Department of Economics

Stockholms
universitet

A BEEF WITH GROWTH? AN EMPIRICAL ANALYSIS OF INCOME AND ANIMAL FARMING

Authors: Caroline Olsson & Gustav Alexandrie

Supervisor: Anna Seim

EC6902 Bachelor thesis in Economics

Spring 2019

Abstract

While a number of studies examine the effects of economic growth on consumption of meat and other animal-based protein, little research has been devoted to assessing the relationship between income and the number of animals that are farmed in meat, dairy and egg production. Using panel data from 155 countries during the period 1992–2013, we find that an increase in GDP per capita is associated with a rise in the per capita annual number of life years that are spent by farmed animals in agriculture as a result of animal-based protein consumption. Furthermore, we find that this relationship diminishes as GDP per capita rises and that there might even be a turning point at which the number of farmed animal life years declines with further increases in per capita income. These results are relevant for recent theoretical work aiming to extend welfare economics to include non-human animals.

Contents

1 Introduction

During the second half of the 20th century and onwards, there has been a substantial increase in meat consumption (Sans & Comris, 2015). This raises a number of concerns. First, the livestock sector generates more than 14% of human-induced greenhouse gas emissions, making it an important driver of global warming (Gerber *et al.*, 2013). Second, the high level of meat and saturated fat consumption in high-income countries has severe public health consequences by contributing to chronic diseases such as cardiovascular disease, diabetes mellitus and some cancers (Walker *et al.*, 2005). Third, meat consumption has important implications for farmed animal welfare (Norwood & Lusk, 2011).

While climate change and public health have received considerable attention in the economics literature, issues concerning the welfare of non-human animals (from now on, simply "animals") have often been neglected. Since conventional welfare economics treats social welfare exclusively as a function of individual utilities of human consumers, animals matter in this framework only insofar as humans have a positive willingness to pay for their welfare (Cowen, 2017). However, empirical evidence suggests that consumers have positive willingness to pay for animal welfare in some contexts (Lagerkvist & Hess, 2010). Moreover, recent work has explored ways of generalizing welfare economics to directly account for the welfare of animals (e.g. Eichner & Pethig, 2006; Johansson-Stenman, 2018; Lusk & Norwood, 2011). Such generalisations are supported both by theoretical arguments in moral philosophy (Singer, 2011) and survey results from several countries suggesting that the majority of people believe that animal welfare should carry intrinsic weight in public decision making (Johansson-Stenman, 2018; Frey & Pirscher, 2018).

A primary motivation behind the present paper is the idea that broadening the scope of economic analysis to incorporate animal welfare may have important implications for the expected social welfare gains from economic development. While economic growth can be viewed as a useful metric of improvements in human welfare (Stevenson & Wolfers, 2013; Jones & Klenow, 2016), it is far less clear that this holds for animal welfare. Growth may well affect the welfare of companion animals as well as animals used in laboratories and for entertainment. However, as Matheny and Leahy (2007) have pointed out, since farmed animals in agriculture outnumber other domesticated animals by a wide margin, concerns about animal welfare are numerically reducible to concerns about farmed animal welfare.[1]

In a year, the average American consumes the equivalent of 28.5 broiler chickens, 0.8 layer chickens, 0.37 pigs, 0.1 beef cows and 0.007 dairy cows. Multiplying these numbers by the average lifespan for each type of animal, this implies that the average number of animal life years that go into the diet of an average US consumer are as follows: 3.3 from broiler chickens, 1 from layer chickens, 0.2 from pigs, 0.1 from beef cows, and 0.03 from dairy cows (MacAskill, 2015). In what follows, we use the term *farmed animal life years (FALYs) per capita* to refer to the sum of animal life years going into an average yearly diet.

The aim of this paper is to assess the relationship between GDP per capita and the number of FALYs per capita. Using panel data from 155 countries during the period 1992–2013, we find that an increase in per capita income is associated with a rise in the per capita annual number of farmed animal life years spent in agriculture as a results of animal-based protein consumption. Furthermore, we find that this relationship diminishes as income rises and that there might even be a turning point at which the number of farmed animal life years declines with per capita income. While far from a complete welfare analysis, these findings suggest that economic growth may carry significant externalities in terms of farmed animal welfare.

The paper is organized as follows. Section 2 contains an overview of the previous literature on the relationship between per capita income and meat consumption. In Section 3, our dataset and regression models are described. Section 4 presents the results from the empirical analysis. In Section 5, we discuss limitation of the findings as well as their implications for farmed animal welfare. Section 6 provides a summary of the findings and suggestions for future research.

2 Previous literature

Global consumption of meat and dairy products has approximately doubled since the 1960s (Sans & Comris, 2015), with consumption of some types of meat, such as beef and mutton, trippleing (York & Gossard, 2004). Similarly, there has been an increase in the consumption of eggs (Kearney, 2010). The empirical literature suggests that the main drivers of *aggregate* animal-based protein consumption on a national level are

---

[1] This paper is limited to discussing domesticated animals, in particular terrestrial farmed animals. For an early discussion of the welfare economics of wild animals, see Ng (1995). For more recent discussion, see Cowen (2003) and Tomasik (2015).

population growth, income growth and urbanisation (Delgado, 2003), with average income being the the main determinant of *per capita* animal-based protein consumption (Schroeder *et al.*, 1996).

Several cross-sectional studies examine the relationship between per capita income and consumption of animal-based protein. Using a multiple ordinary-least-squares (OLS) regression framework in a cross-sectional sample of 132 countries, York and Gossard (2003) find significant relationships between per capita income and per capita meat consumption in Africa, the Middle East and Western nations, but not in Asia. They report that an increase in per capita GDP by $1,000 is associated with a statistically significant increase in annual per capita meat consumption by 1.66, 3.99, and 2.67 kilograms for Africa, the Middle East and Western nations, respectively. Likewise, Gerbens-Leenes *et al.* (2010) use a cross-sectional dataset from 2001 containing 57 countries to estimate the relationship between income and the average daily per capita supply of nutritional energy from animal sources as a fraction of overall nutritional energy. They find an income elasticity of 0.52, meaning that a 1% increase in income is associated with a 0.52% increase in the fraction of nutritional energy from animal sources. However, both these studies may suffer from well-known limitations of cross-sectional analysis, including omitted variable bias.

Some authors have suggested that the relationship between income and animal-based protein consumption may take the form of a *Kuznets curve*, that is, an inverted U-shaped quadratic relationship (Frank, 2007; Cole & McCoskey, 2013; Vranken *et al.*, 2014). This kind of relationship was originally suggested for income and inequality (Kuznets, 1955), but was later extended to environmental economics as a model for the association between income and various indicators of environmental degradation (see Dinda, 2004; for an overview).

In a comprehensive overview, Frank (2007) examines the possible existence of an animal welfare Kuznets curve more broadly, and, more specifically, a Kuznets curve for meat consumption. Frank (2007) suggests a number of theoretical reasons to expect a turning point at which further increases in per capita income reduces meat consumption. For instance, high income levels may allow for more investment in technologies that may reduce meat consumption, such as meat substitutes. Likewise, altruistic concern for animal welfare may be a luxary good, in which case increases in income may reduce meat consumption (given that meat consumption is perceived as negative for animal welfare). However, Frank (2007) finds little empirical support for the existence of a Kuznets curve for meat consumption in the US. On the contrary, the author's survey of the literature concludes that, within the US, higher income is associated with larger meat consumption, and that there does not seem to be a turning point after which demand declines as income rises. Nonetheless, Frank (2007) cites some survey-based studies that show evidence of a positive relationship between income and concern for animal welfare, which suggests a possible mechanism, at the individual level, for a Kuznets curve relationship between income and meat consumption.

Cole and McCoskey (2013) and Vranken *et al.* (2014) use quantitative methodologies to look into the question of a Kuznets curve for meat consumption and income on the country level. They both find evidence in favor of such a curve. However, as the authors of one of the studies point out, the income level required to reach the turning point is "large enough that for many countries this deceleration will not be reached in the foreseeable future" (Cole & McCoskey, 2013). Cole and McCoskey (2013) use panel data for the period 1980–2009 to fit a quadratic model to test for the presence of a Kuznets curve and estimate a potential turning point (i.e. the inflection point of the quadratic function). The model is first estimated in a cross-sectional analysis of a subsample with year 2009 only, fitting a bivariate regression model, and then extended to a panel data analysis of the whole sample, fitting a multiple regression model with a time trend and two additional independent variables (land area and urbanisation). For the bivariate model, they report support for a Kuznets curve relationship, with an estimated turning point at $50,563 (2011 US$ PPP).[2] The multiple regression model also supports the Kuznets curve relationship, with an estimated turning point at $41,895 (2011 US$ PPP). Similarly, Vranken *et al.* (2014) use panel data for the period 1970–2007 to fit a polynomial model, controlling for fixed effects and the effects of culture, geographical area and trade. The resulting turning point for their empirically supported Kuznets curve is estimated to be between $40,312 and $61,043 (2011 US$ PPP).

The relationship between per capita income and the number of farmed animal *life years* spent in agriculture cannot be straightforwardly inferred from the relationship between per capita income and the per capita *amount* of meat consumption. This is due to the fact that increased per capita income may not only change the total amount of meat consumption, but also cause consumers to substitute different kinds of meat.

---

[2] Both Cole and McCoskey (2013) and Vranken *et al.* (2014) originally express their results in 2005 US$ PPP. However, in the present paper, their results are expressed in 2011 US$ PPP to be more comparable with our findings.

For instance, if growth would cause consumers to substitute meat from smaller animals with meat from larger animals, fewer animals need to be raised for a given amount of meat. Whether such substitution occurs depends on the income elasticities for different types of meat. The most comprehensive study of income elasticities for meat is the meta-analysis by Gallet (2010), which combines 393 studies and 3,357 observations. Using panel data meta-regression models, the study reports an average income elasticity of 0.9 for meat in general. For individual types of meat, the meta-analysis finds elasticities of 0.74 for lamb, 0.80 for pork, 0.82 for poultry and 1.00 for beef, although the difference between the estimate for beef and the estimate for meat in general is not statistically significant. However, given the heterogeneous nature of income elasticities for meat (Zhou, 2017), these numbers should be interpreted with caution (see Ioannidis, 2010; for a critical perspective on the over-reliance on meta-analyses).

It should be noted that the income elasticities for meat products seem to vary with per capita income. Using panel data for 32 countries during the period 1975–1990, Schroeder *et al.* (1996) finds that meat products are normal goods or even luxury goods at the lower end of the per capita income distribution, with elasticities ranging from around 1 for pork to over 3 for mutton. As per capita income increases, the income elasticities decline. For mutton, and eventually also for poultry, the income elasticities even become negative at a certain per capita income level, making these products inferior goods.

3 Method

3.1 Data

In contrast to previous studies, we are not estimating the relationship between per capita income and the amount of animal-based protein consumption per capita. Rather, we are estimating the association between income per capita and *farmed animal life years (FALYs) per capita*. The number of FALYs per capita refers to the number of life years of farmed animals that go into the average annual consumption of animal-based protein. In particular, the present study operationalises FALYs per capita in a country i as the number of farmed animal life years required to produce the annual per capita consumption of bovine meat, pigmeat, mutton and goat meat, poultry meat, milk and eggs in i.

To calculate FALYs per capita, we use country-level panel data from the Food and

Agriculture Organization of the United Nations (FAO) on per capita meat consumption in 155 countries between 1992–2013 (FAO, 2019). To avoid problems associated with the disintegration of the Soviet Union and Yugoslavia into new states, only data from 1992 and onwards are used. Similarly, we remove data on Sudan (to avoid problems associated with the creation of South Sudan in 2011) and Belgium and Luxembourg (since these countries had joint meat consumption data until year 2000). Since the Czech Republic and Slovakia did not gain independence until 1993, these countries lack observations for 1992.

The variables in the FAO dataset include per capita consumption of bovine meat, pigmeat, mutton and goat meat, poultry meat, milk and eggs. For each of these variables, we convert the quantity of consumption per capita to the corresponding number of FALYs per capita required to produce that quantity. This is done using the conversion scheme in Matheny and Leahy (2007) for one reference year and then adjusting for average yearly changes in meat, milk and egg per animal using data from the U.S. Department of Agriculture (USDA, 2019a; 2019b; 1995–2019). Since Matheny and Leahy (2007) do not provide any conversion scheme for mutton and goat, we carry out this conversion by combining estimates of the ratio of lamb meat to live weights (Raines, n.d.) and of the average lifespan of farmed lamb (Farm Sanctuary, 2019). Each of these conversions from quantity to the corresponding number of FALYs assumes that the average lifespan of animals has not shifted substantially over time. This assumption is true for broiler chickens (National Chicken Council, 2019), which are the source of more than 90% of all poultry meat (FAO, 2019). However, we lack access to such data for other farmed animal species.[3]

For per capita income, we use panel data from Penn World Table on expenditure-side real GDP per capita at chained PPPs in 2011 US$ (Feenstra *et al.*, 2015). For control variables, we use World Bank data on trade, operationalised as the sum of exports and imports as a share of GDP (World Bank, 2019), and data from the United Nations on urbanisation, operationalised as the percentage of population residing in urban areas (UN, 2018). Both urbanisation and trade have been used as controls in the previous literature on the relationship between per capita income and meat consumption (Cole & McCoskey, 2013; Vranken *et al.*, 2014). A rationale for controlling for urbanisation is that there exists evidence suggesting that it may be a driver of both

---

[3] Even if it turned out that this assumption does not hold for other species, it seems unlikely that this would cause any substantial biases in our results given that broiler chicken life years constitute more than 70% of all FALYs (see Table 1 below).

food consumption patterns (Rae, 1998; Sans & Combris, 2015) and economic growth (Shabu, 2010). Similarly, trade may (apart from its effect on GDP) have an impact on food consumption patterns by allowing for the consumption of imported food.

There are some missing data in most of these datasets. First, the FAO dataset lacks data on pigmeat consumption in Kuwait, Saudi Arabia and the United Arab Emirates. However, these are countries where Islam is the state religion. Given Islamic restrictions on pork consumption and the fact that pigmeat consumption equals 0 in some other Islamic countries in the dataset, these missing values were coded as 0. Second, some countries, notably Afghanistan and North Korea, are missing from the GDP statistics in Penn World Table. However, omitting these countries is unlikely to lead to serious distortions given that they account for less than 5% of the world population (Feenstra *et al.*, 2013). Similarly, the observations that are missing from the trade data are mostly from small countries (World Bank, 2019).

Summary statistics are shown in Table 1. The table indicates that poultry consumption accounts for more than 70% of the total number of terrestrial FALYs per capita. This is not due to a much greater consumption of poultry (in terms of kilograms) compared to other types of meat. Rather, the fact that poultry birds are small compared to other farmed animal species means that more poultry life years are required to produce a given quantity of meat. For instance, while poultry make up only 36% of the weight of meat products produced in the US, it accounts for as much as 98.5% of the total number of animals that are slaughtered in the country (Frank, 2007). A consequence of this is that changes in FALYs per capita are likely to be heavily driven by changes in poultry consumption.

Table 1: Summary statistics

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
GDP per capita (in 1,000US$)	3,408	13.416	15.249	0.142	2.495	18.982	128.000
Urbanisation	3,408	55.774	22.182	6.288	37.900	73.396	100.000
Trade	3,185	81.200	42.562	0.021	52.928	100.497	442.620
FALYs per capita	3,408	2.202	1.696	0.061	0.605	3.280	9.390
Beef cows (life years/capita)	3,408	0.117	0.098	0.002	0.048	0.168	0.694
Pigs (life years/capita)	3,408	0.109	0.132	0.000	0.008	0.173	0.637
Sheep & goats (life years/capita)	3,408	0.030	0.052	0.000	0.005	0.033	0.490
Poultry (life years/capita)	3,408	1.581	1.451	0.001	0.357	2.382	8.239
Dairy cows (life years/capita)	3,408	0.024	0.020	0.0004	0.007	0.036	0.098
Layer chickens (life years/capita)	3,408	0.340	0.262	0.001	0.095	0.539	1.132

3.2 Empirical model

As described in Section 2, it has been suggested that the relationship between income and meat consumption takes the form of a Kuznets curve (Vranken *et al.*, 2014; Cole & McCoskey, 2013). This indicates that there may also be a Kuznets curve relationship between income and FALYs per capita. Following the literature on environmental Kuznets curves (e.g. Moosa, 2017), we capture such a relationship by estimating a quadratic regression model:

$$FALYc_{it} = \alpha_i + \gamma_t + \beta_1 GDPc_{it} + \beta_2 (GDPc_{it})^2 + \sum_{j=1}^{2} \beta_{2+j} X_{ijt} + \varepsilon_{it}, \tag{1}$$

where $FALYc_{it}$ denotes the annual number of FALYs per capita resulting from animal-based protein consumption in country i at time t. $GDPc_{it}$ denotes the real GDP per capita in country i at time t (chained PPPs in thousands of 2011 US\$) and $X_{ijt} \in [Urbanisation_{it}, Trade_{it}]$ denotes control variable j for country i at time t. As described in Section 3.1, urbanisation is operationalised as the percentage of population residing in urban areas whereas trade is operationalised as the sum of export and import as a share of GDP. Country fixed effects α_i are used to control for omitted variables that vary across countries but are constant over time and year fixed effects γ_t are used to control for omitted variables that are constant across countries but vary over time. We also run some alternative versions of (1) that omit the country and time specific intercepts: in particular, we run pooled OLS, random effects and first-difference models.

In addition to the quadratic specifications, a linear-log model is estimated:

$$FALYc_{it} = \alpha_i + \gamma_t + \beta_1 log(GDPc_{it}) + \sum_{j=1}^{2} \beta_{1+j} X_{ijt} + \varepsilon_{it}, \tag{2}$$

where $log(\cdot)$ is the natural logarithm. The reasons for running a linear-log model as opposed to a log-log model are twofold. First, while the linear-log model does *not* take the form of a Kuznets curve, it does allow for a diminishing relationship between GDP per capita and FALYs per capita. The existence of such a diminishing relationship is plausible in light of the previous literature reviewed in Section 2 (Cole & McCoskey, 2013; Vranken *et al.*, 2014). Second, the coefficient β_1 in the linear-log model can be straightforwardly interpreted as the additional number of FALYs per capita that are associated with a 1% rise in GDP per capita. From the perspective of animal welfare, this interpretation is more informative than the elasticities that are yielded when interpreting coefficients of log-log models. As with the quadratic model, we also run pooled OLS, random effects and first-difference versions of the linear-log model (hence, in these versions, no country or time specific intercepts are included).

4 Results

4.1 Specification testing

Table 2 reports a number of diagnostic tests, most of which suggest that fixed effects and first-difference models are the most appropriate specifications for our data. First, using the Breusch and Pagan (1980) Lagrange multiplier test[4], we reject the null hypothesis of no country effects, although the null hypothesis of no time effects is not rejected. This indicates that pooled OLS models may suffer from omitted variable bias due to potential correlations between country fixed effects and the error term. Second, using the Hausman test, we reject the null hypothesis that country-specific effects are uncorrelated with the independent variables. Since this implies that random effects models are inconsistent, fixed effects models are preferred. Third, using Wooldridge's (2002, pp. 282–283) serial correlation test, we reject both the null hypothesis of no serial correlation in the original errors, ε_{it}, and the null hypothesis of no serial correlation for the differenced errors, $\Delta\varepsilon_{it} = \varepsilon_{it} - \varepsilon_{it-1}$. Since this entails that both fixed effects and first-difference models suffer from serial correlation, we use clustered standard errors that are heteroscedasticity and autocorrelation consistent (Arellano, 1987). Given that neither the fixed effects nor the first-difference models are clearly superior to the other in terms of serial correlation, both are reported in the main results. As robustness checks, pooled OLS, random effects and time fixed effects versions of both the quadratic and linear-log models are reported in Table 8 in the appendix.

---

[4] To adjust for missing data, we use Baltagi and Li's (1990) version of the Breusch-Pagan test, which extends it to unbalanced panels. One problem with the Breusch-Pagan test (including Baltagi and Li's (1990) version) is that it assumes that that the alternative hypothesis is two-sided despite the fact that the variance components cannot be negative (Baltagi, 2008, p. 65). However, our results are robust to using one-sided alternative hypothesis, as in the tests by Honda (1985) and King and Wu (1997).

Table 2: Diagnostics tests

Test	**Null hypothesis**	**P-values**	
		All control variables	No control variables
Quadratic model (equation (1))			
Breusch-Pagan (1980)	$H_0 : \sigma_C^2 = 0$	< 0.001	<0.001
Breusch-Pagan (1980)	$H_0 : \sigma_T^2 = 0$	0.112	0.137
Hausman (1978)	$H_0 : Cov(\alpha_i, x_{it}) = 0$	<0.001	<0.001
Woolridge (2002)	$H_0 : Corr(\epsilon_{it}, \epsilon_{it-1}) = 0$	<0.001	<0.001
Woolridge (2002)	$H_0 : Corr(\Delta\epsilon_{it}, \Delta\epsilon_{it-1}) = 0$	<0.001	<0.001
Linear-log model (equation (2))			
Breusch-Pagan (1980)	$H_0 : \sigma_C^2 = 0$	<0.001	<0.001
Breusch-Pagan (1980)	$H_0 : \sigma_T^2 = 0$	0.894	0.981
Hausman (1978)	$H_0 : Cov(\alpha_i, x_{it}) = 0$	<0.001	<0.001
Woolridge (2002)	$H_0 : Corr(\epsilon_{it}, \epsilon_{it-1}) = 0$	<0.001	<0.001
Woolridge (2002)	$H_0 : Corr(\Delta\epsilon_{it}, \Delta\epsilon_{it-1}) = 0$	<0.001	<0.001

4.2 Main findings

Table 3 reports the main quadratic regression models. In all specifications, the linear coefficient is positive and statistically significant at the 1% level. The quadratic coefficient is negative in all specifications and statistically significant at the 1% level in the country fixed effects models as well as one of the first-difference models, while being significant at the 5% and 10% levels in the remaining specifications. Although the negative quadratic coefficients provide some evidence in favour of a Kuznets curve relationship between per capita income and FALYs per capita, the predicted income turning points are very high. Depending on the specification, the turning points vary between \$66,539 and \$115,544 (2011 US\$ PPP), which correspond to the 98th and 99.8th percentiles in our GDP per capita data for 2013. This suggests that, even if there is a Kuznets curve relationship, the vast majority of countries are far from reaching the income turning point.

Table 3: Main quadratic models

	(1)	(2)	(3)	(4)	(5)	(6)
GDP per capita	0.062^{***}	0.034^{***}	0.046^{***}	0.048^{***}	0.032^{***}	0.042^{***}
	(0.010)	(0.011)	(0.011)	(0.010)	(0.010)	(0.013)
(GDP per capita)^2	-0.0004^{***}	-0.0002^{**}	-0.0003^{***}	-0.0002^{***}	-0.0001^{*}	-0.0003^{**}
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Urbanisation				0.025^{***}	0.009	0.031^{***}
				(0.007)	(0.010)	(0.007)
Trade				-0.001^{*}	-0.002^{**}	-0.0003
				(0.001)	(0.001)	(0.0003)
Country FE	Yes	Yes	No	Yes	Yes	No
Year FE	No	Yes	No	No	Yes	No
First-difference	No	No	Yes	No	No	Yes
R^2	0.174	0.040	0.014	0.204	0.052	0.017
Adjusted R^2	0.135	-0.013	0.013	0.164	-0.004	0.016
F Statistic	21.433	5.206	11.899	15.130	4.628	15.877
(p-value)	(0.000)	(0.006)	(0.000)	(0.000)	(0.001)	(0.000)
Turning point	86,097	98,931	66,539	100,721	115,544	69,576
Observations	3,408	3,408	3,253	3,185	3,185	3,034

Note: *p<0.1; **p<0.05; ***p<0.01

Robust standard errors are clustered at the country level.

Table 4 shows the main linear-log regression models. The coefficients for $log(GDP\ per\ capita)$ are statistically significant at the 1% level in all specifications and vary between 0.309–0.594. This means that a 1% increase in GDP per capita is associated with 112–216 additional days (per capita) spent by terrestrial farmed animals in agriculture as a result of animal-based protein consumption. Furthermore, the highest estimates may be the most credible, since they stem from the country fixed effects models (Column (1) and (4)), which have the best goodness of fit, as measured by R^2 and adjusted R^2.

Table 4: Main linear-log models

	(1)	(2)	(3)	(4)	(5)	(6)
log(GDP per capita)	0.594^{***}	0.429^{***}	0.318^{***}	0.520^{***}	0.388^{***}	0.309^{***}
	(0.080)	(0.104)	(0.051)	(0.095)	(0.101)	(0.054)
Urbanisation				0.013^{*}	-0.001	0.028^{***}
				(0.007)	(0.009)	(0.006)
Trade				-0.001	-0.002^{**}	-0.0001
				(0.001)	(0.001)	(0.0003)
Country FE	Yes	Yes	No	Yes	Yes	No
Year FE	No	Yes	No	No	Yes	No
First-difference	No	No	Yes	No	No	Yes
R^2	0.204	0.060	0.008	0.206	0.059	0.0145
Adjusted R^2	0.167	0.008	0.008	0.166	0.004	0.014
F Statistic	55.095	17.061	39.610	19.278	6.034	21.712
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Observations	3,408	3,408	3,253	3,185	3,185	3,034

Note: *p<0.1; **p<0.05; ***p<0.01

Robust standard errors are clustered at the country level.

Both the quadratic and the linear-log models suggest that the relationship between GDP per capita and FALYs per capita is diminishing as income rises. To assess whether this is the case, it is instructive to compare these models to the linear models reported in Table 5. Comparing Table 5 columnwise with Table 3 and 4 in terms of R^2 and adjusted R^2 reveals that the linear models have a lower goodness of fit. This suggests that the diminishing relationships of the quadratic and linear-log models is a better description of the data.

It still needs to be settled whether the diminishing relationship between GDP per capita and FALYs per capita takes the form of a Kuznets curve (as implied by the quadratic models) or whether it is continuously positive, albeit at a decreasing rate (as implied by the linear-log models). Versions of these two models are plotted in Figure 1. Columnwise comparisons of Table 3 and 4 in terms of R^2 and adjusted R^2 suggest that linear-log models consistently outperform the quadratic models in terms of goodness of fit.

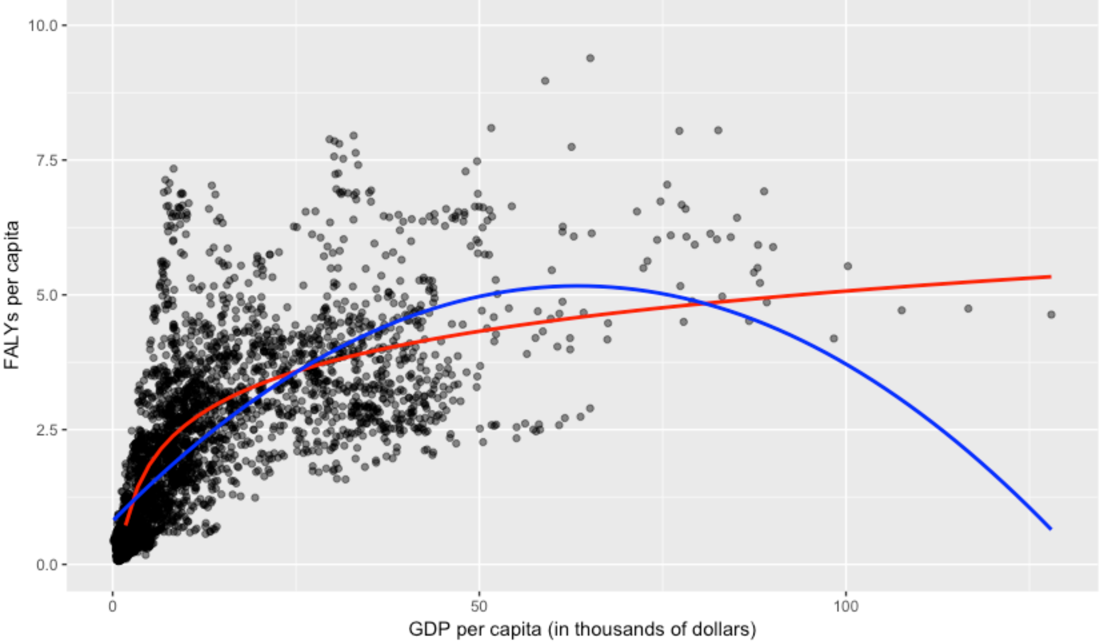
Table 5: Linear models

	(1)	(2)	(3)	(4)	(5)	(6)
GDP per capita	0.030^{***}	0.016^{***}	0.006	0.025^{***}	0.017^{***}	0.009^{*}
	(0.006)	(0.006)	(0.005)	(0.006)	(0.006)	(0.005)
Urbanisation				0.031^{***}	0.009	0.040^{***}
				(0.007)	(0.010)	(0.007)
Trade				-0.001	-0.002^{**}	-0.0001
				(0.001)	(0.001)	(0.0003)
Country FE	Yes	Yes	No	Yes	Yes	No
Year FE	No	Yes	No	No	Yes	No
First-difference	No	No	Yes	No	No	Yes
R^2	0.132	0.031	0.000	0.187	0.046	0.006
Adjusted R^2	0.090	-0.022	0.000	0.146	-0.009	0.005
F Statistic	21.785	7.158	1.851	17.570	4.480	14.796
(p-value)	(0.000)	(0.008)	(0.176)	(0.000)	(0.005)	(0.000)
Observations	3,408	3,408	3,253	3,185	3,185	3,034

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Robust standard errors are clustered at the country level.

While this does not necessarily imply that the linear-log specifications are superior as causal or predictive models, it does suggest that we should be cautious in interpreting the negative quadratic coefficients in the quadratic models as proving the existence of a Kuznets curve. Given that there are so few observations beyond the predicted income turning points, the negative quadratic coefficients might merely reflect the diminishing relationship between GDP per capita and FALYs per capita. At any rate, for countries that are far from the income turning point, the linear-log models are more informative in most situations since their coefficients have a more straightforward interpretation.

Figure 1: Quadratic model (blue) and linear-log model (red)



4.3 Individual farmed animal species

Table 6 presents versions of the linear-log model in which the dependent variable is FALYs per capita *for each individual animal species* (rather than aggregated across all species). The relationship between per capita income and poultry life years is statistically significant and very large in magnitude compared to the coefficients for other animal species. While this relationship is also significant for layer chicken life years and pig life years, the magnitude is much smaller than for poultry. For the remaining animal species, the GDP per capita coefficients are small and non-significant, although some of these coefficients are significant in alternative specifications (see Table 11 and 12 in the appendix). This suggests that our main findings concerning the relationship between per capita income and total FALYs per capita (for all species combined) are driven to a large extent by increases in consumption of poultry, and to some extent by increases in consumption of eggs and pigmeat.

Table 6: Linear-log model with country fixed effects (individual species)

	Dependent variable:					
	FALYs per capita					
	Beef cows	Pigs	Mutton/goats	Poultry	Dairy cows	Layer chickens
	(1)	(2)	(3)	(4)	(5)	(6)
log(GDP per capita)	−0.002	0.017***	−0.0001	0.446***	−0.001	0.060***
	(0.005)	(0.006)	(0.002)	(0.083)	(0.001)	(0.016)
Urbanisation	−0.001	−0.0004	−0.00005	0.014**	−0.0001	0.0004
	(0.001)	(0.001)	(0.0002)	(0.007)	(0.0001)	(0.002)
Trade	−0.0002	−0.00002	−0.0001**	−0.00003	−0.00003**	−0.001***
	(0.0001)	(0.0001)	(0.00003)	(0.001)	(0.00001)	(0.0002)
R^2	0.025	0.0255	0.0129	0.193	0.0465	0.072
Adjusted R^2	-0.0242	-0.0237	-0.0369	0.153	-0.00165	0.0251
F Statistic	2.452	3.612	2.076	19.585	6.325	8.654
(p-value)	(0.066)	(0.015)	(0.106)	(0.000)	(0.000)	(0.000)
Observations	3,185	3,185	3,185	3,185	3,185	3,185

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Robust standard errors are clustered at the country level.

Table 7 reports versions of the quadratic model for individual animal species. As in the linear-log model, the magnitude of the effect is greater for poultry than for other animal species. Interestingly, the linear coefficient in the dairy cow specification is estimated to be negative, suggesting that per capita income may even be associated with a reduction in the number of life years spent by dairy cows in animal agriculture. However, this last result is sensitive to the choice of model specification (see Table 9-12 in the appendix).

Table 7: Quadratic model with country effects (individual species)

	Dependent variable:					
	FALYs per capita					
	Beef cows	Pigs	Mutton/goats	Poultry	Dairy cows	Layer chickens
	(1)	(2)	(3)	(4)	(5)	(6)
GDP per capita	−0.001	0.001	−0.0005	0.046***	−0.0004***	0.003*
	(0.001)	(0.001)	(0.0004)	(0.009)	(0.0001)	(0.002)
(GDP per capita)^2	0.00001	−0.00000	0.00000	−0.0002***	0.00000	−0.00002
	(0.00001)	(0.00001)	(0.00000)	(0.0001)	(0.00000)	(0.00002)
Urbanisation	−0.001	0.0002	0.0001	0.022***	−0.0001	0.003*
	(0.001)	(0.001)	(0.0002)	(0.006)	(0.0001)	(0.001)
Trade	−0.0001	−0.00002	−0.0001*	−0.001	−0.00002*	−0.001***
	(0.0001)	(0.0001)	(0.00003)	(0.001)	(0.00001)	(0.0002)
R^2	0.0292	0.0127	0.0204	0.211	0.106	0.043
Adjusted R^2	-0.0201	-0.0375	-0.0294	0.171	0.0606	-0.00561
F Statistic	1.921	0.813	2.036	14.969	6.748	5.462
(p-value)	(0.110)	(0.519)	(0.092)	(0.000)	(0.000)	(0.000)
Turning point	NA	143,776	NA	99,924	NA	94,747
Observations	3,185	3,185	3,185	3,185	3,185	3,185

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
Robust standard errors are clustered at the country level.

5 Discussion

5.1 Limitations

Our analysis is susceptible to many of the standard problems associated with observational panel data. While country and time fixed effects models can rule out omitted variables that vary across countries but are constant over time as well as omitted variables that are constant across entities but vary over time, there may still be omitted variables that vary both over time and across entities. Since such omitted variables cannot be ruled out, there is no guarantee that the strict exogeneity assumption of fixed effects regression holds. As a result, our regressions do not yield credible causal conclusions.

The lack of causal interpretation does not, however, mean that the estimated relationship between per capita income and FALYs per capita is spurious. In fact, this relationship seems to be highly robust. First, the large number of countries in our sample (155 out of the 195 countries in the world) and a period of more than 20 years lends strength to our estimated relationships. Second, we use clustered standard errors to correct for potential inferences problems stemming from heteroscedasticity and autocorrelation (Arellano, 1987). Third, as can be seen from Figure 1 in Section 4, there does not seem to be any very large outliers that drive the results. Fourth, and most importantly, our main findings are relatively consistent across all specifications.

Another limitation that should be considered is the possibility of measurement errors. The FAO consumption data is based on production data adjusted for exports and imports, and failures to properly adjust for this may lead to measurement errors in the dependent variable. More worryingly, in the absence of international data, we used US data to adjust for changes in animal sizes that have occurred over time. These data are unlikely to be representative for the rest of the world and may lead to biased estimates. In addition, OLS-, fixed effects and first difference models are all known to be sensitive to attenuation bias, or regression dilution, in the presence of measurement errors. If present, the estimator will be biased downward toward zero, but the effect is more pronounced for OLS- or first difference models compared to fixed effects models (Griliches & Hausman, 1986).

5.2 Implications for animal welfare

The findings presented in Section 4 suggest that increases in per capita income are associated with increases in FALYs per capita, at least for the overwhelming majority of countries that have not surpassed the income turning points predicted by the quadratic regression models. Rather than attempting to carry out a complete social welfare analysis of these findings, this section raises some important considerations and challenges associated with carrying out such an analysis.

First, it must be recognized that the social welfare implications of an increased number of FALYs depends on how much weight the social welfare function (SWF) gives to animal welfare in comparison to human welfare (Eichner & Pethig, 2006). As mentioned in the introduction, both theoretical arguments and survey evidence support the view that animals should carry at least some intrinsic weight in public decision making (Johansson-Stenman, 2018). Nevertheless, this perspective is still uncommon in applied economic analyses (for exceptions, see Clarke & Ng, 2006; Norwood & Lusk, 2011).

Second, it should be noted that an increase in FALYs implies a change in the number of individual farmed animals that are brought into existence as opposed to the welfare levels of existing farmed animals (cf. Blackorby & Donaldson, 1992). Analysing the social welfare implications of such a change requires a SWF that ranks states of affairs with different population sizes. While defining such a SWF is associated with a number of problems[5], most economists that have written on the topic favour some type of total or critical-level utilitarian SWF (Ng, 1986; Blackorby *et al.*, 1995). According to such SWFs, social welfare is reduced if individuals (including animals) with net negative welfare are added to the population. Establishing whether the the welfare of farmed animals is positive or negative is therefore crucial to determine how farmed animal welfare is impacted by an increase in the number of FALYs.

Unfortunately, there are no generally agreed upon methods through which animal welfare can be measured with high confidence. The only quantitative estimates of animal welfare in the economics literature are the welfare ratings by Norwood and Lusk (2011). They rate the welfare of different types of farmed animals on a scale from –10 to 10, where negative numbers imply that the animal would be better off not being born. In this rating, some types of farmed animals, such as beef cows, are deemed to

---

[5] In fact, there are impossibility theorems showing that there exists no social welfare function that satisfies a set of compelling axioms in variable population cases (Arrhenius, 2000).

have positive welfare, while others, such as pigs, are deemed to have negative welfare (Norwood & Lusk, 2011, p. 229). However, many authors take a more pessimistic view, arguing that most farmed animals, especially in the US, have net negative welfare (e.g. Matheny & Chan, 2005; Singer, 2011; Sarek *et al.*, 2018).

If these authors are right in their pessimism, and we adopt a total utilitarian SWF that incorporates animal welfare, then the empirical findings presented in Section 4 indicate that economic growth may be associated with significant negative externalities for farmed animal welfare. However, it should be noted that these costs must be weighted against the human welfare gains from higher per capita income (Stevenson & Wolfers, 2013; Jones & Klenow, 2016).

6 Concluding remarks

While previous literature has focused on environmental or public health aspects of meat consumption, issues of animal welfare have often been neglected in economics. In contrast to previous studies examining the relationship between income and meat consumption, the present paper does not focus on the amount of consumed meat, but on the number of additional life years that farmed animals spend in agriculture as a result of increases in meat consumption. As such, the results of this paper could be informative in light of recent work that seeks to extend welfare economics to incorporate animal welfare.

We find that an increase in GDP per capita is associated with a rise in FALYs per capita. Furthermore, we find that this relationship diminishes as income rises and that there might even be a turning point at which the number of per capita farmed animal life years declines with per capita income. Depending on model specification, the estimated income turning points vary between \$66,539 and \$115,544 (2011 US\$ PPP), corresponding to the 98th and 99.8th percentiles of the per capita income distribution for 2013 in our dataset. This is considerably higher than corresponding estimates found in the literature on the relationship between income and meat consumption, which has found turning points between \$40,312 and \$61,043 (Cole & McCoskey, 2013; Vranken *et al.*, 2014). In fact, our estimated turning points are so high that even if there is a Kuznets curve relationship between per capita income and FALYs per capita, it might not be of great practical importance given that few countries are likely to achieve this level of income in the foreseeable future.

The most clear omittance in the present paper is likewise the most readily apparent extension for future research: the expansion of the research question to include fish. Mood and Brooke (2012) estimate that between 37 and 120 billion farmed fish are slaughtered globally each year and the number has been increasing substantially over the years. Farmed fish life years are therefore likely to be a major driver of the changes in the total number of FALYs per capita. The sheer number of animals means it will most likely be influential when assessing the relationship between income and FALYs. Furthermore, the large number also suggests that fish welfare could be an important consideration for an animal welfare.

Although long-term economic growth has great potential for improving human flourishing and well-being (Cowen, 2007), it may also be associated with significant drawbacks such as climate change (Keller, 2004) and technological risks to human life (Jones, 2016). If the welfare of additional farmed animals is net negative, the association between growth and FALYs may be another such drawback. From this perspective, the present paper can be viewed as being part of a greater project of assessing the overall social welfare gains from economic growth. The findings may thus be of relevance not only to public policy, but for any actor that aims to increase social welfare by leveraging economic growth.

References

Arrhenius, G (2000) An impossibility theorem for welfarist axiologies, *Economics & Philosophy*, 16(2), 247-266.

Baltagi, B H , & Li, Q (1990) A Lagrange multiplier test for the error components model with incomplete panels, *Econometric Reviews*, 9(1), 103-107.

Baltagi, B (2008) *Econometric analysis of panel data* , John Wiley & Sons.

Blackorby, C, Bossert, W , & Donaldson, D (1995) Intertemporal population ethics: critical-level utilitarian principles, *Econometrica*, 1303-1320.

Blackorby, C., & Donaldson, D. (1992) Pigs and guinea pigs: a note on the ethics of animal exploitation, *The Economic Journal*, 102(415), 1345-1369.

Breusch, T S , & Pagan, A R (1980) The Lagrange multiplier test and its applications to model specification in econometrics, *The Review of Economic Studies*, 47(1), 239-253.

Clarke, M , & Ng, Y K (2006) Population dynamics and animal welfare: issues raised by the culling of kangaroos in Puckapunyal, *Social Choice and Welfare*, 27(2), 407-422.

Cole, J R , & McCoskey, S (2013) Does global meat consumption follow an environmental Kuznets curve?, *Sustainability: Science, Practice and Policy*, 9(2), 26-36.

Cowen, T (2003) Policing nature, *Environmental Ethics*, 25(2), 169-182.

Cowen, T (2007) Caring about the distant future: why it matters and what it means. *The University of Chicago Law Review*, 74, 5.

Cowen, T (2017) Market failure for the treatment of animals, In *Markets, Morals, and Religion* (pp 73-82) , Routledge.

Dinda, S (2004) Environmental Kuznets curve hypothesis: a survey, *Ecological Economics*, 49(4), 431-455.

FAO (2019) Food balance sheet, http://www fao org/faostat/en/data/FBS. [2019-03-14]

Farm sanctuary (2019) Sheep and goats, https://www farmsanctuary org/learn/factory-farming/sheep-and-goats/. [2019-03-14].

Feenstra, R C , Inklaar, R , & Timmer, M (2013), PWT 8 0–a user guide, https://www.ggdcnet/pwt.[2019-03-20].

Feenstra, R C , Inklaar, R , & Timmer, M P (2015) The next generation of the Penn World Table, *American Economic Review*, 105(10), 3150-82.

Frank, J (2008) Is there an "animal welfare Kuznets curve"?, *Ecological Economics*, 66(2-3), 478-491.

Frey, U J , & Pirscher, F (2018) Willingness to pay and moral stance: The case of farm animal welfare in Germany, *PloS one*, 13(8).

Gallet, C A (2010) The income elasticity of meat: a meta-analysis, *Australian Journal of Agricultural and Resource Economics*, 54(4), 477-490.

Gerbens-Leenes, P W , Nonhebel, S , & Krol, M S (2010) Food consumption patterns and economic growth: Increasing affluence and the use of natural resources, *Appetite*, 55(3), 597-608.

Gerber, P J , Steinfeld, H , Henderson, B , Mottet, A , Opio, C , Dijkman, J , Tempio, G (2013) *Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities*, Food and Agriculture Organization of the United Nations (FAO).

Griliches, Z , & Hausman, J A (1986) Errors in variables in panel data, *Journal of Econometric*s, 31(1), 93-118.

Honda, Y (1985) Testing the error components model with non-normal disturbances, *The Review of Economic Studies*, 52(4), 681-690.

Ioannidis, J P (2010) Meta-research: The art of getting it wrong, *Research Synthesis Methods*, 1(3-4), 169-184.

Johansson-Stenman, O (2018) Animal welfare and social decisions: is it time to take Bentham seriously?, *Ecological Economics*, 145, 90-103.

Jones, C I (2016) Life and growth. *Journal of Political Economy*, 124(2), 539-578.

Jones, C I , & Klenow, P J (2016) Beyond GDP? Welfare across countries and time, *American Economic Review*, 106(9), 2426-57.

Kearney, J (2010) Food consumption trends and drivers, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554), 2793-2807.

Keller, K, Bolker, B M, & Bradford, D F (2004) Uncertain climate thresholds and optimal economic growth. *Journal of Environmental Economics and management*, 48(1), 723-741.

King, M L , & Wu, P X (1997) Locally optimal one-sided tests for multiparameter hypotheses, *Econometric Reviews*, 16(2), 131-156.

Kuznets, S (1955) Economic growth and income inequality, *The American Economic Review*, 1-28.

Lagerkvist, C J , & Hess, S (2010) A meta-analysis of consumer willingness to pay for farm animal welfare, *European Review of Agricultural Economics*, 38(1), 55-78.

National Chicken Council, (2019), U S Broiler Performance, https://www nationalchickencouncil org/about-the-industry/statistics/u-s-broiler-performance/. [2019-03-20].

Ng, Y K (1986) Social criteria for evaluating population change: an alternative to the Blackorby-Donaldson criterion, *Journal of Public Economics*, 29(3), 375-381

Ng, Y K (1995) Towards welfare biology: Evolutionary economics of animal consciousness and suffering, *Biology and Philosophy*, 10(3), 255-285

Norwood, F B , & Lusk, J L (2011) *Compassion by the pound: the economics of farm animal welfare*, Oxford University Press.

MacAskill, W (2015) *Doing good better: Effective altruism and a radical new way to make a difference*, Guardian Faber Publishing.

Matheny, G , & Chan, K M (2005) Human diets and animal welfare: The illogic of the larder, *Journal of Agricultural and Environmental Ethics*, 18(6), 579-594.

Matheny, G , & Leahy, C (2007) Farm-animal welfare, legislation, and trade, *Law & Contemporary Problems*, 70, 325.

Mood, A , & Brooke, P (2012) Estimating the number of farmed fish killed in global aquaculture each year, *Fishcount org uk, 1* http://fishcount org uk/published/std/-fishcountstudy2 pdf. [2019-05-05].

Moosa, I A (2017) The econometrics of the environmental Kuznets curve: an illustration using Australian CO2 emissions, *Applied Economics*, 49(49), 4927-4945.

Rae, A N (1998) The effects of expenditure growth and urbanisation on food consumption in East Asia: a note on animal products, *Agricultural Economics*, 18(3), 291-299.

Sans, P , & Combris, P (2015) World meat consumption patterns: An overview of the last fifty years (1961–2011), *Meat Science*, 109, 106-111.

Sarek, K , Savoie, J , Moss, D (2018) *From humans in Canada to battery caged chickens in the United States, which animals have the hardest lives: results* Charity Entrepreneurship URL: http://www.charityentrepreneurship.com/blog/from-humans-in-canada-to-battery-caged-chickens-in-the-united-states-which-animals-have-the-hardest-lives-results. [2019-04-17].

Schroeder, T C , Barkley, A P , & Schroeder, K C (1996) Income growth and international meat consumption, *Journal of International Food & Agribusiness Marketing*, 7(3), 15-30.

Shabu, T (2010) The relationship between urbanization and economic development in developing countries, *International Journal of Economic Development Research and Investment*, 1(2), 30-36.

Singer, P (2011) *Practical ethics*, Cambridge University Press.

Stevenson, B , & Wolfers, J (2013) Subjective well-being and income: Is there any evidence of satiation?, *American Economic Review*, 103(3), 598-604.

Tomasik, B (2015) The importance of wild-animal suffering, *Rel : Beyond Anthropocentrism*, 3, 133.

UN (2018) World Urbanization Prospects: The 2018 Revision, Online Edition, [File 21: Annual Percentage of Population at Mid-Year Residing in Urban Areas by Region, Subregion, Country and Area, 1950-2050], United Nations, Department of Economic and Social Affairs, Population Division, https://population un org/wup/Download/. [2019-03-14].

USDA (2019a) Livestock and poultry live and dressed weights U S Department of Agriculture Retrieved from: https://www.ers.usda.gov/data-products/livestock-meat-domestic-data/livestock-meat-domestic-data/#All%20meat%20statistics. [2019-03-14].

USDA (2019b) U S milk production and related data (quarterly and annual), U S Department of Agriculture, https://www ers usda gov/data-products/dairy-data/dairy-data/. [2019-03-14].

USDA (1995–2019) Chickens and eggs annual summary U S Department of Agriculture Retrieved from: https://usda library cornell edu/concern/publications/1v53jw96n?locale=en#release-items. [2019-03-14].

Vranken, L , Avermaete, T , Petalios, D , & Mathijs, E (2014) Curbing global meat consumption: Emerging evidence of a second nutrition transition, *Environmental Science & Policy*, 39, 95-106.

Walker, P , Rhubart-Berg, P , McKenzie, S , Kelling, K , & Lawrence, R S (2005) Public health implications of meat production and consumption, *Public Health Nutrition*, 8(4), 348-356.

World Bank (2019), Trade (% of GDP), [API_NE TRD GNFS ZS_DS2_en_excel_v2 _10577124], https://data worldbank org/indicator/ne.trd.gnfs.zs. [2019-03-14].

York, R , & Gossard, M H (2004) Cross-national meat and fish consumption: exploring the effects of modernization and ecological context, *Ecological Economics*, 48(3), 293-302.

Zhou, D , Yu, X , Abler, D , & Chen, D (2017) Projecting meat and cereals demand for China based on a meta-analysis of income elasticities, *China Economic Review.*

Appendix

A1. Alternative specifications of main findings

Table 8: Alternative specifications

	(1)	(2)	(3)	(4)	(5)	(6)
GDP per capita	0.091^{***}	0.050^{***}	0.092^{***}			
	(0.017)	(0.010)	(0.018)			
(GDP per capita)^2	-0.001^{***}	-0.0003^{***}	-0.001^{***}			
	(0.0002)	(0.0001)	(0.0002)			
log(GDP per capita)				0.887^{***}	0.536^{***}	0.904^{***}
				(0.124)	(0.092)	(0.126)
Urbanisation	0.022^{***}	0.026^{***}	0.021^{***}	0.011	0.016^{***}	0.011
	(0.006)	(0.005)	(0.006)	(0.007)	(0.005)	(0.007)
Trade	0.004^{**}	-0.001^{*}	0.004^{**}	0.003	-0.001	0.003
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)
Constant	-0.277	0.246		-0.392	0.295	
	(0.245)	(0.275)		(0.266)	(0.254)	
Specification	Pooled OLS	Random effects	Year FE	Pooled OLS	Random effects	Year FE
R^2	0.591	0.239	0.588	0.629	0.245	0.628
Adjusted R^2	0.590	0.238	0.585	0.629	0.244	0.625
F Statistic	67.471	24.471	64.496	109.628	31.905	104.850
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Turning point	65,040	98,765	65,592	NA	NA	NA
Observations	3,185	3,185	3,185	3,185	3,185	3,185

Note: *p<0.1; **p<0.05; ***p<0.01

Robust standard errors are clustered at the country level.

A2. Individual species models

Table 9: Quadratic model with country and time effects (individual species)

	Dependent variable:					
	FALYs per capita					
	Beef cows	Pigs	Mutton/goats	Poultry	Dairy cows	Layer chickens
	(1)	(2)	(3)	(4)	(5)	(6)
GDP per capita	0.001	0.001	0.0001	0.028***	−0.0001	0.002
	(0.001)	(0.001)	(0.0004)	(0.009)	(0.0001)	(0.002)
(GDP per capita)^2	−0.00001	−0.00000	−0.00000	−0.0001*	−0.00000	−0.00001
	(0.00001)	(0.00001)	(0.00000)	(0.0001)	(0.00000)	(0.00001)
Urbanisation	0.001	0.0002	0.001**	0.006	0.0002*	0.001
	(0.001)	(0.001)	(0.0003)	(0.009)	(0.0001)	(0.002)
Trade	−0.0001	−0.00002	−0.00004	−0.001	−0.00001	−0.001***
	(0.0001)	(0.0001)	(0.00004)	(0.001)	(0.00001)	(0.0002)
R^2	0.00903	0.00513	0.0177	0.0439	0.0282	0.0242
Adjusted R^2	-0.0486	-0.0527	-0.0395	-0.0117	-0.0283	-0.0325
F Statistic	0.904	0.544	2.049	3.390	1.590	3.569
(p-value)	(0.463)	(0.704)	(0.090)	(0.011)	(0.180)	(0.008)
Turning point	78,786	178,830	112,077	117,233	NA	109,605
Observations	3,185	3,185	3,185	3,185	3,185	3,185
Note:						*p<0.1; **p<0.05; ***p<0.01 Robust standard errors are clustered at the country level.

Table 10: Quadratic model with first differences (individual species)

	Dependent variable:					
	FALYs per capita					
	Beef cows	Pigs	Mutton/goat	Poultry	Dairy cows	Layer chickens
	(1)	(2)	(3)	(4)	(5)	(6)
GDP per capita	0.002***	0.001*	0.001	0.033***	0.0001	0.005***
	(0.001)	(0.001)	(0.0004)	(0.011)	(0.0001)	(0.002)
(GDP per capita)^2	−0.00001***	−0.00001	−0.00000	−0.0003**	−0.00000*	−0.00003**
	(0.00000)	(0.00000)	(0.00000)	(0.0001)	(0.00000)	(0.00001)
Urbanisation	−0.002***	0.0005	−0.0003	0.028***	−0.0002**	0.004*
	(0.001)	(0.0004)	(0.0002)	(0.005)	(0.0001)	(0.002)
Trade	−0.00003	−0.00003	−0.00003**	−0.0001	−0.00001	−0.0001
	(0.00004)	(0.00002)	(0.00001)	(0.0003)	(0.00000)	(0.0001)
R^2	0.00709	0.00237	0.00867	0.0106	0.000963	0.0113
Adjusted R^2	0.00611	0.00139	0.00769	0.00961	-2.65e-05	0.0103
F Statistic	4.108	2.949	1.944	18.486	2.835	6.098
(p-value)	(0.003)	(0.022)	(0.106)	(0.000)	(0.027)	(0.000)
Turning point	84,700	82,256	127,984	65,195	62,593	96,888
Observations	3,034	3,034	3,034	3,034	3,034	3,034
Note:						*p<0.1; **p<0.05; ***p<0.01 Robust standard errors are clustered at the country level.

Table 11: Linear-log model with country and time effects (individual species)

	Dependent variable:					
	FALYs per capita					
	Beef cows	Pigs	Mutton/goats	Poultry	Dairy cows	Layer chickens
	(1)	(2)	(3)	(4)	(5)	(6)
log(GDP per capita)	0.014*	0.018***	0.006**	0.288***	0.003***	0.059***
	(0.007)	(0.006)	(0.003)	(0.082)	(0.001)	(0.017)
Urbanisation	0.001	−0.0002	0.001**	−0.003	0.0002*	0.0004
	(0.001)	(0.001)	(0.0003)	(0.009)	(0.0001)	(0.002)
Trade	−0.0001	−0.00001	−0.00004	−0.001	−0.00001	−0.001***
	(0.0001)	(0.0001)	(0.00004)	(0.001)	(0.00001)	(0.0002)
R^2	0.0149	0.0177	0.0293	0.0358	0.049	0.0499
Adjusted R^2	-0.042	-0.039	-0.0269	-0.020	-0.00595	-0.00505
F Statistic	1.664	3.243	3.046	4.571	7.064	7.004
(p-value)	(0.177)	(0.024)	(0.031)	(0.004)	(0.000)	(0.000)
Observations	3,185	3,185	3,185	3,185	3,185	3,185

Note: *p<0.1; **p<0.05; ***p<0.01
Robust standard errors are clustered at the country level.

Table 12: Linear-log model with first differences (individual species)

	Dependent variable:					
	FALYs per capita					
	Beef$_{cows}$	Pigs	Mutton/goat	Poultry	Dairy cows	Layer chickens
	(1)	(2)	(3)	(4)	(5)	(6)
log(GDP per capita)	0.015***	0.009***	0.003	0.229***	0.002***	0.051***
	(0.004)	(0.003)	(0.002)	(0.045)	(0.001)	(0.012)
Urbanisation	−0.002***	0.0003	−0.0002	0.027***	−0.0002***	0.003
	(0.001)	(0.0004)	(0.0002)	(0.005)	(0.0001)	(0.002)
Trade	−0.00002	−0.00002	−0.00002*	0.0001	−0.00001	−0.00004
	(0.00004)	(0.00002)	(0.00001)	(0.0003)	(0.00000)	(0.0001)
R^2	0.00348	0.00287	0.0024	0.00769	0.00297	0.0117
Adjusted R^2	0.00282	0.00221	0.00175	0.00704	0.00231	0.011
F Statistic	4.887	5.413	2.221	25.597	5.207	7.834
(p-value)	(0.003)	(0.001)	(0.088)	(0.000)	(0.002)	(0.000)
Observations	3,034	3,034	3,034	3,034	3,034	3,034

Note: *p<0.1; **p<0.05; ***p<0.01
Robust standard errors are clustered at the country level.