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The asymmetry of economic growth and the carbon intensity of well-being

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ABSTRACT
A key concern when crafting sustainable development policy is maximizing the benefits that derive from economic growth, such as increases in life-expectancy, while also reducing the negative impact that such growth has on environmental systems. In order to explore such tradeoffs research in environmental sociology has focused on a measurement of socio-environmental intensity known as the carbon intensity of well-being (CIWB). We explore the asymmetrical relationship between economic activity and CIWB for 153 nations from 1961–2013, as well as the theoretical implications of such a relationship. We initially find that in developed nations *economic growth has no significant relationship to CWIB*, however, *declines in economic activity do significantly reduce CIWB*. In less developed nations we find that increases and decreases in economic development are both significantly associated to CIWB and have associations which are not distinguishable from one another in magnitude. In an attempt to better understand these differences, we take financial processes into account, finding that such considerations account for the finding of asymmetry. Taken together, the findings of this study demonstrate the importance of considering the possibility of directional asymmetry, as well as the theoretical implications of such asymmetry, when specifying statistical models for regression analyses.

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Introduction

Questions concerning the relationship between socio-environmental intensity and economic growth are of great importance to many aspects of international sustainable development policy. A nuanced understanding of the relationship between socio-environmental intensity measures, such as the carbon intensity of well-being (henceforth CIWB), and measures of economic development can play an important role in identifying developmental pathways that simultaneously optimize human well-being and environmental quality. Here, we contribute to a growing body of literature concerning the relationship between socio-environmental intensity and economic development by exploring whether or not growth in GDP per capita, and decline in GDP per capita, impact CIWB in similar (i.e. symmetrical) ways.

While there are multiple measures of socio-environmental intensity, in the present analyses we focus on CIWB – a ratio measuring the average amount of CO_2 (per capita) emitted per unit of life expectancy at birth – for a number of reasons. The CIWB ratio captures the social good that a population acquires relative to the pollution it releases as a result of social and economic processes. For our purposes, it is of note that a number of national and international entities have operationalized sustainable development using the World Commission on Environment and Development's definition, which identifies sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (UNEP 2012). National level CIWB is a useful tool to engage with this definition of sustainable development, as it provides information about the amount of carbon dioxide emitted by a particular nation in a given year relative to the national life expectancy of individuals born in that year. While other definitions of socio-environmental intensity – such as the environmental intensity of well-being – capture the spirit of sustainable development equally well, we believe that a focus on carbon dioxide emissions offers distinct advantages. For instance, it is widely known that anthropogenic CO_2 emissions, a central component of CIWB, are the largest contributor to global climate change – a biophysical phenomenon which has the capacity to dramatically alter the quality of life of future generations across the globe (IPCC 2014; 2018). In light of this, one can argue that it is appropriate to understand CIWB, or the ratio of CO_2 emissions to life expectancy at birth, as a measure that captures the extent to which the well-being of current generations is gained at the expense of future ones – ultimately rendering it an apt measure of sustainable development.

Considering recent work concerning infrastructural momentum (York 2012), directional asymmetry in regression analyses (York and Light 2017), and the

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relationship between development and CIWB (Givens 2015; Jorgenson 2014; Jorgenson et al, 2015; Jorgenson and Givens 2015; McGee et al. 2017; Mayer 2017), in the present manuscript we expand our understanding of the relationship between CIWB and GDP per capita by exploring the extent to which that relationship is symmetrical for 153 nations from the year 1961 to 2013. Put differently, here we examine whether growth in GDP per capita is associated with CIWB in a manner that is statistically consistent with the association between decreases in GDP per capita and CIWB. In addition, we consider what the presence of asymmetry might tell us about the broader relationship between processes of economic development and socio-environmental outcomes.

Key findings from this analysis present a number of insights that we believe will prove valuable to researchers interested in assessing the association between measures of socio-environmental intensity and economic development. First, we find that in more developed nations the relationship between economic growth and CIWB is not symmetrical to that of economic decline and emissions – such that economic declines reduce CIWB, while economic growth and CIWB have no statistically significant association to one another. Second, the association of CIWB with growth and decline in economic activity is found to be symmetrical in less developed nation states. We attribute the difference in the presence of asymmetry across these nation state groupings to fundamental differences in the form of their economic activity, which leads us to our third finding of interest. Controlling for financial activity within national economies suppresses the finding of asymmetry in developed nations.

In what follows, we provide a brief overview of CIWB and asymmetry, particularly as these concepts apply to one another. We then move to a more detailed discussion of the theoretical and methodological aims of the analyses presented below. Finally, we provide a detailed discussion of the results of our analyses, as well as a number of potential explanations of our findings.

Infrastructural momentum, economic growth, and the carbon intensity of well-being

The broad usefulness of socio-environmental intensity measures has resulted in an increasing number of studies relying on CIWB to examine how particular forms of socio-economic development – such as economic growth, population change, and urbanization – promote sustainability (Givens 2015; Jorgenson 2014; Jorgenson and Givens 2015; McGee et al. 2017). An implicit assumption in the statistical models used to carry out these assessments is that increases and decreases in socio-economic development have symmetrical relationships to CIWB. However, York (2012) recently found that the association between declines in GDP per capita and CO_2 emissions is not symmetrical to the association of economic growth and emissions. Specifically, declines in GDP per capita were associated with reductions in CO_2 emissions that were significantly smaller than the increases in CO_2 emissions found to be associated with economic growth. York (2012) concludes that this outcome is likely a result of the effects of existing infrastructure and durable goods – which do not necessarily disappear as economies shrink – on CO_2 emissions. This phenomenon is referred to as infrastructural momentum.

As CO_2 emissions are a fundamental component of CIWB, it is important to explore if such asymmetry is also present in the association between economic development and CIWB. Unlike CO_2 emissions, however, CIWB is a ratio and thus offers a somewhat less intuitive quantitative interpretation. Thus, it is important to note that – though both components of CIWB change independently and are impacted by processes of development, infrastructural momentum, and social change in unique ways – the value of the CIWB measure is merely representative of the amount of CO_2 emitted per unit of life expectancy at birth. In this respect, a lower CIWB value indicates a lower carbon intensity of socio-economic processes. Conversely, a higher CIWB value is indicative of more carbon intensive processes. This can be taken to mean that a lower CIWB is suggestive of greater levels of sustainable development, while a higher CIWB suggests lower levels of sustainable development – as sustainable development is operationalized here.

As a measure of socio-environmental intensity that is heavily tied to CO_2 emissions, CIWB is likely subject to York's (2012) infrastructural momentum in ways that are both similar to- and rather different from- such emissions. For instance, one might expect that existing infrastructures that emit less CO_2 during periods of economic decline may also serve to maintain a more or less consistent quality of life for the populations in question during these periods. Such a phenomenon should lead us to anticipate that socio-environmental intensity will decrease during periods of economic decline at a rate which is faster than that of CO_2 emissions'. The expected disparity in the rate of reduction seen in CO_2 emissions and CIWB results from the fact that carbon intensive processes, phenomena that typically increase as a result of economic growth, tend to slow – or even halt – during periods of economic decline. Contrariwise, those processes that are necessary for the maintenance of well-being – and life expectancy in particular – often remain unchanged.

Moreover, it is reasonable to suppose that the overall status of a nation's economic development (i.e. whether it falls within the United Nation's classifications of more developed or less developed) may indicate whether infrastructures that serve to increase longevity currently exist, as well as whether they are likely to remain intact during periods of economic decline. Socio-economic distinctions between developed and less developed nations may also be suggestive of differences in the primary mode of economic growth across these nation groups. For instance, developed nations may be more likely to experience economic growth as a result of financial processes, which typically are not deeply tied to CO_2 emissions. On the other hand, less developed nations are often in a position where the primary means of economic growth are the production of goods for export to developed nations, processes that are heavily associated with emissions. For these reasons, we explore the presence of directional asymmetry within the U.N.'s more developed (DC) and less developed (LDC) nation-state classifications.

The fact that the two components of CIWB have independent relationships to economic processes is also worthy of some consideration. Numerous studies find that economic growth increases CO_2 emissions cross-nationally, as well as over time within nations. Such studies also note that the positive association between economic activity and CO_2 emissions is the result of nations' reliance on carbon intensive processes, such as the burning of fossil fuels, to stimulate the majority of their growth (Clement et al, 2017; Jorgenson and Clark 2012; Liddle and Lung 2010; York et al. 2003). On the other hand, economic development is also known to increase life expectancy. Though, the associations between average life expectancy, other measures of well-being (e.g. happiness), and economic activity have often been found to be ones of diminishing returns (Brady, Kaya, and Beckfield 2007; Di Tella and MacCulloch 2006; Di Tella, Haisken-De New, and MacCulloch 2010; Layard 2010)- a phenomenon that has been noted in the implementation of energy infrastructures as well (Mazur 2013). Put differently, while economic development is clearly beneficial to the well-being of most populations, beyond a certain level of social wealth economic activity ceases to improve social well-being – an empirical reality that is broadly referred to as 'the Preston curve' (Preston 1975, 2007).

As a result of the somewhat countervailing relationships between economic growth and emissions, and life expectancy and emissions, it has become a point of interest to explore the relative tradeoffs between growth in emissions and growth in life expectancy that have been found to accompany increases in the size of economies. This is particularly so considering that such tradeoffs are at the heart of most contemporary conceptualizations of sustainable development. It is largely as a result of such interests that analyses concerning measures of socio-environmental intensity (e.g. CIWB) have been developed, a point to which we now turn.

The carbon intensity of well-being and directional symmetry

In one of the first attempts to measure socio-environmental intensity, Dietz, Rosa, and York (2012) critically evaluate the claim that environmental stressors are conducive to well-being by reformulating the Stochastic Frontier Production Model (SFPM) to assess what they term the environmental efficiency of well-being. Based on their findings, the authors argue that for developed economies improvements in life expectancy from growing affluence (measured as GDP per capita) is a relationship of diminishing returns – as is suggested by the Preston curve (1975). However, Dietz, Rosa, and York (2012) also find that in low-income nations affluence substantially improves well-being – albeit while also increasing emissions. Since Dietz, Rosa, and York's (2012) publication, a number of studies have used the environmental intensity of human well-being (EIWB), which is a ratio of the ecological footprint (see Borucke et al. 2013) to life expectancy at birth (Knight 2014; Knight and Rosa 2011). For example, a study by Jorgenson and Dietz (2015) assesses the temporal effect of affluence on EIWB finding that, through time, economic growth increases EIWB in developed nations, but has little effect on EIWB in less developed nations.

The technique employed by Jorgenson and Dietz (2015) has been a common approach used to assess the environmental intensity of social processes, particularly CIWB (Givens 2015; Jorgenson 2014; Jorgenson and Givens 2015). With regard to economic development, these studies broadly argue that development processes increase the amount of CO_2 emitted per unit of life expectancy attained. Such findings also suggest that as time passes the association between growth and the environmental intensity of social processes increases. We draw attention to the fact that these studies have successfully illustrated the effect that socio-economic development generally has on sustainability. However, we also note that the methodology employed within these studies – and all studies which rely upon regression techniques, for that matter – necessarily assumes the effect of increases in the independent variable, economic growth in this case, is equivalent and opposite (i.e. symmetrical) to the effect of decreases in the independent variable, or economic decline. With respect to the present subject matter, acceptance of the assumption of symmetry tacitly suggests that the primary effect of development on the environmental intensity of social processes is a result of growth in the value of the independent variable. In other words, the general takeaway of the work described above, and other work concerning CIWB (McGee, Ergas, Greiner, Clement 2017) is that growth is what drives change in CIWB.

This point merits elaboration. The assumption of symmetry in analyses exploring the association between social factors that change over time tends to suggest that the historical impact of decline in the independent variable – or reduction in the size of the GDP per capita in this case – has an inconsequential effect on the dependent variable. This assumption, where it exists explicitly, and not simply as a result of modeling techniques, is – rather reasonably – based on the fact that the historical trajectory of socio-economic development has generally been one of growth. However, we argue that acceptance of the assumption of directional symmetry may lead to confusion in some instances, particularly when one considers that economic growth and economic decline are the result of vastly different social and political circumstances. Similarly, such changes yield significantly different social and environmental outcomes, and likely have dramatically different social implications across developed and less developed nation-state groups.

For instance, in a cross-regional, longitudinal exploration of the association between socio-environmental intensity and economic activity, Jorgenson (2014) finds that the relationship between GDP per capita and CIWB changes over time and concludes that 'The findings for the analysis of mostly high-income nations in North America, Europe and Oceania indicate that, rather than becoming more sustainable, economic growth continues to increase CIWB' (p. 188). Similarly, McGee et al. (2017) examined the relationship between slum and non-slum patterns of urban development and CIWB, finding that growth in urbanization increases CIWB to a greater degree in nations without slum patterned urban development than in nations with slum patterned urban development (though in either case the positive association was one of diminishing returns). We do not doubt the accuracy of these findings, but the approach used to carry out the analyses implicitly suggests that the distinction between the effect of growth and decline in measures of social development is statistically negligible – despite the fact that both indicators of development happened to decrease a number of times in the nations observed.

In a similar vein, a new method developed by Jorgenson (2014), and subsequently employed in a number of other studies (Givens 2015; Jorgenson and Givens 2015, 2015) relies upon interactions between time dummy variables and GDP per capita to assess the extent of decoupling between economic growth and CIWB. We do not intend to diminish the importance or usefulness of employing interactions in such ways. Yet, we do wish to highlight that such interactions also carry an unstated assumption of directional symmetry. Thus, each time dummy interaction with GDP per capita assumes that the effect of growth in GDP per capita is symmetrical to the effect of decline in the relevant year. We note that, as with regression more broadly, this method may, in fact, be capturing the relationship between declines in economic size and CIWB- since there are a substantial number of years in which development indicators declined in the samples used in all of the studies discussed thus far.

We argue that it may be illuminating to assess whether the findings of analyses that employ regression techniques are primarily driven by growth or declines in the independent variable. We also acknowledge that it is entirely possible, and in many cases likely, that the assumption of symmetry – so often employed by default – is appropriate. Such a situation which would simply indicate that growth and decline in the independent variable equally drive the results of regression analyses. To this end, using data drawn from the World Bank's World Development Indicators database (2015), the present study proceeds to present a number of analyses that highlight an instance where it is the case that directional asymmetry is present in the relationship between the dependent and independent variables of primary interest.

To achieve this aim, we proceed as follows. First, we explore the presence of directional symmetry in the relationship between GDP per capita and CIWB in more developed and less developed nation groups. We then explore whether directional symmetry is present in each year for which observations are included by relying upon interaction terms. Thus, in addition to examining whether or not the average effect of economic growth on CIWB is symmetrical to the average effect of economic decline on CIWB during the period under consideration, we also explore if the assumption of symmetry in these associations is valid in particular years by employing the recently developed time-dummy interaction method (Jorgenson 2014).

By calling attention to this assumption we also aim to expand upon the recent work of York and Light (2017). York and Light, through Lieberson (1985), point out that 'reversibility is a ubiquitous principle in most social research' and that 'researchers and policy analysts alike typically (usually implicitly) assume symmetrical causation' (p.1). Taking this statement as a starting point, we argue that an additional concern regarding assumptions of symmetry in many social science studies is that the general trend of an independent variable is often assumed to be the driver of its estimated association to a dependent variable. In other words, in instances where the independent variable of interest has both negative and positive values, it is possible that the negative values bear an association to the dependent variable that is entirely different than – or asymmetrical to – that of the positive values. If this were the case, but symmetry was assumed in the modeling approach, then a shared slope estimate would be incorrectly attributed to both the positive and negative changes in the independent variable being considered. In such an instance it is possible that the shared slope estimate represents an overestimation of the relationship between the declining values of the independent variable and the dependent variable, while also leading to an underestimation of the relationship between the growing values of the independent variable and the dependent variable – or vice versa.

Aims and hypotheses

In light of the discussion above, we believe it is worth revisiting the stated goals of this study, which are twofold. First and foremost, we aim to explore the theoretical implications of an asymmetrical association between economic development and CIWB. Second, we hope to further demonstrate the importance of interrogating the hidden assumption of symmetry in sociological analyses. To fulfill these goals, we turn to a discussion of relevant literature that demonstrates why asymmetry between economic development and CIWB is likely.

While asymmetry is not itself a theory, we argue that it does offer a pathway toward more robust theory application in sociological explorations. As York and Light (2017) note, 'An empirical finding of asymmetry suggests the need to theorize the nature of processes that lead to it' (11). With such needs in mind, and in anticipation of empirical confirmations of asymmetry, we hypothesize that the relationship of economic growth to CIWB is negligible in more developed nations. We argue this is so as a result of the fact that in DCs economic development has generally shifted away from processes that directly produce well-being and CO_2 emissions. That is not to say that well-being and emissions are no longer increasing in developed nations, rather that in such nations economic growth is *relatively* decoupled from CO_2 emissions and – as research relating to the Preston curve (1975) has demonstrated (e.g. Brady, Kaya, and Beckfield 2007; Di Tella and MacCulloch 2006; Layard 2010) – well-being. Put differently, in more developed nations the relationship between GDP per capita and emissions per capita, as well as the relationship between GDP per capita and life expectancy at birth, have begun to attenuate as a result of the economic activities that drive such relationships being exported to less developed nation-states. A process that has been rather well demonstrated by Jorgenson and Clark (2009; 2012), among others (e.g. Rice 2007; Greiner and McGee 2018). Considering such structural relationships, we also contend that in DCs any correlation between economic development and CIWB likely derives from the association that declines in economic development have with emissions.

Though such a notion may seem counterintuitive at first passing, one reason to suspect that the association between economic growth and environmental intensity is negligible in DCs is the context under which economic development typically occurs in these countries, as compared to LDCs. Since the collapse of the Soviet Union, an increasing proportion of economic growth in DCs has derived from financial markets (Assa 2012; Stockhammer 2013), which have a very different effect on life expectancy and emissions than industrial economic development does. For instance, in France (a more developed country) from 1990 to 2013, overall economic development increased while emissions declined and life expectancy at birth grew marginally. Notably, throughout the same period the value of stocks as a percentage of GDP increased substantially. Meanwhile in Argentina (a less developed country), the trajectory of economic development almost matches that of emissions, and life expectancy at birth has also consistently increased. Unlike France, however, in Argentina the value of stocks as a percentage of GDP remains relatively stagnant throughout the period.

Economic development in both DCs and LDCs is tied to the accumulation of wealth, which is extracted domestically in each subgroup of nations. However, in DCs, in addition to domestic wealth accumulation, wealth is accumulated from LDCs- which defines the relationship between DCs and LDCs as one which is characterized by unequal exchange (Chase-Dunn and Jorgenson 2007; Rice 2007; Greiner and McGee 2018). Specifically, natural resources are extracted from LDCs in both raw and manufactured forms in order to support middle/consumer classes in DCs. These processes of exchange and extraction are facilitated by the financialization of markets in DCs. In particular, processes of financialization in DCs are responsible for investment in, and consumption of, products and goods that are exported from LDCs to DCs. As markets have globalized the financialization of economies in DCs has allowed for a broad increase in foreign direct investment. This shift has also enabled the establishment of production activities in LDCs that have become increasingly costly in DCs as a result of growth in both labor and environmental protection standards (Chase-Dunn and Jorgenson 2007). At the same time, the export of the products that are the result of labor efforts in LDCs to DCs has been enabled by the expansion of financial and credit mechanisms within DC marketplaces. Such growth is exemplified well by increasing financial profits, and by the growing share of debt relative to GDP in DCs (Harvey 2010; Foster and McChesney 2012). An important, additional effect of such changes to the global economy is likely manifested in the apparent attenuation of the relationship between economic growth and the emission of carbon dioxide among DCs, as well as the simultaneous intensification of this relationship in LDCs (Jorgenson and Clark 2012; Greiner and McGee 2018).

When all these factors are taken into consideration, it would seem rather reasonable to suspect that growth in economic activity in DCs might not have a notable association with the ratio of CO_2 emissions per capita to life expectancy at birth, as in such nations both life expectancy at birth and emissions per capita have begun to demonstrate an attenuating relationship with increasing economic activity. However, we might expect that economic decline in DCs would still be associated with a reduction in emissions per capita, as the production process and transportation activities which do occur in such spaces would likely begin to slow. On the other hand, in LDCs economic activity has continually been demonstrated to be associated with increases in life expectancy at birth and emissions per capita. Thus, in such nations, it is reasonable to assume that increases and decreases in economic activity will be largely symmetrical to one another in their association with CIWB. The above hypotheses can be stated more formally as follows:

H1- In DCs the association between CIWB and GDP per capita is asymmetrical, such that declines in GDP per capita are associated with declines in CIWB, but increases in GDP per capita have little association with CIWB.

H2- In LDCs the association between growth and decline in GDP per capita and CIWB will be symmetrical to one another.

H3- The directional asymmetry in the association between CIWB and GDP per capita among DCs is the result of the dominance of financial processes in such nations.

Data and methods

Country level panel data from the World Bank (2015) was used for all analyses performed in this study. Where available, data was included for all nations with a population of 500,000 or more for the period of 1960 to 2013. Descriptive statistics for the variables included can be found in Table 1. Since the World Bank keeps data on both Hong Kong and Macao separately from China, they are treated as separate nations in the analyses presented here. Natural logarithmic transformations were performed on all variables included in our analyses, making the estimated associations elasticity coefficients that represent the percent change in CIWB for a 1% change in the independent variable (York, Rosa, and Dietz 2003).

In all analyses all variables were first differenced prior to natural log transformation, which makes their values representative of their annual change, rather than a total value. First differencing enables the examination of directional asymmetry by allowing for the identification of growth and decline in theoretically relevant variables, and for the exploration of the association of such changes independent of one another. To this end, after first-differencing slope dummies were used in order to allow separate slope estimates to be calculated for positive and negative change in the primary independent variable, GDP per capita. Additionally, we note that using first-differenced data allows for the control of non-contemporaneous factors, such as geography, by focusing on within nation change (York and Light 2017).

The dependent variable, CIWB, was calculated using the World Bank's data on anthropogenic CO_2 emissions per capita[1] and life expectancy at the time of birth. Specifically, we follow previous research in this area (Dietz, Rosa, and York 2012; Jorgenson 2014) in placing carbon dioxide emissions per capita in the numerator and life expectancy in the denominator. We then add a constant to the numerator in order to prevent variation in CIWB being driven predominantly by changes in CO_2 per capita, as suggested by Dietz et al (Dietz, Rosa, and York 2012). This is necessary as a result of the fact that the coefficient of variation for CO_2 per capita, 1.72, is notably larger than the coefficient of variation for life-expectancy, 0.181. By adding the constant, 37.26, to CO_2 per capita the coefficients of variation for the two components of CIWB are made equivalent. It should be emphasized that since CIWB is a ratio that measures the human well-being obtained for each unit of CO_2 emitted, a lower CIWB is more desirable than a high CIWB in the context of sustainable economic development. CIWB is calculated as follows:

$$\mathrm{CIWB} = [(\mathrm{CO_2PC} + 37.26)/\mathrm{LE}]*100$$

Table 1. Descriptive statistics of untransformed variables (N = 4625).

Variables	Mean	Median	SD	Min.	Max.
CO_2 emissions (metric tons per capita)	3.45	1.40	5.05	.01	67.11
Life expectancy at birth, total (years)	64.79	67.90	11.11	19.26	83.83
CIWB per capita	503.44	188.21	861.55	66.01	8059.38
GDP per capita (constant 2010 US$)	8857.31	2597.69	14583.13	222.46	103588.60
Population ages 15–64 (% of total)	59.04	57.91	7.14	45.75	85.87
Manufacturing (percent of GDP)	15.16	14.69	7.24	.10	45.67
Urban population (% of total)	48.34	47.88	24.15	2.94	100.00
Stocks traded (% of GDP)	29.24	7.85	60.72	0.00	952.67

Nations with a reported 100% urbanization are Hong Kong, Macao, Bosnia and Herzegovina, Micronesia, and Singapore

In order to perform our analyses, we use a generalized least squares regression model with robust standard errors to adjust for clustering of residuals by nation. The use of such a model corrects for time dependent disturbances in year to year changes in variables, and controls for country specific, extemporaneous, effects as well. We also include year dummy variables in all models to control for effects from year specific changes that are common to all nations.[2]

We first assess the estimated impact of economic declines and growth on CIWB in both DCs and LDCs. Doing so allows us to explore whether an asymmetrical relationship exists between such factors in either nation state group. Having done so, we examine the possibility of asymmetry in the relationship between economic growth, economic decline, and CIWB in every year that such declines occurred. We consider the implications of existing asymmetry and the overarching implications of economic downturns to CIWB. Ultimately, we are led to conclude that to appropriately assess the existence of asymmetry between economic development and CIWB one must account for the fact that economic development is carried out differently in developed and less developed nations.

In order to test for the robustness of findings presented here we performed sensitivity analyses without year dummies and/or control variables. In all such analyses results remained consistent with those presented here. Significance reports in all models are based on a .05 alpha level with a two-tailed test. The model constructed for our analyses is as follows:

$$\begin{aligned}\ln(\mathrm{CIWB}_{it}) = \beta_0 &+ \beta_1 \ln(\text{GDP per capita increase}_{it}) \\ &+ \beta_2 \ln(\text{GDP per capita decrease}_{it}) \\ &+ \beta_3 \ln(\text{Percent Urban}_{it}) \\ &+ \beta_4 \ln(\text{Percent Manufacturing GDP}_{it}) \\ &+ \beta_5 \ln(\text{Percent Population } 15-64_{it}) \\ &+ \beta_6 \ln(\text{Stocks Traded Percent GDP}_{it}) \\ &+ \beta_7(\text{year } 1961_t) \ldots + \beta_{59}(\text{year } 2013_t) \\ &+ e_{it}\end{aligned}$$

Where 'CIWB_{it}', our outcome of interest, represents change in the carbon intensity of well-being for nation i in year t; 'GDP per capita increase_{it}' indicates the value of the increase in GDP per capita in country i during year t relative to year t-1; 'GDP per capita decrease_{it}' indicates the value of the decrease in GDP per capita in country i during year t, relative to year t-1; 'Percent Urban_{it}' is the value of the change in the percent of the population residing in urban areas of nation i in time t, relative to time t-1; 'Percent Manufacturing GDP_{it}' is the value of the change in the percent of GDP that is accounted for by manufacturing activity in nation i during time t, relative to time t-1; 'Percent Population 15-64_{it}' indicates the change in the percent of the economically productive population during time t, relative to time t-1, in country i; 'Stocks Traded Percent GDP_{it}' is the value of the change in the total value of stocks traded as a percent of GDP in nation i during time t, relative to time t-1; 'year_t' is a control for period specific effects; and e_{it} is the stochastic residual term for nation i in period t.

Results

In order to examine the association of change in GDP per capita with CIWB, while also allowing for directional asymmetry in this relationship and accounting for the modifying impact of varying levels of economic development, we estimated two initial models. Model 1 of Table 2 examines the asymmetric association of GDP per capita with CIWB in DCs, while model 2 of Table 2 examines the same relationship in LDCs. In both models, we control for variables that have been used in previous research exploring similar topics (see Jorgenson 2014; York 2008), such as the percent of the population living in urban areas, the percent of total GDP that is attributed to manufacturing activities, and the age structure of the population.

Our control variables are found to not have a significant association with CIWB in DCs (model 1).

Table 2. Generalized least-squares panel regression models of the influence on CIWB, 1961–2013. All variables are in natural logarithmic form. All models include year dummy variables (not shown) to control for period effects. The standard errors are robust, accounting for clustering by nation.

Independent variables	Model 1. *Developed Countries* Coefficients (standard errors)	Model 2. *Less Developed Countries* Coefficients (standard errors)	Model 3. *Developed Countries* Coefficients (standard errors)	Model 4. *Less Developed Countries* Coefficients (standard errors)
GDP per capita increase	−.025 (.145)	.280*** (.080)	.307* (.136)	.478*** (.116)
GDP per capita decrease	.883*** (.127)	.337*** (.064)	.555* (.225)	.488** (.178)
Urbanization (% of population)	−1.112 (.603)	.054 (.141)	1.23*** (.288)	.015 (.196)
Manufacturing (% of GDP)	.026 (.023)	.026* (.011)	.045 (.050)	.042 (.031)
% of population age 15–64	1.13 (.733)	.830** (.296)	.759 (1.09)	.945* (.458)
Stocks traded (% of GDP)	–	–	−.007* (.003)	−.001 (.003)
R^2 (within)	.089	.035	.149	.128
N nations/totals	44/1,098	109/3,492	43/797	45/766

+***p < .001 **p < .01 *p < .05 (two-tailed tests)

When model 1 and model 2 samples are constrained to match those of model 3 and model 4 results remain substantively consistent with those presented above.

However, the percent of total GDP that is attributed to manufacturing activities, and the percentage of the population that is age 15–64 both have a positive association with CIWB in LDCs (model 2). These results indicate that the age structure of a population and manufacturing only influence CIWB in LDCs, an outcome that is to be expected when the implications of the associations of increases and decreases in GDP per capita across the two nation state groups are considered in light of unequal ecological exchange (see discussion section for further consideration of this).

Model 1 limits the examination of asymmetry in the relationship that change in GDP per capita has with CIWB to DCs, as such nations are defined within the World Bank's 'World Development Indicators' database (2015). Interestingly, model 1 suggests that, among DCs, growth in GDP per capita has no significant association with CIWB. However, the coefficient for GDP per capita decrease indicates that a 1% reduction in GDP per capita is associated with a .883% decrease in CIWB. Model 1 findings are illustrated in Figure 1, which visually demonstrates that in DCs decline in GDP per capita reduces CIWB, while economic growth does not (note that the relationship between increases in GDP per capita and CIWB was found to be non-significant in this model at a .05 test, as indicated by this association's depiction in red in Figure 1). Further, Figure 1 demonstrates that similar models that assume symmetry significantly underestimate the rate at which declines in GDP per capita decrease CIWB, and overestimate the association of growth with CIWB. These results are broadly supportive of hypothesis H1.

Model 2, tests for the presence of asymmetry in the relationship that change in GDP per capita has with CIWB in LDCs, and in doing so examines the validity of hypothesis H2. Model 2 findings suggest that, when all LDCs with available data are accounted for, the relationships between increases and decreases in GDP per capita and CIWB are symmetrical. More specifically, model 2 findings indicate that a 1% increase in GDP per capita is associated with a .280% increase in CIWB, and that a 1% decrease in GDP per capita does not result in a substantially different decrease in CIWB (though the coefficients for both increases and decreases in GDP per capita are significantly different from 0, they are not significantly different from one another). Thus, model 2 results provide support for H2.

The results from Table 2, models 1 and 2, generally indicate that differences in national socio-economic structure may lead to variation in the relationship between CIWB and development. To test this more directly, we include the variable stocks traded as a percent of GDP in model 3 of Table 2. If, as hypothesis H3 supposes, differences in the nature of the association between GDP per capita and CIWB are the result of processes of financialization in DCs leading to different manifestations of infrastructural momentum, then we should expect that controlling for stocks traded would suppress the observation of asymmetry in DCs. Model 3 findings do suggest this is the case. When stocks traded as a percentage of GDP is controlled for the associations between GDP per capita increases, GDP per capita decreases, and CIWB are statistically distinguishable from 0, but are not statistically distinguishable from one another. That is to say, in models that control for variation in the extent of national financialization the association between CIWB and change in GDP per capita is

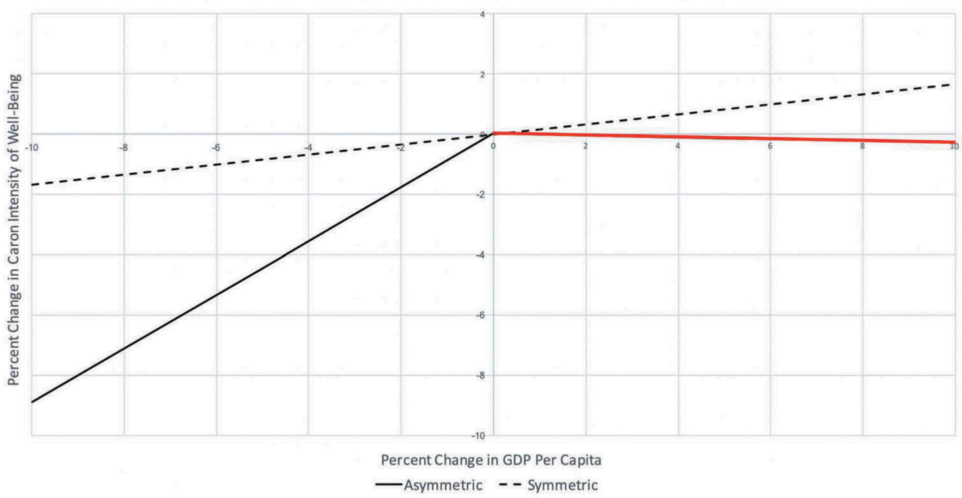

Figure 1. Estimated effect of annual change in GDP per capita on Carbon Intensity of Well-Being in developed nations from 1961 to 2013. Asymmetric slope estimates are based on model 1 coefficients. Symmetric slope estimates are based on a model identical to model 1 where independent variable effects are assumed to be directionally symmetrical. Findings demonstrate that the association of declines with GDP per capita on CIWB is underestimated in symmetrical models, while the association of GDP per capita increases on growth in CIWB is overestimated. Note that the effect of GDP per capita increases on CIWB is not significantly different from 0. In order to better identify this statistical non-significance, the portion of the line corresponding to GDP per capita increases has been rendered a red. Figure 1 suggests that in developed nations, while declines in GDP per capita appear to be an effective way to decrease CIWB, increases in GDP per capita are not.

directionally symmetrical in DCs – just as it is in LDCs. Additionally, in model 4 we find that the inclusion of stocks traded as a percent of GDP in the analysis of asymmetry in LDCs does not change the results in any meaningful way from those estimated in model 2. This suggests that in LDCs the inclusion of a control for financial processes does not alter the finding of directional symmetry in the association between GDP per capita and CIWB. Taken together, these findings lend additional support to hypothesis H3.

In order to engage more directly with previous research on CIWB, we continue employing an additional modeling approach that draws upon the work of Jorgenson (2014) – by using year dummy interactions – to explore the presence of asymmetry within nations throughout the time period observed. Specifically, Tables 3 and 4 use statistical interactions between time dummy variables and GDP per capita in both LDCs and DCs. These models assess whether there is an asymmetrical relationship between GDP per capita and CIWB in particular years. The years in which there is an asymmetrical relationship between GDP per capita and CIWB are reported in the tables, however the full models (e.g. those that show the expected impact of both decreases and increases in GDP per capita in each year) can be made available upon request. In these models we create separate variables for increases and decreases in GDP per capita using the same technique described above and interact each variable with year dummies. Each coefficient reports the main effect of increases and decreases in GDP per capita in that year. In these models' asterisks indicate the relative significance of each coefficient with respect to zero.

Findings indicate that there are a number of years in both LDCs and DCs where the association between both growth and declines in GDP per capita, and CIWB are asymmetrical to each other. This suggests that, in the years highlighted, the expected effect of GDP per capita on CIWB in nations that experienced GDP per capita increases is not symmetrical to the association between declines in GDP per capita and CIWB. These models demonstrate that, similar to the overall association between GDP per capita and CIWB, throughout the period observed there are specific years in which the expected impact of GDP per capita on CIWB is asymmetrical. Specifically, in DCs we note that the association of declines with CIWB is significant in far more instances than that of increases. Further, in years when both growth and decline is significant and asymmetrical, the estimated relationship of economic decrease tends to be much larger than the association of increases. These findings suggest that estimates of the association of GDP per capita and emissions in models that assume symmetry are being driven by the relationship between decline in GDP per capita and CIWB. As a result, acceptance of the assumption of symmetry may result in overestimation of the relationship between GDP per capita and CIWB.

Table 3. Generalized least-squares panel regression models for the relationship of increases and decreases in GDP per capita with CIWB 1961–2013 in DCs.

Year with asymmetry	GDP per capita increase Coefficients	GDP per capita decrease Coefficients
1971	.797***	45.813***
1973	.901***	− .600***
1975	4.487***	− 1.423*
1991	.2453	− .032
1998	−.045	− 3.080***
1999	−.0692	1.567**
2000	−.122	− 8.247***
2003	−.021	2.264**
2004	.119	− 3.166***
2005	.402	.901***
2007	.542	− 17.558***
2011	1.071***	.421***

Table 4. Generalized least-squares panel regression models for the relationship of increases and decreases in GDP per capita with CIWB 1961–2013 in LDCs.

Years with asymmetry	GDP per capita increases LDCs	GDP per capita decreases LDCs
1962	.128	−4.33***
1970	.656***	−.168
1971	.609**	.553**
1972	.797***	.191*
1980	−.515	−.922*
2004	.061	−.874*
2009	.089	1.184***

Discussion

Based on the results discussed above it is clear that the relationship between economic growth and CIWB in LDCs is symmetrical, and that there is an asymmetrical relationship between CIWB and GDP per capita in DCs derived from variation in their socio-economic structure. Namely, we argue that our results stem from the increasing tendency for economic growth to occur through financialization in DCs, and for infrastructural momentum to maintain life-expectancy even as such nations experience economic decline. Noting these findings, we argue that it would be beneficial for future research to consider the potential presence of asymmetry when examining the relationship between CIWB and economic growth cross-nationally.

Methodologically, our findings suggest that in DCs the assumption of symmetry overestimates the relationship between economic growth and CIWB. Overall, economic growth appears to have no significant association with CIWB in DCs. However, when financial processes are controlled for this is no longer the case.

Temporally, economic growth has a significant independent association to CIWB in both DC and LDCs, however in DCs we find that in many of the years where economic growth has a significant association to CIWB the association of declines in economic development are asymmetrical to those estimates. Thus, our findings provide broad support for previous research on CIWB that have assumed symmetry (Jorgenson 2014; Givens 2015; Jorgenson ; Jorgenson and Givens 2015). Specifically, our findings suggest that over time increases in GDP per capita still have a significant association with CIWB. However, we also find that this relationship does appear to be less pronounced in models that account for asymmetry. As a result of these findings we argue that future research should consider assessing the relationship between economic growth and CIWB separately from the association between declines and CIWB in DCs, or any aggregate group of nations that may approximate the composition of DCs.

While there are likely multiple mechanisms driving the asymmetrical relationship between GDP per capita and CIWB, here we present two theoretically oriented explanations that are also suggestive of avenues for future research. In line with York (2012), we contend that infrastructural momentum likely affects the relationship between CIWB and economic development in DCs. However, unlike York, we do not find asymmetry across all nations with available data, instead, we find an asymmetrical association only in more developed nations. Additionally, while York finds that declines in GDP per capita are associated with smaller reductions in CO_2 emissions than those estimated in symmetrical models, we find that *declines in GDP per capita result in larger reductions of CIWB than symmetrical models estimate*. Thus, our results expand on York's work in that we find that infrastructural momentum makes developed nations more ecologically efficient – with respect to CIWB – during periods of economic decline.

We suspect that the large decreases in CIWB during periods of economic decline are, in part, a product of increasing financialization in DCs, a socio-economic change which greatly affects how periods of economic growth and decline occur (Davis and Kim 2015; Foster 2007) – a supposition that is supported by the results of Model 3. Financialization is a process that is dominant in DCs, which explains why we only find asymmetrical relationships in those nations, as well as why those relationships change rather dramatically when financial processes are accounted for. We note that financialization has two effects on economic growth that are related to asymmetry. First, financialization has resulted in the development of non-democratic institutions that have power over the use and allocation of resources, such as fossil fuels, and that expand the production of CO_2 emissions (Downey 2015). In large part, the strengthening of such institutions is tied to the expansion of financial debt, as well as expanding investment in production processes in LDCs. Second, financialization has resulted in increasingly frequent economic recessions that are tied to the transformation of assets – such as mortgages and bank loans – into tradable securities. A process which has led to greater levels of financial instability (Tomaskovic-Devey, Lin, and Meyers 2015; Foster and McChesney 2012; Harvey 2003). As a result, the years in which DC economies decline are likely tied to change in CO_2 emissions through the weakening of power structures that control the allocation of CO_2 intensive resources, as well as through a reduction in the extent of transportation and production processes associated with normal economic function in such nations. Finally, a key difference between development processes in DCs and LDCs is that in DCs the infrastructures which contribute to the maintenance of life expectancy are already well established and, as is suggested by the infrastructural momentum (York 2012) hypothesis, are not removed when economic activity subsides. As a result, when economic slowdowns occur in DCs there is likely a reduction in the numerator of CIWB (i.e. CO_2 emissions per capita), but stability in the denominator (i.e. life expectancy). The ultimate outcome of such changes is that CIWB is reduced, indicating that socio-economic processes are less ecologically intensive.

Conclusion

Above, we explored the association between GDP per capita and CIWB in light of recent discussions concerning directional asymmetry in regression analyses (York 2012; York and Light 2017). To carry out this research we used robust generalized least squares regression models with year dummy estimators, and first-differenced variables. Our findings provide an example of how consideration of asymmetry in regression analyses can lead researchers to consider their data in unique ways.

For instance, initial findings presented here suggest that there is asymmetry in the association between GDP per capita and CIWB in more developed nations, but that this association is statistically symmetrical in less developed nations. More precisely, we find that in more developed nations economic growth does not appear to be associated with increases in CIWB, but that decreases in economic size are associated with notable reductions in CIWB. Drawing from research concerned with environmental world systems and unequal ecological exchange, we note that such a finding might, in fact, be representative of the fundamentally different ways that economic activity is carried out across these development groups. With this in mind we incorporate a proxy measure of the presence of financial processes in a nation's economy (i.e. the value of stocks traded as a percent of GDP) to see if such considerations are able to explain the presence of asymmetry in more developed nations. We find that the inclusion of this variable appears to explain away the finding of asymmetry. Taken as a whole, we argue these findings indicate that differences in the association between economic growth and CIWB across the more and less developed nation groups is likely a result of two structural traits that are common to more developed nations.

First, we argue that the observed asymmetry in the association between economic growth and CIWB in more developed countries results from processes of infrastructural momentum – where the infrastructures that contribute to life expectancy at birth (the well-being in CIWB), are maintained during periods of economic decline, even as social processes that might contribute to CO_2 emissions are slowed. The second socio-economic characteristic that we argue contributes to asymmetry in the economic growth, CIWB relationship is the financialization that economic activity has undergone in more developed nations following World War II. That is to say that, as the value of financial processes in the economic structure of more developed nations has grown, the impact of economic growth on emissions has become increasingly indirect. Thus, analyses of the relationship between CIWB and economic growth in more developed nations that do not account for variation in the maturity of financial apparatus are likely to show no association between these facets of the social world. Importantly, exploring the implicit assumption of symmetry in the regression analyses presented here is what led us to these conclusions. If we had proceeded without first testing for asymmetry in the association of interest, the slope estimate that is attributable to economic decline would have been partially attributed to economic growth, leading to the conclusion that economic growth drives CIWB even outside of considerations of economic structure – such as the extent of financialization.

We note that the present study is limited in a number of ways that we believe provide opportunities for future research. For instance, while exploring the relationship between economic growth, economic decline, and CIWB within developed and less developed nation groups is illuminating in many ways, such distinctions are also rather broad and may overlook important variation within these two groups. Additionally, while we rely on one operationalization of financialization, the increasing prominence of financial tools in the global economy (and in more developed nations in particular) has occurred across a number of dimensions. Thus, it may be illustrative to explore the meaning of different understandings of financialization, as well as other socio-structural changes, to the complex of relationships interrogated here. To this end, we believe that future research may benefit from exploring the existence of asymmetry in nations that have experienced specific types of economic development over time, across differing geographies, and at a variety of geospatial scales.

Notes

1. Although some previous analyses exploring CIWB have used consumption-based emissions, we focus on production-based CO2 emissions because this variable captures a larger sample of nations and years. Furthermore, it has been noted that the largest contributor to consumption-based emissions in most countries is territorial emissions from domestic production (Peters, Davis, and Andrew 2012).
2. In order to address issues raised by Allison (2019) concerning inflated standard errors, we perform sensitivity analyses wherein all models presented below are constructed as generalized least square mixed effects regression analyses, as proposed by Allison (2019). As expected, standard error estimates are reduced, but the findings are not changed in any substantial way from those presented here.

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No potential conflict of interest was reported by the authors.

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