diseases by enabling us to rule out some possible reasons and look for alternative explanations.

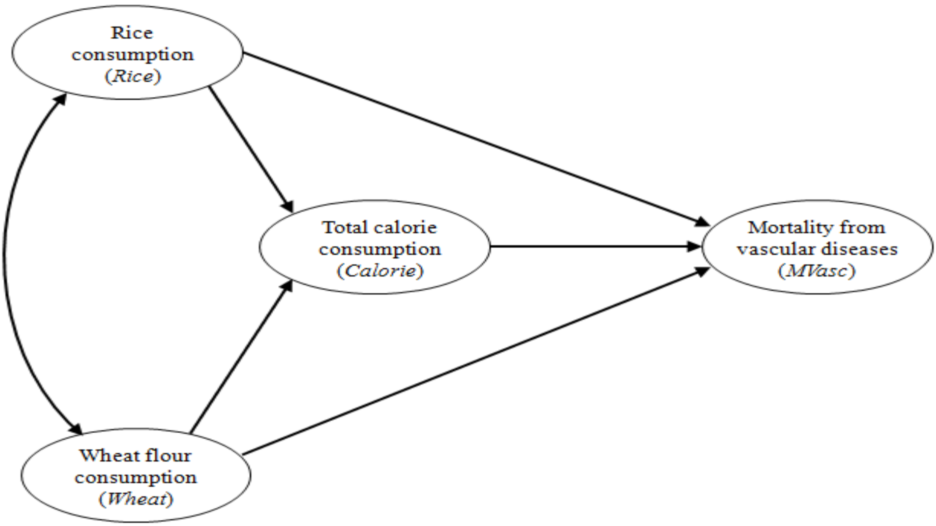

Figure 1. Model with hypothesized relationships.

Research Method

Data on rice consumption (*Rice*), wheat flour consumption (*Wheat*), total calorie consumption (*Calorie*), and mortality from vascular diseases (*MVasc*) was obtained from the China Study II dataset (Junshi et al., 2006). This dataset, which is described in more detail in Appendix A, contains data for the years of 1983, 1989 and 1993. The data is related to biochemistry, diet, lifestyle, and mortality from various diseases. It covers 69 counties in China.

The data was analyzed through a nonlinear robust path analysis (Kock, 2015; Kock & Gaskins, 2014) and implemented with the software WarpPLS 5.0 (Kock, 2015). This software was chosen due to some of its advanced features that were needed in our study, such as the ability to conduct nonlinear robust path analyses, generation of outputs for model fit and quality assessment, as well as support for multicollinearity and predictive validity tests. The main software settings used are provided in Appendix B.

In a nonlinear robust path analysis, nonlinearity among linked variables is taken into consideration in the calculation of coefficients of association. This is an important feature in our analyses, because food-mortality associations tend to be nonlinear (Johansson, 1994; O'Sullivan et al., 2013). Since this is a robust type of analysis, restrictive parametric conditions such as multivariate normality do not have to be met. This is noteworthy because we conducted a normality assessment that suggested that none of the four variables in our model was normally distributed. This assessment employed the classic Jarque-Bera test (Bera & Jarque, 1981; Jarque & Bera, 1980) and Gel and Gastwirth's (2008) robust modification of this test.

Because data from multiple years was used, we controlled for a variable storing the year in which the data were collected and for cluster mean variables that stored the average rice consumption (*Rice*), wheat flour consumption (*Wheat*), and total calorie consumption (*Calorie*), for each of the years in which the data was collected. We also replicated our analyses using data for only a single year, namely 1989, obtaining results nearly identical to those based on the whole sample. The year of 1989 was chosen for this replication because it was the intermediate year between the extremes represented by the two other years in the dataset, and because it was the year for which the most complete data subset was available. Additionally, we controlled for the ratio of females-to-males in each county to account for differences in diet and lifestyle between the sexes and related differences in mortality (He et al., 2005).

We conducted several model and data validation tests, summarized in Appendix B, to ensure that the results were not biased and that there was a good fit between our model and the data. Those tests suggest that the model is free of multicollinearity (Kock & Lynn, 2012), that acceptable predictive validity values were achieved in connection with all variables (Geisser, 1974; Stone, 1974; Kock 2015), and that all model fit and quality indices reached suitable levels (Kock, 2011; 2015).

Results and Discussion

Coefficients of association were assigned to each of the hypothesized relationships in our model (Figure 2). Rice consumption (*Rice*) and wheat flour consumption (*Wheat*) were significantly and negatively correlated (r = -0.803, P < 0.001) with each other. Both rice consumption (*Rice*) and wheat flour consumption (*Wheat*) were significantly and positively associated with total calorie consumption (*Calorie*), with the association involving rice consumption (*Rice*) (β = -0.318, P < 0.001) being much stronger than the association involving wheat flour consumption (*Wheat*) (β = -0.174, P < 0.001).

These results suggest a major divide in terms of rice and wheat flour consumption. The very strong and negative correlation between rice consumption (*Rice*) and wheat flour consumption (*Wheat*) suggests that the more rice is consumed in a county, the less wheat flour is consumed, and vice-versa.

As noted, in terms of total calorie consumption (*Calorie*), the association involving rice consumption (*Rice*) is much stronger than the association involving wheat flour consumption (*Wheat*). This suggests that rice tends to make up a bigger percentage of total calorie consumption than wheat flour.

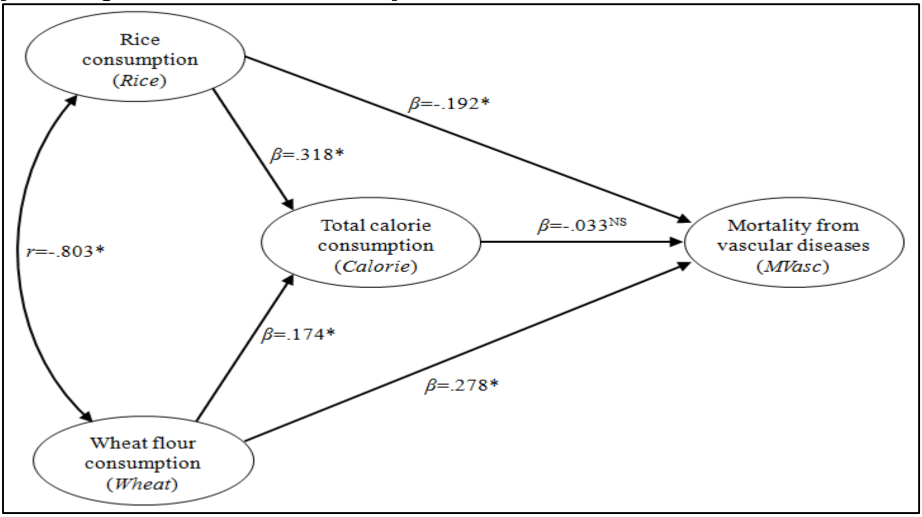

Figure 2. Model with results in terms of overall effects. The correlation between *Rice* and *Wheat* is a bivariate coefficient of association. The path coefficients next to straight arrows are multivariate coefficients of association; they assume hypothesized directions of causality and control for competing effects. The existence of competing effects is represented by two or more arrows pointing at the same variable. Notes: * P<.001; NS non-significant.

In other words, a diet primarily of rice is one in which other components do not contribute as many calories as in a diet primarily of wheat flour. Modern processed foods tend to have high calorie contents and be generally less healthy than foods that are not processed or are minimally processed (Cutler et al., 2003). Therefore, in our dataset, rice consumption (*Rice*) may be a marker of a healthier diet, with fewer processed foods in it. This seems to have historically been the case in China and Japan (Liu & Li, 2000; Matsuzaki, 1992).

Both rice consumption (*Rice*) and wheat flour consumption (*Wheat*) were significantly associated with mortality from vascular diseases (*MVasc*). Total calorie consumption (*Calorie*) was not significantly associated (β = -0.033, non-significant) with mortality from vascular diseases (*MVasc*), after controlling for rice consumption (*Rice*) and wheat flour consumption (*Wheat*). Regarding mortality from vascular diseases (*MVasc*), the association involving rice consumption (*Rice*) (β = -0.192, P < 0.001) was of the opposite sign as the association involving wheat flour consumption (*Wheat*) (β = -0.278, P < 0.001).

Overall, the relationship between rice consumption (*Rice*) and mortality from vascular diseases (*MVasc*) is negative (Figure 3), which means that the linear equivalent of the relationship would have a negative slope. The nonlinear relationship depicted, which presents a better fit with the data than the equivalent linear relationship, suggests that at around 400 grams of rice consumed per day per person, the relationship turns from negative to positive.

The nonlinear pattern of the association between rice consumption (*Rice*) and mortality from vascular diseases (*MVasc*) is what one would expect in connection with consumption of almost any healthy food or liquid, including water (Johansson, 1994; Sonnenblick et al., 1993). Intake up to a point promotes health, thus decreasing mortality but beyond that point becomes health-detrimental. The left side of the curve shows a pattern of increased mortality from vascular diseases (*MVasc*) with *decreased* rice consumption (*Rice*), which may be due to malnutrition negatively affecting resistance against infections and thus promoting vascular diseases (Leinonen & Saikku, 2002). Here, rice consumption is a marker of nutrition status.

The right side of the curve shows a pattern of increased mortality from vascular diseases (*MVasc*) with *increased* rice consumption (*Rice*), likely due to excess rice consumption. Even though the detrimental effect of excessive rice consumption in terms of mortality from vascular diseases is not mediated by total calorie consumption, it may be mediated by excess body fat gain in response to a combination of excess calories *and* high insulin levels (Cordain et al., 2003; Taubes, 2008). The excess body fat gain promotes insulin resistance, which is a known precursor of vascular diseases (DeFronzo & Ferrannini, 1991). Also, excessive rice consumption may crowd out other foods that bring in important nutrients.

Overall, the relationship between wheat flour consumption (*Wheat*) and mortality from vascular diseases (*MVasc*) is positive, and, although nonlinear, no change in sign is observed (Figure 4). That is, increases in wheat flour consumption (*Wheat*) are associated with increases in mortality from vascular diseases (*MVasc*) throughout the dataset when we control for rice consumption (*Rice*) and total calorie consumption (*Calorie*).

The pattern of the association between wheat flour consumption (*Wheat*) and mortality from vascular diseases (*MVasc*) is what one would expect in connection with consumption of a food that is detrimental to health. This is puzzling, given that wheat flour is similar to rice in terms of carbohydrate content, glycemic index and load, and total calorie content. In fact, wheat flour contains greater contents of protein and various vitamins than rice (USDA, 2015), being in this respect more nutritious. The human body has minimal daily protein and vitamin intake requirements (Campbell et al., 1994; Selhub et al., 1993; Young et al., 1973). While both wheat flour and rice are poor sources of many required nutrients, such as vitamins A and C, generally speaking, the minimal daily nutrient requirements appear to be met more easily with wheat flour than rice (USDA, 2015).

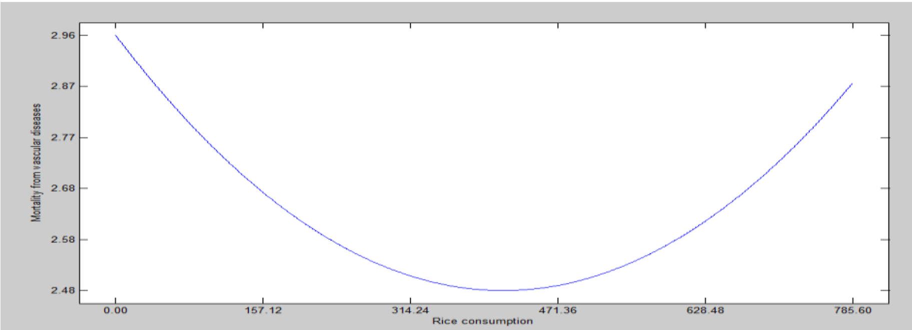

Figure 3. Mortality from vascular diseases and rice consumption. Notes: Horizontal (X) axis values are grams of rice consumed per day per person, averaged for each county; vertical (Y) axis values are deaths from all vascular diseases within ages 35–69 per 1,000 people, averaged for each county.

The primary protein in wheat flour is gluten, which has been hypothesized to be detrimental to the health of individuals who suffer from celiac disease (Mora et al., 1993). However, the incidence of celiac disease in Japan and China appears to be extremely small compared with other countries (Cummins et al., 2009), and there is very limited evidence of gluten-related health problems in individuals who do not suffer from celiac disease (Biesiekierski et al., 2011; Biesiekierski et al., 2013). Therefore, it is difficult to explain the pattern of the association between wheat flour consumption (*Wheat*) and mortality from vascular diseases (*MVasc*) based on the gluten content of wheat flour.

Rice consumption (*Rice*) ranges from zero to about 785 grams of rice consumed per day per person. Wheat flour consumption (*Wheat*) ranges from zero to about 751 grams of wheat flour consumed per day per person. These similar ranges lead to different ranges of variation in mortality from vascular diseases (*MVasc*); with a range from 2.48 to 2.96 associated with rice consumption (*Rice*), and a range from 2.44 to 3.85 associated with wheat flour consumption (*Wheat*). These different ranges are reflected in the strength of the associations with mortality from vascular diseases (*MVasc*); wheat flour consumption (*Wheat*) was more strongly associated with mortality from vascular diseases (*MVasc*) than rice consumption (*Rice*).

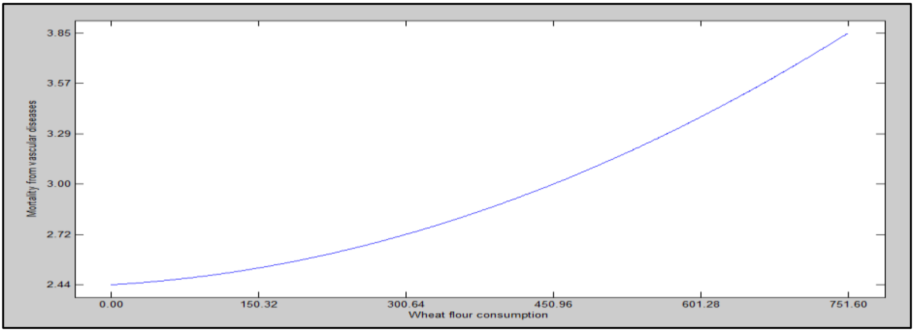

Figure 4: Mortality from vascular diseases and wheat flour consumption. Notes: Horizontal (X) axis values are grams of rice consumed per day per person, averaged for each county; vertical (Y) axis values are deaths from all vascular diseases within ages 35–69 per 1,000 people, averaged for each county.

Wheat and Culture

The results of our analyses strongly suggest that wheat flour consumption appears to be significantly associated with vascular diseases, but so far the answer to our original research question has been elusive: *Why does wheat flour consumption appear to be significantly associated with vascular diseases?* Biochemical explanations, such as acute insulin responses, have proven to be less than satisfactory. In this section, we put forth the notion that wheat consumption may be a marker of cultural elements that increase the prevalence of vascular diseases.

In Asian countries, the move from rice to wheat flour consumption has historically paralleled a move from more traditional and rural to more modern and urban lifestyles (Liu & Li, 2000; Matsuzaki, 1992; Pingali, 2007). This is essentially a cultural move, with impacts on lifestyle variables such as physical activity, exposure to sunlight, and consumption of processed foods. Compared with modern urban life, traditional rural life generally incorporates greater levels of physical activity, greater exposure to sunlight, and lower consumption of processed foods.

Greater levels of physical activity are strongly associated with decreased mortality from vascular diseases (Blair et al., 1996; Thompson et al., 2003). Greater exposure to sunlight leads to greater levels of circulating vitamin D, which is associated with lower prevalence of vascular diseases (Holick, 2004; Wang et al., 2008). Lower consumption of processed foods, and their replacement with unprocessed or minimally processed foods such as fruits and vegetables, is also associated with lower prevalence of vascular diseases (Bazzano et al., 2002).

When we make the reasonable assumptions that rice consumption (*Rice*) and wheat flour consumption (*Wheat*) are respectively correlated with rice and wheat farming, another cultural change paralleling the move from rice to wheat flour consumption is increased social isolation (Talhelm et al., 2014). There is conclusive evidence that social isolation is a significant cause of vascular diseases (Rozanski et al., 1999). The link between vascular diseases and social isolation seems to be mediated by chronic mental stress (Mallon et al., 2002).

Talhelm et al. (2014) studied 1162 Han Chinese participants in six sites. Their study suggests that a history of farming rice or wheat leads to differences in the levels of social isolation found in different cultures. The authors found evidence that farming rice makes cultures more interdependent, leading to lower levels of social isolation; whereas farming wheat makes cultures more independent, promoting greater levels of social isolation. The study, consistently with reviews of it (Henrich, 2014), concludes that these agricultural legacies extend to other parts of the modern world.

The above discussion provides the basis on which we can provide a counterintuitive answer our original research question: *Why does wheat flour consumption appear to be significantly associated with vascular diseases?* In China, the reason may be what could be called a "wheat culture," characterized by increased consumption of wheat flour and a set of correlated culturally-induced factors including decreased levels of physical activity, decreased exposure to sunlight, increased consumption of processed foods, and increased social isolation. We do not believe that there is enough evidence to unequivocally point to consumption of wheat flour *per se* as the problem. The problem appears to lie in the set of correlated culturally-induced factors, which occur together with wheat flour consumption and which appear to be health-detrimental.

Limitations and Alternative Explanations

Like any empirical research study, ours may be biased by omitted confounders. That is, it is possible that the relationships we uncovered among rice consumption (*Rice*), wheat flour consumption (*Wheat*), total calorie consumption (*Calorie*), and mortality from vascular diseases (*MVasc*) are biased by correlated variables that have not been explicitly included in the model. While we have conducted a number of tests to rule out biases, the problem of omitted confounders is pervasive in epidemiological research. In this type of research, investigators try to create and validate models based on incomplete information.

The possibility of the existence of omitted confounders calls for the consideration of alternative explanations. For example, there is evidence that vascular diseases may be caused, at least in part, by infectious diseases (Fong, 2000; Leinonen & Saikku, 2002). This is partly supported by our analysis of the nonlinear relationship, with a parabolic relationship between rice consumption and vascular diseases. The left side of the parabola shows a pattern of increased mortality from vascular diseases with decreased rice consumption, which may be due to malnutrition negatively affecting resistance against infections and thus promoting vascular diseases.

However, our analyses do not rule out other possible factors. In fact, the existence of a complex interplay of factors would be consistent with past research on the multifaceted and intricate nature of vascular diseases (Fong, 2000). We speculate here that the emergence of a wheat culture in China may be a fundamental causative factor behind an increasing incidence of vascular diseases. Still, one could argue that such a wheat culture would be more urbanized, with better access to treatments against infectious diseases and, thus, should be associated with *less* vascular disease. This underscores the need for more research on the topic, including a possible confounder—incidence of infectious diseases.

Another argument that could be raised against our wheat culture hypothesis is related to wheat flour consumption and gut health. Indeed, as we noted earlier, the primary protein in wheat flour is gluten, which can be detrimental to the health of individuals who suffer from celiac disease (Mora et al., 1993). Although celiac disease appears to be very rare in China compared with other countries (Cummins et al., 2009), and there is scant evidence of gluten-related health problems in individuals who do not suffer from celiac disease (Biesiekierski et al., 2011; Biesiekierski et al., 2013), our findings underscore the need for more research on the topic.

We recommend further research using the general methodological approach we employed here but with more complex models that include additional variables that could have confounded the results of our analyses. Such variables include level of urbanization, level of poverty, incidence of infectious diseases, access to treatments against infectious diseases, and incidence of gut health problems. We also recommend future research addressing the wheat culture hypothesis we put forth in other parts of the world because our hypothesis builds primarily on data from China.

Conclusion

We set out to answer a research question: *Why does wheat flour consumption appear to be significantly associated with vascular diseases?* In order to do so, we analyzed data on rice consumption, wheat flour consumption, total calorie consumption, and mortality from vascular diseases obtained from the China Study II dataset (Junshi et al., 2006). This dataset covers the years of 1983, 1989 and 1993; the data is related to biochemistry, diet, lifestyle, and mortality from various diseases in 69 counties in China.

Our search for an answer to the research question above has led us to investigate biochemical explanations, related to carbohydrate content, glycemic index and load, and total calorie content. We also explored the role of gluten to explain the apparently health-detrimental nature of wheat flour. None of these explanations were found to be fully satisfactory. This was in part due to the similarities in biochemical responses elicited by both wheat flour and rice, and the fact that rice consumption seems to be generally associated with good health in Asian countries.

Wheat flour consumption in China, and perhaps in many other countries, may be accompanied by culturally-induced factors characteristic of a rural-to-urban transition, including: decreased levels of physical activity, decreased exposure to sunlight, increased consumption of processed foods, and increased social isolation. This health-detrimental "wheat culture" is perfectly compatible with the pattern of the association between wheat flour consumption and mortality from vascular diseases that our analyses uncovered. The pattern suggests that any wheat flour consumption is detrimental in terms of vascular diseases, which cannot be reconciled with biochemical evidence.

Our analyses point at a counterintuitive conclusion: it may not be wheat flour consumption that is the problem, but the wheat culture associated with it. In our analyses, wheat flour consumption appears to act as a proxy for the extent to which this wheat culture is expressed in a population. The more this culture is expressed, the greater is the prevalence of vascular diseases.

References

Apovian, C. M., & Gokce, N. (2012). Obesity and cardiovascular disease. *Circulation*, 125(9), 1178–1182. doi: 10.1161/CIRCULATIONAHA.111.022541

Barclay, A. W., Petocz, P., McMillan-Price, J., Flood, V. M., Prvan, T., Mitchell, P., & Brand-Miller, J. C. (2008). Glycemic index, glycemic load, and chronic disease risk—a meta-analysis of observational studies. *The American Journal of Clinical Nutrition*, 87(3), 627–637.

Bazzano, L. A., He, J., Ogden, L. G., Loria, C. M., Vupputuri, S., Myers, L., & Whelton, P. K. (2002). Fruit and vegetable intake and risk of cardiovascular disease in US adults: the first National Health and Nutrition Examination Survey Epidemiologic Follow-up Study. *The American Journal of Clinical Nutrition*, 76(1), 93–99.

Bera, A.K., & Jarque, C.M. (1981). Efficient tests for normality, homoscedasticity and serial independence of regression residuals: Monte Carlo evidence. *Economics Letters*, 7(4), 313–318. doi:10.1016/0165-1765(81)90035-5

Biesiekierski, J. R., Newnham, E. D., Irving, P. M., Barrett, J. S., Haines, M., Doecke, J. D., ... & Gibson, P. R. (2011). Gluten causes gastrointestinal symptoms in subjects without celiac disease: A double-blind randomized placebocontrolled trial. *The American Journal of Gastroenterology*, 106(3), 508–514. doi: 10.1038/ajg.2010.487

Biesiekierski, J. R., Peters, S. L., Newnham, E. D., Rosella, O., Muir, J. G., & Gibson, P. R. (2013). No effects of gluten in patients with self-reported non-celiac gluten sensitivity after dietary reduction of fermentable, poorly absorbed, short-chain carbohydrates. *Gastroenterology*, 145(2), 320–328. doi: 10.1053/j.gastro.2013.04.051

Blair, S. N., Kampert, J. B., Kohl, H. W., Barlow, C. E., Macera, C. A., Paffenbarger, R. S., & Gibbons, L. W. (1996). Influences of cardiorespiratory fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. *The Journal of the American Medical Association*, 276(3), 205–210.

Braitman, L. E., Adlin, E. V., & Stanton, J. L. (1985). Obesity and caloric intake: the National Health and Nutrition Examination Survey of 1971–1975 (HANES I). *Journal of Chronic Diseases*, 38(9), 727–732. doi: 10.1016/0021-9681(85)90114-6

Campbell, T. C., & Campbell, T. M. (2005). *The China Study*. Dallas, TX: BenBella Books.

Campbell, W. W., Crim, M. C., Dallal, G. E., Young, V. R., & Evans, W. J. (1994). Increased protein requirements in elderly people: new data and retrospective reassessments. *The American Journal of Clinical Nutrition*, 60(4), 501–509.

Cordain, L., Eades, M. R., & Eades, M. D. (2003). Hyperinsulinemic diseases of civilization: more than just Syndrome X. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 136(1), 95–112. doi: 10.1016/S1095-6433(03)00011-4

Cummins, A. G., & Roberts-Thomson, I. C. (2009). Prevalence of celiac disease in the Asia–Pacific region. *Journal of Gastroenterology and Hepatology*, 24(8), 1347–1351. doi: 10.1111/j.1440-1746.2009.05932.x

Cutler, D. M., Glaeser, E. L., & Shapiro, J. M. (2003). Why have Americans become more obese? *Journal of Economic Perspectives*, 17(3), 93–118. doi: 10.2139/ssrn.373121

Davis, W. (2011). *Wheat Belly*. Emmaus, PA: Rodale.

DeFronzo, R. A., & Ferrannini, E. (1991). Insulin resistance: A multifaceted syndrome responsible for NIDDM, obesity, hypertension, dyslipidemia, and atherosclerotic cardiovascular disease. *Diabetes Care*, 14(3), 173–194. doi: 10.2337/diacare.14.3.173

Dimsdale, J. E. (2008). Psychological stress and cardiovascular disease. *Journal of the American College of Cardiology*, 51(13), 1237–1246. doi: 10.1016/j.jacc.2007.12.024

Fong, I.W. (2000). Emerging relations between infectious diseases and coronary artery disease and atherosclerosis. *Canadian Medical Association Journal*, 163(1), 49–56.

Galal, O. M. (2002). The nutrition transition in Egypt: Obesity, undernutrition and the food consumption context. *Public Health Nutrition*, 5(1a), 141–148.

Geisser, S. (1974). A predictive approach to the random effects model. *Biometrika*, 61(1), 101–107. doi:10.1093/biomet/61.1.101

Gel, Y.R., & Gastwirth, J.L. (2008). A robust modification of the Jarque–Bera test of normality. *Economics Letters*, 99(1), 30–32. doi: 10.1016/j.econlet.2007.05. 022

Harris, K. A., & Kris-Etherton, P. M. (2010). Effects of whole grains on coronary heart disease risk. *Current Atherosclerosis Reports*, 12(6), 368–376. doi: 10.1007/s11883-010-0136-1.

He, J., Gu, D., Wu, X., Reynolds, K., Duan, X., Yao, C., ... & Whelton, P. K. (2005). Major causes of death among men and women in China. *New England Journal of Medicine*, 353(11), 1124–1134. doi: 10.1056/NEJMsa050467

Henrich, J. (2014). Rice, psychology, and innovation. *Science*, 344(6184), 593–594. doi: 10.1126/science.1253815

Holick, M. F. (2004). Sunlight and vitamin D for bone health and prevention of autoimmune diseases, cancers, and cardiovascular disease. *The American Journal of Clinical Nutrition*, 80(6), 1678S–1688S.

Jarque, C.M., & Bera, A.K. (1980). Efficient tests for normality, homoscedasticity and serial independence of regression residuals. *Economics Letters*, 6(3), 255–259. doi: 10.1016/0165-1765(80)90024-5

Johansson, S. R. (1994). Food for thought: Rhetoric and reality in modern mortality history. *Historical Methods*, 27(3), 101–125. doi: 10.1080/01615440.1994.10594227

Johnson, J. V., Hall, E. M., & Theorell, T. (1989). Combined effects of job strain and social isolation on cardiovascular disease morbidity and mortality in a random sample of the Swedish male working population. *Scandinavian Journal of Work, Environment & Health*, 15(4), 271–279. doi: 10.5271/sjweh.1852

Junshi, C., Boqi, L., Wenharn, P., Campbell, C., and Peto, R. (2006). *Geographic study of mortality, biochemistry, diet and lifestyle in rural China*. Oxford, England: Oxford University.

Kock, N. (2010). Using WarpPLS in e-collaboration studies: An overview of five main analysis steps. *International Journal of e-Collaboration*, 6(4), 1–11. doi: 10.4018/jec.2010100101

Kock, N. (2011). Using WarpPLS in e-collaboration studies: Descriptive statistics, settings, and key analysis results. *International Journal of e-Collaboration*, 7(2): 1–18. doi: 10.4018/jec.2011040101

Kock, N. (2014). *Single missing data imputation in PLS-SEM*. Laredo, TX: ScriptWarp Systems.

Kock, N. (2015). *WarpPLS 5.0 User Manual*. Laredo, TX: ScriptWarp Systems.

Kock, N., & Gaskins, L. (2014). The mediating role of voice and accountability in the relationship between Internet diffusion and government corruption in Latin America and Sub-Saharan Africa. *Information Technology for Development*, 20(1), 23–43. doi: 10.1080/02681102.2013.832129

Kock, N., & Lynn, G.S. (2012). Lateral collinearity and misleading results in variance-based SEM: An illustration and recommendations. *Journal of the Association for Information Systems*, 13(7), 546–580.

Leinonen, M., & Saikku, P. (2002). Evidence for infectious agents in cardiovascular disease and atherosclerosis. *The Lancet Infectious Diseases*, 2(1), 11–17. doi: 10.1016/s1473-3099(01)00168-2

Liu, X. Q., & Li, Y. H. (2000). Epidemiological and nutritional research on prevention of cardiovascular disease in China. *British Journal of Nutrition*, 84(S2), S199–S203. doi: 10.1079/096582197388699

Ludwig, D. S. (2002). The glycemic index: Physiological mechanisms relating to obesity, diabetes, and cardiovascular disease. *The Journal of the American Medical Association*, 287(18), 2414–2423. doi: 10.1001/jama.287.18.2414

Mallon, L., Broman, J. E., & Hetta, J. (2002). Sleep complaints predict coronary artery disease mortality in males: a 12-year follow-up study of a middle-aged Swedish population. *Journal of Internal Medicine*, 251(3), 207–216. doi: 10.1046/j.1365-2796.2002.00941.x

Matsuzaki, T. (1992). Longevity, diet, and nutrition in Japan: Epidemiological studies. *Nutrition Reviews*, 50(12), 355–359. doi: 10.1111/j.1753-4887.1992.tb02479.x

Mendis, S., Puska, P., & Norrving, B. (2011). *Global atlas on cardiovascular disease prevention and control*. Geneva, Switzerland: World Health Organization.

Mora, S., Weber, G., Barera, G., Bellini, A., Pasolini, D., Prinster, C., ... & Chiumello, G. (1993). Effect of gluten-free diet on bone mineral content in growing patients with celiac disease. *The American Journal of Clinical Nutrition*, 57(2), 224–228.

O'Sullivan, T. A., Hafekost, K., Mitrou, F., & Lawrence, D. (2013). Food sources of saturated fat and the association with mortality: A meta-analysis. *American Journal of Public Health*, 103(9), e31–e42. doi: 10.2105/ajph.2013.301492

Pingali, P. (2007). Westernization of Asian diets and the transformation of food systems: implications for research and policy. *Food Policy*, 32(3), 281–298. doi: j.foodpol.2006.08.001

Poirier, P., & Eckel, R. H. (2002). Obesity and cardiovascular disease. *Current Atherosclerosis Reports*, 4(6), 448–453. doi: 10.1007/s11883-002-0049-8

Rexrode, K. M., Manson, J. E., & Hennekens, C. H. (1996). Obesity and cardiovascular disease. *Current Opinion in Cardiology*, 11(5), 490–495. doi: 10.1097/00001573-199609000-00007

Rosenheck, R. (2008). Fast food consumption and increased caloric intake: a systematic review of a trajectory towards weight gain and obesity risk. *Obesity Reviews*, 9(6), 535–547. doi: 10.1111/j.1467-789x.2008.00477.x

Rozanski, A., Blumenthal, J. A., & Kaplan, J. (1999). Impact of psychological factors on the pathogenesis of cardiovascular disease and implications for therapy. *Circulation*, 99(16), 2192–2217. doi: 10.1161/01.cir.99.16.2192

Selhub, J., Jacques, P. F., Wilson, P. W., Rush, D., & Rosenberg, I. H. (1993). Vitamin status and intake as primary determinants of homocysteinemia in an elderly population. *The Journal of the American Medical Association*, 270(22), 2693–2698. doi: 10.1001/jama.270.22.2693

Singh, S. (2009). Global food crisis: magnitude, causes and policy measures. *International Journal of Social Economics*, 36(1/2), 23–36. doi: 10.1108/03068290910921163

Smith, C. E., & Tucker, K. L. (2011). Health benefits of cereal fibre: A review of clinical trials. Nutrition Research reviews, 24(01), 118–131. doi: 10.1017/s0954422411000023

Sonnenblick, M., Friedlander, Y., & Rosin, A. J. (1993). Diuretic-induced severe hyponatremia. Review and analysis of 129 reported patients. *CHEST Journal*, 103(2), 601–606. doi: 10.1378/chest.103.2.601

Sowers, J. R. (1998). Obesity and cardiovascular disease. *Clinical Chemistry*, 44(8), 1821–1825. doi: 10.1515/hmbci-2013-0025

Stone, M. (1974). Cross-validatory choice and assessment of statistical predictions. *Journal of the Royal Statistical Society, Series B*, 36(1), 111–147.

Talhelm, T., Zhang, X., Oishi, S., Shimin, C., Duan, D., Lan, X., & Kitayama, S. (2014). Large-scale psychological differences within China explained by rice versus wheat agriculture. *Science*, 344(6184), 603–60. doi: 10.1126/science.1246850

Taubes, G. (2008). *Good calories, bad calories*. New York, NY: Anchor Books.

Thompson, B. (2004). *Exploratory and confirmatory factor analysis: Understanding concepts and applications*. Washington, DC: American Psychological Association.

Thompson, P. D., Buchner, D., Piña, I. L., Balady, G. J., Williams, M. A., Marcus, B. H., ... & Wenger, N. K. (2003). Exercise and physical activity in the prevention and treatment of atherosclerotic cardiovascular disease: A statement from the Council on Clinical Cardiology (Subcommittee on Exercise, Rehabilitation, and Prevention) and the Council on Nutrition, Physical Activity, and Metabolism

(Subcommittee on Physical Activity). *Circulation*, 107(24), 3109–3116. doi: 10.1161/01.cir.0000075572.40158.77

USDA (2015, June 28). *USDA National Nutrient Database for Standard Reference*. Retrieved from http://ndb.nal.usda.gov

Van Gaal, L. F., Mertens, I. L., & Christophe, E. (2006). Mechanisms linking obesity with cardiovascular disease. *Nature*, 444(7121), 875–880. doi: 10.1038/nature05487

Wang, T. J., Pencina, M. J., Booth, S. L., Jacques, P. F., Ingelsson, E., Lanier, K., ... & Vasan, R. S. (2008). Vitamin D deficiency and risk of cardiovascular disease. *Circulation*, 117(4), 503–511. doi: 10.1161/circulationaha.107.706127

Waxman, M., & Stunkard, A. J. (1980). Caloric intake and expenditure of obese boys. *The Journal of Pediatrics*, 96(2), 187–193. doi: 10.1016/s0022-3476(80)80800-6

Wright, S. (1934). The method of path coefficients. *The Annals of Mathematical Statistics*, 5(3), 161–215. doi: 10.1214/aoms/1177732676

Young, V. R., Taylor, Y. S., Rand, W. M., & Scrimshaw, N. S. (1973). Protein requirements of man: efficiency of egg protein utilization at maintenance and sub-maintenance levels in young men. *The Journal of Nutrition*, 103(8), 1164–1174.

Appendix A: The China Study II dataset

The China Study II dataset contains data for the years of 1983, 1989 and 1993 related to biochemistry, diet, lifestyle and mortality from various diseases in 69 counties in China (Junshi et al., 2006). The research was conducted in those 69 counties because they comprised genetically similar populations that tended, over generations, to live and eat in the same general ways and in the same locations.

This dataset is referred to as related to "The China Study II" to differentiate it from a previous, more limited dataset, with results summarized in a book titled "The China Study" (Campbell & Campbell, 2005). The investigation leading to the China Study II dataset has also been referred to as "The China–Cornell–Oxford Project". The dataset has been compiled through extensive field research in a project whose principal investigators and respective affiliations were: Chen Junshi, Chinese Academy of Preventive Medicine; Liu Boqi, Chinese Academy of Medical Sciences; Pan Wenharn, Academia Sinica; Colin Campbell, Cornell University; and Richard Peto, University of Oxford.

As part of the study, a total of 8,000 adults have been interviewed at length, as well as provided blood and urine samples. Additionally, a three-day weighed dietary survey was performed twice, allowing reproducibility of results to be assessed and deemed appropriate. The mean values for several hundred descriptive variables have been compiled for each county. We used four of those variables in our analyses. Table A.1 shows the names of the variables used in our analyses, the corresponding variable codes in the China Study II dataset, and a description of the variables.

Table A.1: Variables used in the analyses

Variable	Code	Description
Rice	D037	Grams of rice consumed per day per person
Wheat	D038	Grams of wheat flour consumed per day per person
Calorie	D001	Total calories consumed per day per person
MVasc	M059	Mortality from all vascular diseases within ages 35-69 per 1,000 people

Note: Code = variable code in the China Study II dataset.

The authors of the China Study II presented as the chief purpose of their data compilation to describe the wide range of differences among different counties in lifestyles and disease-specific mortality rates in China (Junshi et al., 2006). They

Corresponding author's e-mail: nedkock@tamiu.edu

Citation: Kock, Ned. 2015. Wheat flour versus rice consumption and vascular diseases: Evidence from the China Study II data. *Cliodynamics* 6(2): 130–146.

noted that the real importance of their study was purely descriptive, providing a better appreciation of the extraordinarily wide range of lifestyles and of disease rates across different Chinese counties, which they expected would lead to more specific studies. Our study can be seen as an instance of more specific studies that can be conducted based on the China Study II dataset.

Appendix B: Model and data validation results

The following WarpPLS software settings were used. The missing data imputation algorithm used was "Multiple Regression Imputation", which has been found to be the best performer in situations, like ours, where measurement error is not explicitly modeled (Kock, 2014; 2015). The outer model analysis algorithm selected was "Robust Path Analysis". The default inner model analysis algorithm selected was "Warp2 Basic", which identifies noncyclical nonlinear relationships (e.g., U curves and sections of such curves) and adjusts variable scores accordingly (Kock, 2010). This nonlinear algorithm has been designed to minimize Simpson's paradox instances (Kock, 2015). No other inner model analysis algorithms were used. The resampling method used in the analysis was "Stable3", a nonparametric P value calculation method.

Variance inflation factors (VIFs) and stone-Geisser Q^2 coefficients are reported in Table B.1. The VIFs have been calculated simultaneously for all variables, based on a full collinearity test (Kock & Lynn, 2012). This is a test that enables the simultaneous identification of both vertical and lateral collinearity. The Stone-Geisser Q^2 coefficients (Geisser, 1974; Stone, 1974) are provided for each of the two endogenous variables in the model, and are used for predictive validity assessment (Kock, 2015).

Table B.1: Full collinearity VIFs and Q^2 coefficients

Variable	VIF	Q^2
Rice	3.694	-
Wheat	3.870	-
Calorie	1.361	.130
MVasc	1.276	.239

Notes: VIF = variance inflation factor; Q^2 = predictive validity coefficients.

The absence of VIFs greater than 5 is an indication that our path model is free of multicollinearity (Kock 2015; Kock & Lynn, 2012). We use here the threshold of 5 for VIFs because in our model all of the variables were measured through one single indicator. If the variables had been measured through multiple indicators, we could have used a lower threshold, possibly 3.3 (Kock & Lynn, 2012).

The absence of negative Q^2 coefficients is an indication of acceptable predictive validity in connection with all endogenous variables in our model (Geisser, 1974; Stone, 1974; Kock 2015). Testing predictive validity is important in our model because all variables are measured through single indicators. Given this we cannot employ other common validity tests in the context of confirmatory factor analyses (Thompson, 2004), such as convergent and discriminant validity tests.

Model fit and quality indices can help researchers establish the degree of fit between model and data, as well as the degree of model-wide collinearity, in path models (Kock, 2011). Table B.2 lists six fit and quality indices (Kock, 2011; Kock, 2015) related to our model: average path coefficient (APC), average R^2 (ARS), average adjusted R^2 (AARS), average block variance inflation factor (AVIF), average full collinearity VIF (AFVIF), and Tenenhaus GoF (GoF). Significance levels (in the form of P values) are provided for the APC, ARS and AARS indices. Interpretation criteria are provided for the AVIF, AFVIF and GoF indices.

Table B.2: Model fit and quality indices

Index	Value	Interpretation
Average path coefficient (APC)	.282	P<.001
Average R^2 (ARS)	.341	P<.001
Average adjusted R^2 (AARS)	.337	P<.001
Average block VIF (AVIF)	1.598	Acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)	2.257	Acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)	.584	Small >= .1, medium >= .25, large >= .36

The APC, ARS and AARS indices reached levels whose chance probabilities were lower than one-tenth of a percent, suggesting a good fit between the model and the data. The values of the AVIF and AFVIF indices suggest absence of multicollinearity at the variable block level (AVIF) and in the model as a whole (AFVIF). Finally, the value of the GoF index suggests that the overall goodness-of-fit level between model and data is large.