Manufacturing the Urban Rift: Manufacturing as a Moderator of the Urbanization–CO_2 Emissions Relationship, 2000–2013

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Abstract

Previous research suggests that the urbanization–CO_2 emissions relationship is contingent on various structural factors. We aim to advance this area of scholarship by investigating how manufacturing influences urbanization's association with national-level CO_2 emissions. In particular, we focus on the extent to which manufacturing is a moderator of the urbanization–CO_2 emissions relationship. To do so, we use an interaction between standard measures of urbanization and manufacturing in panel models of national-level anthropogenic CO_2 emissions for an overall global sample as well as various reduced samples of nations defined by income level and region. We find that emissions are positively associated with this interaction for our global sample as well as for samples restricted to high-income nations and for nations in Asia. These results highlight the role that the organization of manufacturing and production plays in shaping national economies and, in turn, the urbanization–CO_2 emissions relationship in different regional and structural contexts.

Keywords: climate change, CO_2 emissions, manufacturing, sustainability, urbanization

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Introduction

According to the United Nations (2016), 60% of the world's population is expected to live in urban areas by the year 2030, with much of the growth occurring in the Global South. This rapid pace of urbanization will have considerable environmental challenges associated with it (e.g., energy use, land use change, water consumption, and air and water pollution), so much so that leading environmental studies texts consider urbanization to be one of the world's grand sustainability challenges, especially in the context of anthropogenic climate change (e.g., Lee et al., 2013). And with this, recent analyses observe positive associations between urbanization and carbon dioxide (CO_2) emissions for nations across different regional and structural contexts (Givens, 2015; Jorgenson et al., 2014)—that is, that CO_2 emission rates increase as urbanization intensifies, structured by social forces operating beyond any one nation-state—but further research is needed to better understand the processes and mechanisms through which urbanization affects greenhouse gas emissions.

In this preliminary study, we aim to modestly advance this area of research by investigating the specific influence of manufacturing on urbanization's association with CO_2 emissions. We examine this moderating relationship—that is, how manufacturing affects the urbanization–CO_2 emissions relationship—by using interactions between standard measures of urbanization and manufacturing, and we estimate longitudinal models of national-level anthropogenic carbon emissions for an overall global sample as well as various reduced samples of nations defined by income level and by region.

We find that for our entire sample, national CO_2 emissions are positively associated with the interaction between urbanization and manufacturing, and that this association is statistically significant for samples restricted to (1) high-income nations and (2) nations in Asia, suggesting that manufacturing often acts as a moderator for the relationship between national-level urbanization and emissions. In other words, these results suggest that manufacturing can exacerbate the impact of urbanization on emissions.

Urbanization and CO_2 emissions

According to the United Nations (2019), 68% of the global population will live in urban areas by 2050, up from 55% today. Further population shifts to urban areas will have substantial environmental impacts. Urban areas constitute approximately 70% of global carbon emissions today, and are expected to grow over time (International Energy Agency, 2008). However, as the world's population continues to grow, urban areas could offer opportunities for more sustainable organizations of living due to available efficiencies (Dodman, 2009). For example, urban residents often live in denser areas comprising smaller dwellings that have a smaller energy footprint (Glaeser, 2012; York & Rosa, 2012), and they can also take advantage of public goods like public transportation that are less energy and carbon intensive than driving individual vehicles (Figueroa et al., 2014).

Yet, urban processes and conditions are also heterogeneous across disparate scales, times, regions, and nations (Smith, 1996). Recent research finds that regional differences are important to consider when studying relationships between human and natural systems (Marcotullio et al., 2014; Rudel, 2005). Of particular relevance for the current study, Jorgenson et al. (2014) find that the national-level association between urbanization and CO_2 emissions changes over time and differs by region. They observe a relative decoupling (the association decreases over time—CO_2 emission rates begin to slow relative to continuing growth in urbanization) between urbanization and CO_2 emissions per capita for nations in the combined regions of North America, Europe, and Oceania (NAEO), whereas the association between emissions and urbanization remains steady or increases in magnitude through time for nations in other regions. In addition, Jorgenson et al. (2014) observe a decreasing association between urbanization and emissions per unit of GDP (gross domestic product) within nations in the NAEO region and in Latin America (i.e., urbanization in these regions has become more carbon efficient), whereas the associations between emissions per unit of GDP and urbanization for nations in other regions in the analysis have remained relatively constant over time (i.e., urbanization in other regions did not become more carbon efficient). Others, like Poumanyvong and Kaneko (2010), have demonstrated that the magnitude of the relationship between CO_2 emissions and urbanization can also depend on the income level of a country. They observe that urbanization has its largest positive effect on CO_2 emissions in middle-income countries, and its smallest positive effect on emissions in high-income countries.

The regionally specific and income group–specific findings of cross-national research considering the impact of urbanization on CO_2 emissions are similar to analyses of other human drivers of emissions, such as income inequality, economic growth, and population growth. This has driven environmental and social scientists across various disciplines to underscore the importance of conducting such nuanced analyses of the drivers of anthropogenic CO_2 emissions and other environmental outcomes (Jorgenson et al., 2019), which speaks to a fundamental principle articulated by leading structural human ecologists—context matters (Dietz, 2013).

Urban political economists also highlight that regions and income groups differ tremendously in urban trajectory and form (Smith, 1996), which we suggest can influence the effect that urbanization has on CO_2 emissions. For example, rapid urbanization has given rise to urban mega-slums in developing nations (Davis, 2006). Even though the percentage of people living in urban slums has decreased over time, the total number of people living in slums has increased in developing nations from 792 million in the year 2000 to 881 million in 2014 (UN-HABITAT, 2016). Currently, nations in sub-Saharan Africa and southern Asia have the highest rates of urban slum prevalence (55.9% and 31.3% respectively) (UN-HABITAT, 2016). Slum dwellers often live in unsafe conditions with little access to suitable water, sewerage, and energy infrastructure (Rice & Rice, 2012). Their lack of basic access to resources, such as forms of fossil fuel energy, can have a suppressing effect on CO_2 emissions even though overall growth in urban populations can contribute to increases in CO_2 emissions (Givens, 2015; Jorgenson et al., 2010). Thus, the urbanization–CO_2 emissions relationship is likely moderated through various structural forces and social inequities (Clement, 2010).

Manufacturing as a moderator of the urbanization–CO_2 emissions relationship

Historically, the growth of manufacturing coincides with urbanization. By connecting labor and capital together in space, industrialists can take advantage of an ample and competitive labor supply that helps fuel further industrial production. Urbanization also encourages economic agglomeration by clustering firms within cities, metropolitan areas, and regions, allowing them to benefit from economies of scale and specialization. These processes often result in the introduction of capital-intensive technologies that can potentially improve production efficiency by lowering costs and reducing material inputs per unit of production, while leading to the overall expansion of output (Gould et al., 2004). This phenomenon, known as the "Jevons paradox," can lead to greater efficiency at micro levels but expand the total amount of pollution or resource use at macro levels (York & McGee, 2016). Urbanization plays a key role in facilitating the Jevons paradox by concentrating resources and labor in dense spaces, which can lower marginal costs, but also fuel demand and facilitate additional production by taking advantage of large consumer markets, utilizing the built infrastructure of urban areas to move goods across the world, and having access to a large labor pool.

However, how these processes operate is context-specific. Like urbanization, there is significant heterogeneity in industrial manufacturing processes across the global economy (Brady et al., 2011). Over the latter part of the twentieth century, the global organization of production shifted from a predominately US-dominated, Fordist economy to one defined as flexible accumulation, characterized by dispersed global supply chains, product differentiation, and intensified spatial competition (Harvey, 1990). These structural changes have played a key role in shifting carbon-intensive industries and manufacturing processes to developing countries (Mahutga, 2006; Thombs, 2018).

Foreign direct investment, international trade, and global governance institutions have facilitated the expansion of carbon-intensive manufacturing into developing nations and regions (Jorgenson & Clark, 2012; Jorgenson et al., 2007; Thombs, 2018). Many of these industries locate to urban areas with ample labor resources and supply chain linkages, leading to increases in fossil fuel energy consumption within these regions. Therefore, we might expect to observe a moderating effect of manufacturing on the relationship between urbanization and CO_2 emissions.

In the preliminary analysis below, we build on the bodies of literature and research on urbanization and manufacturing/industrialization to test how they potentially interact to affect CO_2 emissions. In other words, we assess whether manufacturing is a moderator for the association between urbanization and emissions for nations in different economic and regional contexts.

Data and methods

Sample

We analyze an unbalanced data set consisting of annual observations for 116 countries during the period 2000 to 2013. Manufacturing data are relatively limited for many countries prior to 2000, particularly for former Soviet nations and for a number of high-income countries. Consistent with methods employed in past research in environmental sociology and related disciplines (Jorgenson et al., 2019; Rudel, 2005), we also estimate models for reduced samples of nations defined by national income level (high income, middle income, low income), and region (Africa; Asia; South and Central America and the Caribbean (SCA); and North America, Europe, and Oceania (NAEO)) (Jorgenson, 2014; Jorgenson et al., 2014). The countries included in the overall sample are listed in Table 1.

Table 1. Countries included in the analysis

Africa	Asia	SCA	NAEO
HIGH INCOME Equatorial Guinea **MIDDLE INCOME** Cameroon Cote d'Ivoire Egypt Gabon Ghana Mauritania Mauritius Morocco Nigeria Republic of the Congo Senegal South Africa Tunisia Zambia **LOW INCOME** Benin Burkina Faso Burundi Central African Republic Chad Democratic Republic of the Congo Ethiopia The Gambia Guinea Kenya Liberia Malawi Mozambique Rwanda Sierra Leone Tanzania Togo Uganda Zimbabwe	**HIGH INCOME** Bahrain Japan Republic of Korea Russia Saudi Arabia Singapore **MIDDLE INCOME** Armenia Azerbaijan China Georgia India Indonesia Iran Jordan Kazakhstan Kyrgyz Republic Laos Lebanon Malaysia Mongolia Myanmar Pakistan Philippines Sri Lanka Thailand Turkey Vietnam Yemen **LOW INCOME** Bangladesh Nepal Tajikistan	**HIGH INCOME** Chile Trinidad & Tobago Uruguay **MIDDLE INCOME** Argentina Bolivia Brazil Colombia Costa Rica Cuba Dominican Republic Ecuador El Salvador Guatemala Honduras Jamaica Nicaragua Panama Paraguay Peru Venezuela **LOW INCOME** [none]	**HIGH INCOME** Australia Austria Belgium Canada Cyprus Czech Republic Denmark Finland France Germany Greece Ireland Italy Netherlands New Zealand Norway Poland Portugal Slovak Republic Spain Sweden Switzerland United Kingdom United States **MIDDLE INCOME** Albania Belarus Bulgaria Macedonia Mexico* Romania Ukraine **LOW INCOME** [none]

SCA = South and Central America and the Caribbean; NAEO = North America, Europe and Oceania.

* Mexico is included with North America due to it being a part of the North American Free Trade Agreement.

Dependent variable

Our dependent variable is total CO_2 emissions, measured in million metric tons. These data, which include emissions from the burning of fossil fuels and the manufacture of cement, were obtained from the World Resource Institute's Climate Analysis Indicator Tool, which provides public national-level climate data for the majority of the world's nations (WRI & CAIT, 2018). Total emissions is a widely used and substantively important dependent variable across disciplines, since the accumulation of overall CO_2 emissions in the atmosphere is a primary cause of anthropogenic climate change.

Independent variables

We include annual observations for six predictors in the analysis, all of which are commonly used in research on the human drivers of emissions: urbanization, GDP per capita, total population, trade openness, manufacturing as a percentage of GDP, and services as a percentage of GDP (Dietz, 2017; Jorgenson et al., 2019; Rosa & Dietz, 2012). Urbanization is measured as the percentage of the nation's population living in urban areas (World Bank, 2018). GDP per capita controls for a country's level of economic development, measured in constant 2010 US dollars. Total population counts all residents regardless of legal status or citizenship, except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin. To control for integration into the global economy, we include trade (exports plus imports) as a percentage of GDP. Manufacturing as a percentage of GDP and services as a percentage of GDP are included to control for the general structure of a country's economy. All independent variables were obtained from the World Bank (2018). To test whether the effect of urbanization is moderated by manufacturing (and vice versa), we include a continuous interaction variable in the analysis (i.e., Urbanization × Manufacturing).

Estimation technique and models

We use a time-series cross-sectional Prais-Winsten regression model with panel-corrected standard errors (PCSE), allowing for disturbances that are heteroskedastic and contemporaneously correlated across panels. We use PCSE because the feasible generalized least-squares estimator that is often used to analyze panel data produces standard errors that can lead to extreme overconfidence with data sets that do not have very many more time periods than panels. We correct for AR(1) disturbances (first-order autocorrelation) within panels, and since we have no theoretical basis for assuming the process is panel-specific, we treat the AR(1) process as common to all panels (Beck & Katz, 1995).[2] We include country-specific and year-specific intercepts to control for both case-specific and period-specific effects, the equivalent of a two-way fixed effects model. This modeling technique controls out between-country variation in favor of estimating within-country effects, a relatively conservative approach commonly used in panel analyses (Allison, 2009). Combined, these intercepts alone explain most of the variation in our outcome, which leads to relatively conservative hypothesis testing.

Consistent with much past research on anthropogenic emissions (as summarized in Rosa & Dietz, 2012) all non-binary variables are transformed into logarithmic form. Thus, the regression models estimate elasticity coefficients where the coefficient for the independent variable is the estimated net percentage change in the dependent variable associated with a 1% increase in the independent variable.

Two models are estimated for the overall sample as well as the reduced samples defined by national income and by region. The first model provides baseline results, whereas the second model includes the continuous interaction term, Urbanization × Manufacturing. The models are:

Model 1: $\text{Total Carbon Emissions}_{it} = \beta_1 \text{ GDP per capita}_{it} + \beta_2 \text{ Population}_{it} + \beta_3 \text{ Urbanization}_{it} + \beta_4 \text{ Trade}_{it} + \beta_5 \text{ Manufacturing}_{it} + \beta_6 \text{ Services}_{it} + \beta_7 \text{ year 2001}_t + \ldots + \beta_{19} \text{ year 2013}_t + u_i + e_{it}$

Model 2: $\text{Total Carbon Emissions}_{it} = \beta_1 \text{ GDP per capita}_{it} + \beta_2 \text{ Population}_{it} + \beta_3 \text{ Urbanization}_{it} + \beta_4 \text{ Trade}_{it} + \beta_5 \text{ Manufacturing}_{it} + \beta_6 \text{ Services}_{it} + \beta_7 \text{ Urbanization}_{it} {}^*\text{Manufacturing}_{it} + \beta_8 \text{ year 2001}_t + \ldots + \beta_{20} \text{ year 2013}_t + u_i + e_{it}$

Subscript i represents the nation-state as the unit of analysis, t represents each year, u_i is the country-specific disturbance term, and e_{it} is the disturbance term for each country in each year. As a reminder, the dependent variable and the independent variables are logged.

Results

Table 2 presents the estimates for Model 1 and Model 2 for the full sample as well as the samples restricted to high-income, middle-income, and low-income nations. For Model 1, we find that the effect of the predictors on national CO_2 emissions depends to some extent on the income category of a country. Two predictors, GDP per capita and total population, have statistically significant effects on emissions for all analyzed samples. Other predictors like urbanization and trade have significant effects on CO_2 emissions for the entire sample, for the sample restricted to middle-

2 We found autocorrelation to be present using the Wooldridge test and heteroskedasticity to be present using the xttest3 command in Stata Software, Version 15.

income nations, and for the sample restricted to low-income nations, but not for the sample restricted to high-income nations. The effect of services on emissions is statistically significant for the sample of low-income nations, and the main effect of manufacturing on emissions is not statistically significant for any analyzed sample.

Turning to Model 2, with the incorporation of the continuous interaction term for Urbanization × Manufacturing, the linear coefficients for the two variables are to be interpreted as conditional relationships (Jaccard et al., 1990).[3] In other words, the linear coefficient for urbanization or manufacturing is the estimated effect on CO_2 emissions when the other variable equals zero. Similar to Model 1, in Model 2 the estimated effects of GDP per capita and total population on national emissions are statistically significant for all the analyzed samples. The estimated effect of urbanization on emissions is only statistically significant for the entire sample, and the effect of trade is significant for all analyzed samples except the sample restricted to high-income nations. The estimated effect of manufacturing on emissions is negative and statistically significant for the entire sample and for the sample restricted to high-income nations, and the estimated effect of services on emissions is positive and statistically significant in the sample restricted to low-income nations. In other words, the effect of manufacturing and services on emissions varies across income groups.

The estimated coefficient of interest—the interaction for Urbanization × Manufacturing—is positive and statistically significant for the entire sample and for the sample restricted to high-income nations. This coefficient has two general interpretations. First, it suggests that the association between CO_2 emissions and urbanization intensifies as manufacturing levels increase. Second, it suggests that the association between manufacturing and CO_2 emissions intensifies as urbanization increases. This general finding is likely due to several factors. First, in an unreported sensitivity analysis where we remove the nations located in Asia from the high-income sample, the estimated coefficient for the interaction between urbanization and manufacturing becomes only marginally statistically significant. The magnitude of the coefficient also decreases from 0.151 to 0.099, indicating that the high-income nations in Asia are largely influencing this estimated coefficient.

However, it is not too surprising that the estimated coefficient for the interaction between urbanization and manufacturing remains marginally significant when high-income nations located in Asia are excluded. Increases in urbanization in the non-Asian high-income countries often involve the further expansion of built infrastructure, such as transportation systems and buildings, and even though most high-income countries have gone through periods of relative deindustrialization,

3 In a sensitivity analysis available upon request, we also estimate the models with CO_2 per capita as the dependent variable. The findings are similar. The one exception is for the NAEO region where the interaction is significant at the 0.05 level. However, the magnitude of the coefficient is substantively the same.

many of these countries remain global leaders in a range of energy-intensive industry, much of which is located in or near urban areas. For example, the United States and Germany are global leaders in iron and steel production; the United States, Germany, and Italy are among the world's largest producers of cement; and Australia, Canada, Germany, Norway, and the United States produce substantial amounts of nonferrous metals, including aluminium, copper, tin, and zinc (US Geological Survey, 2014).

Table 2. Unstandardized coefficients for the regression of total carbon dioxide emissions by income level, 2000–2013: PW regression model estimates with PCSE and an AR(1) correction

	All nations		High-income nations		Middle-income nations		Low-income nations	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
GDP per capita	0.532^ (0.046)	0.521^ (0.045)	0.705^ (0.125)	0.710^ (0.129)	0.327^ (0.086)	0.345^ (0.092)	0.524^ (0.075)	0.562^ (0.075)
Population	1.602^ (0.280)	1.593^ (0.283)	1.270^ (0.174)	1.312^ (0.174)	0.975** (0.358)	1.024** (0.353)	1.160^ (0.208)	1.308^ (0.282)
Urbanization	0.642^ (0.057)	0.382** (0.130)	–0.005 (0.353)	–0.217 (0.377)	0.440^ (0.111)	0.013 (0.400)	0.521# (0.273)	0.072 (0.501)
Trade	0.069^ (0.016)	0.065^ (0.016)	0.046 (0.073)	0.020 (0.071)	0.062^ (0.009)	0.061^ (0.008)	0.083* (0.039)	0.069# (0.041)
Manufacturing	–0.007 (0.025)	–0.345* (0.164)	0.057 (0.065)	–0.527* (0.265)	–0.046 (0.033)	–0.692 (0.466)	0.003 (0.018)	–0.547 (0.387)
Services	0.101 (0.065)	0.097 (0.065)	–0.133 (0.175)	–0.069 (0.173)	0.098 (0.126)	0.109 (0.134)	0.118** (0.045)	0.128** (0.041)
Urbanization × Manufacturing		0.098# (0.050)		0.151* (0.062)		0.192 (0.134)		0.175 (0.127)
Number of countries	116	116	34	34	60	60	22	22
N	1543	1543	451	451	808	808	284	284
Min/max number of observations	1/14	1/14	4/14	4/14	1/14	1/14	3/14	3/14
R^2	0.991	0.991	0.996	0.997	0.988	0.988	0.968	0.968
Number of coefficients	135	136	53	54	79	80	41	42

Note. Panel-corrected standard errors are in parentheses; unit-specific and period-specific intercepts are unreported.

# *p* <.10. * *p* <.05. ** *p* <.01. ^ *p* <.001 (two-tailed tests).

Table 3 presents the estimated models of carbon emissions for the reduced samples of nations defined by region (Africa, Asia, SCA, and NAEO). Similar to Model 1 in Table 2, we find that the effects of the predictors on national-level emissions vary across regions. The estimated effects of GDP per capita, total population, and urbanization on emissions are all statistically significant for every regional sample. However, there is a considerable amount of difference in the estimated urbanization coefficient across the models. The coefficient is largest in the NAEO sample (0.911), whereas the coefficient in the SCA sample is negative (–0.492).

Unlike urbanization, the estimated coefficient for trade is consistent across regions and is positive and statistically significant for all regionally defined samples except the sample of nations in NAEO. The results for manufacturing and services are slightly more nuanced. The sample of nations in Africa is the only region with a statistically significant coefficient for the main effect of manufacturing (–0.042). The samples of nations in Asia and NAEO have a statistically significant coefficient for services, but the estimated effect is positive for the sample of nations in Asia (0.187) and negative for the sample of nations in NAEO (–0.324).

We find that the estimated effect of the interaction between urbanization and manufacturing on CO_2 emissions is positive and statistically significant for the sample of nations in Asia, whereas it is nonsignificant in the models for the other regionally defined samples. The positive effect of the interaction on emissions for the sample of nations in Asia is consistent with the well-established observation that manufacturing has played a notable role in the development trajectories of most countries in the region, coinciding with rapid urbanization in recent decades. This finding is also likely due to the types of manufacturing that are concentrated within urban areas in these nations. For example, multiple nations in Asia are among the leading global producers in energy-intensive industries, including cement, iron, and steel production. China and India were by far the largest cement-producing countries in the world in 2013, while China, Japan, and India were the largest iron and steel producers (US Geological Survey, 2014). These industries tend to be concentrated in or near urban areas, and are largely powered by fossil fuels. For example, industrial-based coal consumption for nations in Asia, most notably China and India, increased substantially during the first decade of the twentieth century (International Energy Agency, 2017).

The null findings for the interaction between urbanization and manufacturing in the models for the other regional samples of nations could be due to several reasons. First, numerous NAEO and SCA countries have experienced deindustrialization and shifts away from labor-intensive manufacturing with a trend toward service and finance-based economies (Brady et al., 2011). Much of this is tied to shifts in the global organization of production, which has resulted in a 'tilt' of carbon-intensive processes from developed countries to developing countries over time (Thombs, 2018).

Second, the null findings for the samples of nations in Africa and SCA could be due to the large urban slum populations in these regions (Davis, 2006). The prevalence of urban slums is known to have a suppressing effect on carbon-intensive processes and overall energy consumption (Jorgenson et al., 2010). Many nations in Asia also have a relatively large urban slum prevalence, but the extensive industrialization of most nations in this region could be offsetting the potential suppressing effect of urban slums on fossil fuel energy consumption and carbon emissions.

A third possible reason for the interaction's null effect on emissions for the sample of nations in Africa is simply that most nations in the region are less urbanized and industrialized than nations in other regions. However, as nations in Africa continue to urbanize, combined with the impetus for industrialists to seek out new geographical and structural spaces for cheap labor and less regulation, the urbanization–manufacturing relationship and its impacts on carbon emissions for nations in this region could become more pronounced in the future.

Table 3. Unstandardized coefficients for the regression of total carbon dioxide emissions by region, 2000–2013: PW regression model estimates with PCSE and an AR(1) correction

	Africa		Asia		SCA		NAEO	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
GDP per capita	0.419^ (0.080)	0.419^ (0.081)	0.149* (0.069)	0.156* (0.066)	0.828^ (0.158)	0.837^ (0.156)	0.584^ (0.052)	0.589^ (0.051)
Population	1.248** (0.443)	1.247** (0.440)	0.355# (0.196)	0.388* (0.197)	2.237^ (0.359)	2.258^ (0.360)	1.459^ (0.184)	1.429^ (0.185)
Urbanization	0.198** (0.068)	0.188 (0.216)	0.870^ (0.218)	0.367 (0.311)	–0.492# (0.259)	–0.607* (0.289)	0.911^ (0.144)	1.361^ (0.412)
Trade	0.109* (0.046)	0.109* (0.048)	0.048^ (0.015)	0.049^ (0.014)	0.212^ (0.060)	0.215^ (0.061)	0.032 (0.044)	0.037 (0.045)
Manufacturing	–0.042# (0.023)	–0.056 (0.253)	–0.015 (0.041)	–0.681** (0.235)	–0.090 (0.068)	–0.310 (0.261)	0.030 (0.053)	0.812 (0.659)
Services	0.038 (0.080)	0.037 (0.081)	0.187* (0.095)	0.175# (0.092)	0.078 (0.121)	0.123 (0.140)	–0.324* (0.138)	–0.307* (0.138)
Urbanization × Manufacturing		0.004 (0.081)		0.180** (0.064)		0.059 (0.069)		–0.188 (0.157)
Number of countries	34	34	31	31	20	20	31	31
N	432	432	412	412	272	272	427	427
Min/Max number of observations	1/14	1/14	4/14	4/14	9/14	9/14	7/14	7/14
R^2	0.985	0.985	0.992	0.992	0.992	0.992	0.998	0.998
Number of coefficients	53	54	50	51	39	40	50	51

Note. Panel-corrected standard errors are in parentheses; unit-specific and period-specific intercepts are unreported. SCA = South and Central America and the Caribbean; NAEO = North America, Europe, and Oceania.

# *p* <.10. * *p* <.05. ** *p* <.01. ^ *p* <.001 (two-tailed tests).

Because the interpretation of continuous interaction terms can be relatively complicated, we report the urbanization and manufacturing slope coefficients at various levels of the moderator variable (the 1st, 25th, 50th, 75th, and 99th percentiles) (Thombs, 2017; UCLA Institute for Digital Research and Education, 2019). This approach allows for the slope coefficients of urbanization and manufacturing to be derived while the moderator is held constant. In other words, it illustrates how the effect of each variable changes at various levels of the moderator variable. These slope coefficients are derived by using the margins command in Stata Software, Version 15. We report the urbanization and manufacturing slope coefficients for the three samples with a statistically significant interaction (All Nations, High-Income Nations, and Nations in Asia) in Table 4. As in Models 1 and 2, the coefficients should be interpreted as elasticity models. In other words, a 1% increase in urbanization or manufacturing is associated with a percentage increase in CO_2 emissions at a specific level of the moderating variable.

For the entire sample, the urbanization slope coefficient increases from 0.465 at the 1st percentile of manufacturing (2.3%) to 0.720 at the 99th percentile of manufacturing (31.4%). However, urbanization appears to have a much smaller moderating effect on manufacturing. At the lowest level of urbanization (9.9%), the manufacturing slope coefficient is negative (–0.120). It is statistically equivalent to zero at the 25th percentile (38.8%) and remains so through the 99th percentile (97.7%).

The opposite is true for the sample restricted to high-income countries. The urbanization slope coefficient is zero at all levels of manufacturing. However, the manufacturing slope coefficient increases as urbanization increases. At the 1st percentile of urbanization, the association between manufacturing and CO_2 emissions is zero. The slope coefficient becomes positive and statistically significant (0.127) at the 75th percentile (75.5%) and increases to 0.166 at the 99th percentile of urbanization.

Turning to the sample of countries in Asia, the coefficient for urbanization increases as manufacturing level increases. The coefficient increases from 0.520 at the 1st percentile of manufacturing to 0.986 at the 99th percentile of manufacturing. Similarly, for the sample of nations in Asia the manufacturing slope coefficient increases as urbanization increases. At the 1st percentile of urbanization, the manufacturing coefficient is negative (–0.269). At the 25th percentile, the manufacturing coefficient is zero, and then at the 75th percentile, the coefficient increases to 0.096. At the highest level of urbanization, the manufacturing coefficient is positive and statistically significant, with a value of 0.142.

Table 4. Slope coefficients for urbanization and manufacturing for All Nations, High-Income Nations and Nations in Asia

	Urbanization slope coefficients				Manufacturing slope coefficients		
Manufacturing percentiles	**All nations**	**High-income nations**	**Nations in Asia**	**Urbanization percentiles**	**All nations**	**High-income nations**	**Nations in Asia**
1st (2.3%)	0.465^ (0.092)	−0.089 (0.374)	0.520# (0.273)	1st (9.9%)	−0.120* (0.052)	−0.180 (0.132)	−0.269** (0.095)
25th (9.7%)	0.604^ (0.049)	0.126 (0.386)	0.774^ (0.225)	25th (38.8%)	0.014 (0.032)	0.026 (0.070)	−0.024 (0.039)
50th (14.7%)	0.645^ (0.051)	0.189 (0.393)	0.849^ (0.216)	50th (58.2%)	0.053 (0.048)	0.088 (0.063)	0.049 (0.047)
75th (18.9%)	0.670^ (0.056)	0.227 (0.398)	0.894^ (0.212)	75th (75.5%)	0.079 (0.060)	0.127* (0.063)	0.096# (0.058)
99th (31.4%)	0.720^ (0.072)	0.304 (0.410)	0.986^ (0.208)	99th (97.7%)	0.104 (0.072)	0.166** (0.067)	0.142* (0.071)

Note. Panel-corrected standard errors are in parentheses; unit-specific and period-specific intercepts are unreported. The coefficients in each sample are statistically different from one another. The pairwise comparisons of the estimates are available upon request.

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

Conclusion

In this preliminary study we engaged the growing body of research that highlights the various socioecological dynamics that influence the urbanization–CO_2 emissions relationship. We contribute to this scholarly literature by examining how level of manufacturing moderates urbanization's effect on national-level CO_2 emissions.

We find that, while the interaction between urbanization and manufacturing has a positive effect on emissions for our global sample, this effect is primarily driven by the reduced samples of high-income nations and nations in Asia.

These findings highlight the importance of examining urbanization from a regional and structural perspective and underscore the role that the global organization of manufacturing and production plays in moderating urbanization's effect on CO_2 emissions.

However, this study has limitations. First, both the urbanization and manufacturing measures used in the analysis are unable to capture the full scope of both conditions. The urbanization measure is defined by a single indicator of the percentage of nations' populations residing in urban areas, making it unable to capture the multiple and oftentimes unequal dimensions of urbanization. Likewise, the manufacturing measure consists of industries defined as such by the International Standard Industrial Classification. This includes an array of industries from recycling to the manufacturing of steel and does not take into account the heterogeneous composition of the manufacturing sector, especially across income groups and regions. Second, the time period covered in the analysis (14 years) limits the temporal generalizability of the results. The dearth of available longitudinal data that are suitable for reliable and valid comparisons, especially for manufacturing, may explain why the interaction between urbanization and manufacturing for some of the reduced samples was found to be nonsignificant.

As the world continues to urbanize, future research should investigate more closely the various mechanisms by which urbanization affects CO_2 emissions across disparate economic, structural, and regional contexts. By examining in more nuanced ways how these various socioecological processes interact with one another, and especially how other factors and conditions act as a moderator for the effect of urbanization on emissions, additional research can better identify and explain the ways in which urbanization can further contribute to, or help mitigate, anthropogenic climate change.

In a related vein, the findings for this study have implications for the Sustainable Development Goals (SDGs) (United Nations, 2019). This study suggests that some of these goals may be in contention with one another. For example, SDG #9 calls for the promotion of sustainable industrialization and a significant increase in manufacturing in developing nations, whereas SDG #11 calls for sustainable cities and communities, and SDG# 13 calls for urgent action to combat climate change and its impacts. However, as we illustrate, these goals are likely in contention with one another as greater industrialization is likely to come at the cost of greater emissions as urban areas continue to grow. Given the current structure of the global organization of production and manufacturing, the further promotion of industrialization in rapidly developing nations within regions such as Asia may come at the cost of less-sustainable cities. Thus, "significantly raising industry's share of gross domestic product," as called for in the SDGs, could increase the carbon intensity of cities within this and other regions, which is antithetical to a holistic sustainable development agenda and climate change mitigation in particular (United Nations, 2018).

Along similar lines, this study, in tandem with other recent analyses (Givens, 2015; Jorgenson et al., 2014), suggests that policymakers would benefit from incorporating a structural approach to addressing urban–ecological issues. As the findings for this study indicate, urbanization and global economic processes such as manufacturing are to some extent tied together in ways unique to region and structural location, which should be given further consideration in developing sustainability indicators and constructing policy measures (Wachsmuth et al., 2016). This is particularly relevant as many cities have taken a leading role in creating policy to mitigate and adapt to climate change (e.g., C40 Cities).[4] However, local levels of government are often more restricted in scope and less powerful than national governing bodies (Thombs, 2019). Additional policymaking at the national and international levels is needed to address urban–ecological issues tied to inequities within the global organization of manufacturing and production.

In conclusion, the complex urbanization–CO_2 emissions relationship is one of the most paramount socioecological problems of the twenty-first century. Analyzing its underlying mechanisms and relationships to other socioeconomic factors, such as how manufacturing moderates the effect of urbanization on emissions, are crucial to increasing our understanding of this grand sustainability challenge.

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