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Effects of Urbanization on Climate Change: Evidence from Bangladesh

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Abstract
Urbanization is believed to be a driving force of an economy which facilitates the transfer of surplus labor from the rural agricultural sector to the urban industrial sector and contributes to economic development. However, unplanned urbanization can at times boomerang, exerting negative impacts that not only adversely affect the economy but also stimulate environmental degradation. The aim of this paper is to analyze the effects of urbanization on climate change in Bangladesh, a country that has a history of being vulnerable to natural calamities. This paper specifically addresses the effects of urbanization, and other control variables, on emission of selected greenhouse gases and on the average annual temperature change in Bangladesh. Augmented Dickey-Fuller test, Johansen Cointegration test, Vector Error-Correction Model (VECM) causality test, and Granger causality test are conducted in this paper to analyze the data. Moreover, the techniques of Dynamic Ordinary Least Squares (DOLS) and Fully-Modified Ordinary Least Squares (FMOLS) are used to estimate the associated relationships between the variables considered. The causality test results show that urbanization is found to have a causal effect on the greenhouse gas emissions and temperature change in the long run. In contrast, a unidirectional causality is also found to be running from urbanization to carbon dioxide emission in the short run. In light of the regression model estimates it is found that initially urbanization leads to a fall in greenhouse gas emissions and reduces the temperature change, but the relationship eventually gets reversed with time whereby urbanization is found to trigger climate change in Bangladesh. These findings have significant implications for urban planners and policy makers.

Keywords: Climate change; Urbanization; Bangladesh.

1. Introduction

As urbanization is escalating worldwide, cities are now becoming crucial in dealing with climate change. According to UN Habitat, cities contribute to 70 per cent of global greenhouse gas emissions whilst occupying only 2 percent of the world's land. Thus urban areas are disproportionately responsible for climate change. This problem is projected to become more acute in the future. UN habitat estimates suggest that in 2030, 60 per cent of the world population will live in urban areas. Although at present, the majority of Bangladeshis live in rural areas, there is a salient trend towards increased urbanization. While on the one hand, cities can be potential drivers of climate change, on the other hand, they can also be potential victims. This is because the consequences of climate change, which include rising sea levels and extreme weather events, can directly endanger cities.

Climate change is an existential threat to mankind. The problem is so significant, and the probable consequences of inaction are so catastrophic, that procrastination on this issue would be nothing but self-destructive foolishness. Therefore, there is an urgent need for evidence based research to enlighten policy making that would tackle this global menace. In this backdrop, this study seeks to investigate the relationship between urbanization and climate change. This research is carried out in the context of Bangladesh, which is one of the most vulnerable countries to climate change.

2. Theoretical Framework

The process of urbanization, in the context of Bangladesh, can be explained using the two sector surplus labor model, also known as the Lewis model [1]. Arthur Lewis envisaged the developing economy as characterized by dualism, in the form of a rural agricultural sector and an urban industrial sector. In the initial stages of development, the rural agricultural sector is large in size, uses traditional technology, and employs family workers on implicit wage akin to a 'work-sharing-output-sharing' basis.

The producers in this sector are subsistence farmers who carry out production mainly for their own consumption, and not for the market. The capital per worker in the rural agricultural sector is low, so the productivity of labor is low. The implicit wage paid to the workers is equal to the average product of labor, and is relatively low compared to the urban industrial sector. Since there is vast pool of surplus labor in the rural agricultural sector, the marginal product of labor is zero, and workers can be extracted without reducing the total output of the sector. On the other hand, the urban industrial sector is small in size, uses modern technology, and employs hired workers on explicit wages. The producers in this sector are capitalists who carry out production with the sole intention of maximizing profit through sales in the market. The capital per worker in the urban industrial sector is high, so the productivity of labor is high. The explicit wage paid to the workers is equal to the marginal product of labor, and is relatively high compared to the rural agricultural sector. There is no surplus labor in the urban industrial sector, so the marginal product of labor is positive.

The rural-urban wage differential acts as an incentive for workers to migrate from the rural agricultural sector to the urban industrial sector. This process not only drives urbanization, but also facilitates structural transformation of the economy. Transferring labor from the low productivity rural agricultural sector to the high productivity urban industrial sector increases overall output with no damage or loss to the agricultural sector. This is because the marginal product of surplus workers is zero. In the urban industrial sector, total output exceeds the total cost of production which results in positive profit. This profit is immediately and fully reinvested into the business by the capitalist. The capital stock thus increases, which increases the demand for labor. More workers are attracted to the urban industrial sector from the rural agricultural sector. According to Lewis, this process will continue until all the surplus labor in the rural agricultural sector has been transferred to the urban industrial sector. This is when a country will reach a state of development, according to Lewis.

In one ponders upon the Lewis model even superficially, the climate change implications of the model become immediately obvious. While structural change may be conducive to development, it is detrimental to the environment. As people move into cities, each person's carbon footprint increases. Soon we reach a juncture where the accumulation of these enlarged footprints creates a huge dent in environmental quality.

As Bangladesh is progressing in its development journey, its economy is undergoing structural change. According to International Labor Organization's (ILO) estimates, in 1991 the share of agriculture in employment in Bangladesh was 69.5 percent, whilst the share of services in employment was 16.9 percent. However, in 2018, the share of agriculture in employment had declined to 37.6 percent, whereas the share of services in employment increased to 41 percent. Such simultaneous contraction of the size of the agriculture sector and the expansion of the size of the service sector is a manifestation of structural change in the economy.

The subsequent sections of this paper will elucidate that this structural change is accompanied by rising temperatures and greater emissions of greenhouse gases. Therefore, the Lewis model offers a valid framework for the nexus between urbanization and climate change in the context of Bangladesh**.**

3. Literature Review

Climate change is the most common indicator of the urbanization-led environmental degradation in the existing literature which is approximated by the level of carbon dioxide (CO_2) emission. Underscoring the necessity of identifying the possible factors attributing to CO_2 emissions, Bargaoui and Nouri (2017) performed a panel data analysis of the CO_2 emissions driving forces in the context of a panel of countries during the period 1890 and 2010. The estimations following the regression analysis revealed positive but statistically insignificant impacts of urbanization on CO_2 emissions while population, gross domestic product (GDP) per capita and industrialization were referred to be the key determinants of CO_2 emissions in these countries. In contrast, Zhang *et al.* (2017), using a similar methodology, found evidence of a non-linear relationship between urbanization and CO_2 emissions in the context of a panel of 141 countries over the period 1961 to 2011. The authors asserted that initially as urbanization increases it leads to a fall in the level of CO_2 emissions, however, at a certain point in time the relationship gets reversed whereby further urbanization accounts for higher levels of CO_2 emissions. In line with the estimations, it was found that the threshold level of urbanization was 73.80% which implied that urbanization imposes negative externalities on the environment when three-fourths of the population resides in the urban areas.

In a study by Dash and Mallick (2017), the dynamics engulfing urbanization and annual temperature rise in the middle-east was empirically investigated. The authors employed annual data from 1990 to 2012 and used panel ordinary least squares estimation technique to estimate a model in which average annual temperature was regressed as a function of urbanization and other crucial control variables. Based on the estimations, the authors proposed a positive linkage between urbanization and annual average temperatures across the middle-eastern region. The effects of urbanization on emissions of several greenhouse gases were indirectly reviewed in an environmental Kuznets curve analysis by Aung *et al*. (2017). The results obtained clearly linked urbanization to greenhouse emissions since both the estimated short and long run coefficients attached to the urbanization variable were found to be positive and statistically significant in all the three cases, implying that a rise in the urban population growth leads to simultaneous rises in the emissions of the aforementioned greenhouse gases. In another study by Chapman *et al.* (2017), the impacts of urbanization and climate change on the urban temperatures was reviewed via a systematic review of scientific articles from Jan 2000 to May 2016. The authors have advocated that the magnitude of the impact of urbanization on temperature rise varied across nations. The idea was also put forward that the urbanization-temperature rise nexus displayed ambiguity, as in some regions of North-Eastern USA urban population growth resulted in local temperatures going up by as much as 5 degrees Celsius, while it conversely led to lower temperatures in Paris and Brussels.

4. Methodology

This study is based on annual time series data of Bangladesh from 1991 to 2016. The dependent variables were carbon dioxide emissions measured in kilotons, methane emissions measured in kilotons of equivalent carbon dioxide emissions, and annual average temperature change. Data for all the dependent variables was collected from the Food and Agriculture Organization of the United Nations' Statistical Database (FAOSTAT). The independent variables were the urban population as a share of the total population, value added by the industry sector as a percentage of GDP, net foreign direct investment inflows measured in current US dollars, GDP per capita measured in constant 2010 US dollars, and renewable energy consumption as a share of total final energy consumption. Data for all the independent variables was collected from World Bank's World Development Indicators (WDI) database.

At first, data of all the variables were tested for unit root in order to determine the stationarity of the variables that are considered in this paper. We used the augmented Dickey-Fuller unit root tests to detect possible existence of unit roots, if any, in our data set. The general form of the augmented Dickey-Fuller test equation is given as

$$\Delta y_t = a_0 + \gamma y_{t-1} + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \varepsilon_i \quad (1)$$

$$\text{where,} \gamma = -\left(1 - \sum_{i=1}^{p} a_i\right) and\ \beta_i = -\sum_{i=1}^{p} a_j$$

The null hypothesis of the augmented Dickey-Fuller test is that the variable contains a unit root. The alternative hypothesis of the augmented Dickey-Fuller test is that the variable was generated by a stationary process. The decision rule is that if $\gamma = 0$, then we cannot reject the null hypothesis that the variable contains a unit root.

Once the variables were found to be stationary, the Johansen cointegration test was run to find possible linear combinations of the variables which could be considered stationary. Cointegration is a measure of the degree to which two values are sensitive to the same mean over a given time period. Two time series are said to be cointegrated if their linear combination is stationary. Cointegration, however, does not indicate the direction of the relationship between two time series.

The regression analyses were preceded by the Granger causality test (Granger 1969, 1988) and the Vector Error Correction Model (VECM) approach to detect the long and short run causal associations. The presence of non stationarity can lead to ambiguous or misleading conclusions in the Granger causality tests (Engel and Granger, 1987). Only when the variables are cointegrated, it is possible to deduce that a long run relationship exists between the non-stationary time series.

When we take y and x as our variables of interest, then the Granger causality test (Granger, 1969) determines whether past values of y add to the explanation of current values of x. If previous changes in y do not help explain current changes in x, then y does not Granger cause x. However, it must be kept in mind that Granger causality is not true causality, and making such inferences would lead to the *post hoc ergo proter hoc* ("after this, therefore because of this") fallacy. In this paper, the causality tests among all the concerned variables are conducted. After confirming the long run causalities between the variables considered in the model, the Vector Error Correction Model (VECM) approach provides the short run causal relationships. Engle and Granger (1987) showed that the VECM is an appropriate method to model the long-run as well as short-run dynamics among the cointegrated variables. A VECM is a type of a restricted vector autoregressive (VAR) model, which has cointegrating relations built into the specification. These cointegrating relations restrict the long run behaviour of the endogenous variable to converge to their cointegrating relationships. Hence, deviations from the long-run equilibirium in the previous lag are corrected in the next lag. This mechanism is known as error-correction, and it performs a series of partial short-run adjustments.

These tests are followed by regression analysis using the technique of Dynamic Ordinary Least Squares (DOLS) (Stock and Watson, 1993). The DOLS estimator was chosen since it is consistent and asymptotically efficient even if the independent and dependent variables are cointegrated. The generic specification of the DOLS model is as follows:

$$Y_t = \beta_0 + \theta X_t + \sum_{j=-p}^{p} \delta_j \Delta X_{t-j} + u_t \qquad (2)$$

Where, ΔX_{t-p} = value of independent variable X, lagged P units in the past, X_t = value of the independent variable X at time t, ΔX_{t+p} = value of independent variable X, lagged P units in the future.

If the dependent and independent variables are cointegrated then they have a shared stochastic trend. Under such circumstances, the DOLS estimator is especially useful since it is consistent even if the independent variables are endogenous. However, since cointegration tests can often be misleading, it is imperative that models are firmly grounded on economic theory and sound logical reasoning.

For robustness check, we also consider the Fully Modified Ordinary Least Squares (FMOLS) estimator. The generic specification of the FMOLS model is as follows:

$$y_t = \beta_0 + \beta_1 z_t + e_{1t} \qquad (3)$$

$$\Delta z_t = e_{2t}$$

$$\begin{bmatrix} e_{1t} \\ e_{2t} \end{bmatrix} = N\, i.i.d \left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_1^2 & 0 \\ 0 & \sigma_2^2 \end{bmatrix} \right)$$

where, e_{1t} and e_{2t} are residuals that are stationary but may be correlated with each other and have serial correlation within themselves. The FMOLS estimator was chosen since it can handle models where the errors may be serially correlated and the independent variables may be endogenous.

5. Results

To begin with, the entire dataset considered in this paper is tested for possible unit roots using the augmented Dickey-Fuller test. The results of the augmented Dickey-Fuller test are shown in Table 1.

Table 1. Results of Augmented Dickey-Fuller (ADF) Unit Root Test.

Variable	ADF Statistic [a]	Critical Value	Decision on Stationarity
		First Difference I (1)	
CO2	-4.08**	-3.59	Stationary at first difference I (1)
CH4	-5.61*	-3.59	Stationary at first difference I (1)
ATC	-5.68*	-3.60	Stationary at first difference I (1)
UPOP	-3.96**	-3.59	Stationary at first difference I (1)
$UPOP^2$	-3.31***	-3.59	Stationary at first difference I (1)
IND	-3.59**	-3.59	Stationary at first difference I (1)
FDI	-3.93**	-3.59	Stationary at first difference I (1)
GDPPC	-4.79*	-3.59	Stationary at first difference I (1)
REC	-3.84**	-3.59	Stationary at first difference I (1)

Notes: (a) Considering both constant and trend; Critical Values are given at 95% level; The optimal lag selection was based on the Schwarz Information Criterion (SIC); *, **and *** denote statistical significance at 1%, 5% and 10% levels respectively.

Since the test statistics are statistically significant for all of the variables, we can reject the null hypothesis that the variables at first difference contain unit roots. In light of the results of the unit root test, it can be concluded that all the variables included in the regression models are stationary at their first differences, I(1), which nullifies the possibility of the regressions to be performed being spurious. The stationary tests were followed by the Johansen test of cointegration between the variables.

Table 2. Results of Johansen Cointegration Test.

Model	Null	Alternative	Trace Statistic	95% Critical Value	Decision
			Trace Test		
(i)	r = 3	r = 4	50.20**	47.85	4 cointegrating equations
(ii)	r≤3	r = 4	55.57*	47.85	4 cointegrating equations
(iii)	r≤4	r = 5	30.56**	29.79	5 cointegrating equations
			Maximum Eigenvalue Test		
Model	Null	Alternative	Max-Eigen Statistic	95% Critical Value	Decision
(i)	r = 1	r = 2	51.90*	40.07	2 cointegrating equations
(ii)	r≤1	r = 2	53.90*	40.08	2 cointegrating equations
(iii)	r≤3	r = 4	33.22*	27.58	4 cointegrating equations

*Notes: Linear deterministic trend; Selection of the lag is based on Schwartz Information Criterion (SIC); *, **and *** denote statistical significance at 1%, 5% and 10% levels respectively.*

Both the trace statistic and maximum eigenvalue statistic of the Johansen cointegration test are statistically significant, so we can reject the null hypothesis of no cointegration. The Johansen cointegration test results in Table 2 show that there is statistical evidence implying the presence of cointegrating equations in the regression models. Thus, there is long run association between the variables considered in the models whereby the prerequisites of stationarity and cointegrating relationships for proceeding to the causality analysis are fulfilled.

The long run causal associations between the variables incorporated in the regression models are analysed using the Granger causality test. The corresponding results are reported in Table 3. The results obtained from the test provide robustness to the regression findings since, in light of the causality test estimations, there is a bidirectional causal association between the share of urban population (UPOP) and CO_2 emission and unidirectional causalities running from UPOP to methane (CH_4) emission and annual average temperature change (ATC) respectively. This implies that in the long run, urbanization does have the power to influence the causes and effects of climate change by stimulating change in the corresponding variables considered in this paper.

Table 3. Results from Granger Causality Test (Lag=2).

Model	Null Hypothesis	F – Stat.	Decision on Causality
(i)	UPOP does not Granger Cause CO_2	3.52**	Bidirectional Causality
	CO_2 does not Granger Cause UPOP	2.99***	
(ii)	UPOP does not Granger Cause CH_4	3.86**	Unidirectional Causality
	CH_4 does not Granger Cause UPOP	0.70	UPOP $\longrightarrow$ CH_4
(iii)	UPOP does not Granger Cause ATC	2.72***	Unidirectional Causality
	ATC does not Granger Cause UPOP	0.44	UPOP $\longrightarrow$ ATC

*Note: The estimated F-Statistics are tested to be statistically significant at 10% level of significance; *, **and *** denote statistical significance at 1%, 5% and 10% levels respectively; the optimal lag length selection is based on the Schwarz Information Criterion (SIC).*

The short run causal associations derived from the VECM causal analysis are reported in Table 4. According to the estimated results, a short run unidirectional causality is found to be running from UPOP to CO_2 portraying the power of urbanization in influencing CO_2 emission in Bangladesh. In contrast, a reverse unidirectional causal association is found between UPOP and CH_4. This suggests that although urbanization can account for changes in CO_2 emissions in the short run, it does not influence CH_4 emissions in the short run. On the other hand, no causal short run association is found between UPOP and ATC implying the inability of urbanization in causing changes in the annual temperature in Bangladesh in the short run.

Table 4. Results from Vector Error Correction Model Causality Test.

Model	Null Hypothesis	Chi Sq. –Stat.	Decision on Causality
(i)	UPOP does not Granger Cause CO_2	7.86*	Unidirectional Causality
	CO_2 does not Granger Cause UPOP	0.37	UPOP $\longrightarrow$ CO_2
(ii)	UPOP does not Granger Cause CH_4	3.09	Unidirectional Causality
	CH_4 does not Granger Cause UPOP	6.52**	CH_4 $\longrightarrow$ UPOP
(iii)	UPOP does not Granger Cause ATC	1.47	No Causality
	ATC does not Granger Cause UPOP	0.97	

*Note: The estimated F-Statistics are tested to be statistically significant at 10% level of significance; *, **and *** denote statistical significance at 1%, 5% and 10% levels respectively; the optimal lag length selection is based on the Schwarz Information Criterion (SIC).*

The estimated coefficients following the DOLS and the FMOLS regression are reported in Table 5. In general, the results from both the regression analyses exhibit similar signs but only the FMOLS estimates are found to be statistically significant. The regression results confirm that urbanization indeed is one of the prime reasons to account for the causes of climate change in Bangladesh. As far as the greenhouse gas emissions are concerned, the results show that initially the relationships of CO2 and CH4 emissions with UPOP are negative and statistically significant. However, the signs get reversed when the squared term of the UPOP variable is considered, implying that although initially a rise in UPOP can attribute to lower volumes of these two greenhouse gases, in the long run UPOP growth does exert a negative impact on the environment by boosting these emissions and attributing to climate change. Moreover, the relationship between ATC and UPOP also displays similar trends implying that in the long run, urbanization does attribute to higher temperatures in Bangladesh. Thus, the regression results are in line with suggesting the negative impacts of urbanization on climate change in Bangladesh. The regression results also portray the negative relationships between renewable energy consumption and climate change since the corresponding negative and statistically significant estimated coefficients attached to renewable energy consumption (REC) in all three models imply that as the amount of consumption of renewable energy increases within the economy, emissions of CO_2 and CH_4 go down which is also reflected in simultaneous reduction in annual change in temperatures. Furthermore, the estimated coefficients attached to gross domestic product per capita (GDPPC) in all three models are found to be negative and statistically significant, which implies that economic growth does have a positive impact on mitigating climate change in Bangladesh. This could be because as the economy of Bangladesh grows, the purchasing power of its people increases which enables greater use of the relatively expensive non-renewable energy resources and CO2 and CH4 emissions decline and the ATC reduces simultaneously.

Table 5. Results from FMOLS and DOLS Model Estimation.

Dependent Var.	CO^2		CH^4		ATC	
Regression	FMOLS	DOLS	FMOLS	DOLS	FMOLS	DOLS
UPOP	-11734.3*	-16058.4	-6807.9***	-5480.6	-5.04**	-0.48
	(3607.6)	(4210.1)	(3652.3)	(3183.4)	(0.28)	(0.56)
$UPOP^2$	335.5*	470.4	230.9**	256.7	0.09***	0.02
	(92.6)	(135.8)	(93.7)	(102.7)	(0.01)	(0.01)
IND	594.9	-3237.1	-1170.82**	-3221.4	0.84**	-0.03
	(525.2)	(947.9)	(531.7)	(716.7)	(0.06)	(0.08)
FDI	$1.6*10^{-06}$	$-8.2*10^{-06}$***	$-1.4*10^{-06}$	-1.07***	$1.4*10^{-09}$**	$-5.7*10^{-10}$*
	$(1.3*10^{-06})$	$(1.3*10^{-06})$	$(1.3*10^{-06})$	(10.0)	$(8.8*10^{-11})$	$(2.0*10^{-10})$
GDPPC	-136.5**	-125.8	-116.4**	-117.7	-0.07**	-0.01
	(54.6)	(77.3)	(55.3)	(58.4)	(0.01)	(0.01)
REC	-1057.6*	-926.633	-414.0***	-88.0	-0.42**	-0.02
	(245.8)	(219.8)	(248.8)	(166.2)	(0.01)	(0.04)
Constant	234250.9*	34235.4	23195.4**	227205.4	109.7**	8.84
	(62992.1)	(63446.2)	(63773.7)	(0.49)	(0.02)	(9.83)
Adj. R^2	0.95	0.48	0.96	0.49	0.98	0.41

*Note: The standard errors are provided within the parentheses; *, **and *** denote statistical significance at 1%, 5% and 10% levels respectively.*

6. Conclusion

Cities contribute to and are affected by climate change. Urbanization is accompanied by an increase in industrialization and an increase in per capita energy consumption, both of which exacerbate climate change. The findings of this study have established a link between urbanization and climate change by using empirical evidence. This paper provides impetus for further research on the nexus between urbanization and climate change. Cities are at the frontline of the battle against climate change.

In light of the findings of this study, we make the following recommendations for policy makers and urban planners:

- Engage stakeholders and conduct a vulnerability assessment study to identify adaptive capacities of cities
- Identify issues, convert issues to objectives, and mainstream climate change into urban planning
- Prioritize adaptation options through a clear implementation framework that integrates into existing policies, whenever practical and feasible
- Develop a monitoring and evaluation system to measure the implementation progress, and weigh up actions against objectives.

The results of this study are a wake-up call for policy makers to integrate climate change into urban planning. By incorporating climate change considerations, we can mitigate the adverse effects of urbanization on climate change and design the sustainable cities of the future.

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