The Great Recession, the Treadmill of Production and Ecological Disorganization: Did the Recession Affect Ecological Disorganization Across US States, 2005-2014?

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Abstract

The treadmill of production, ecological Marxist, steady-state economics and the natural science literatures suggest that economic growth and pollution are linked. We use the economic downturn resulting from the Great Recession in 2008-2009 as a natural experiment to test this hypothesis. Specifically, we examine the effect of the Great Recession on pollution measured by the Environmental Protection Agency's Toxics Release Inventory (TRI) using maps and fixed-effects regression models for US states for the period 2005-2014. Multivariate time-series analysis demonstrates that even when adjusting for controls there is a unique and negative effect of the recession on TRI levels. We situate our findings in the relevant literature, suggest possibilities for what the recession effect may be capturing, and discuss some implications of increased pollution levels.

KEYWORDS: treadmill of production; ecological Marxism; pollution; recession; TRI emissions; ecological disorganization

1. Introduction

It has long been posited that economic production and the ecological crisis are connected. An important perspective on that connection was developed in environmental sociology (Schnaiberg 1980) and ecological Marxism (Foster 1992; O'Connor 1988) and suggests that it is constantly expanding production that is increasing environmental harm. Specifically, an increased reliance on natural resources, fossil fuels and chemical labor to intensify production is harming the environment at an accelerating rate that can only be described as a 'treadmill of production' or 'ToP' (Gould, Pellow and Schnaiberg 2008).The intensification of production generates ecological disorganization (i.e., a condition that exists when ecosystems cannot reproduce and regenerate and which has been linked to the detrimental effects of ecological additions and withdrawals on the ecosystem by Schnaiberg). This perspective about the connection between the economy and environment is also consistent with traditional or orthodox assessments in the steady state economics literature (Daly 1974, 1991), the limits to growth literature (Meadows et al. 1972; Meadows, Ragnarsdóttir and Peet 2010), the scientific literature (Rockstrom et al. 2009a, 2009b) and the social analysis of ecological footprints (Jorgenson and Burns 2007).

One area that is understudied in the entwined relationship between economic development and ecological disorganization is impeded economic development. That is, can inhibited economic development slow ecological disorganization? In other words, what is also referred to as "economic degrowth" (Kallis 2011) may have positive effects with respect to the ecological crisis. Given the extent of the current ecological crisis, those 'positive effects' may not turn back the ecological disorganization clock, but can at least temporarily obstruct the expansion of ecological disorganization, possibly even temporarily limiting the deleterious impacts of the ToP on the extent or expansion of ecological disorganization. Interesting in this regard is the potential effect of the Great Recession of 2008-2009 on the regression of the treadmill of production and on ecological disorganization. The Great Recession, which affected world markets during the early 2000s, was exacerbated by financial crises and the subprime mortgage crises in the US during 2008 and 2009 (Fligstein and Goldstein 2011). In the US, the Great Recession was marked by a decline in real gross domestic product, rising unemployment, a declining and stagnant stock market, and a fall in household net worth and manufacturing output and productivity (Kotz 2009). These conditions essentially establish a natural experiment in which the effects of slowing the ToP on ecological disorganization can be observed. To do so, we examine the trend in toxic releases by US manufacturers across US states before (2005-2007), during (2008-2009) and after (2010-2014) the Great Recession as measured by the US Environmental Protection Agency's Toxics Release Inventory (TRI).

2. Background

The deleterious effects of economic production on environmental stability and the disorganization of ecosystems have long been recognized. In our view, there are two primary explanations of this association since the 1970s. The first includes what can be classified as more traditional or orthodox economic analyses of that connection illustrated in the steady state economics literature by Daly (1973), the *Club of Rome* 'Limits to Growth' report (Meadows et al. 1972) and its 30 year up-date (Meadows, Randers and Meadows 2004), and Nicholas Georgescu-Roegen's (1971) *The Entropy Law and Economic Process,* which led to the development of ecological economics. The second approach characterized as a heterodox or non-traditional economic approach to this subject includes theory and research in environmental sociology and ecological Marxism associated with the work of James O'Connor, John Bellamy

Foster, Allan Schnaiberg, and many empirical studies of related arguments by Andrew K. Jorgenson.

The first notable empirical effort to address the relationship between economic growth and ecological (in)stability was Meadows et al.'s well known study, *The Limits to Growth*. Using computer simulations, the authors examined three projections of ecological collapse using industrialization, pollution, ecological resource depletion, food production and world population data, while accounting for the ability of changes in technology to offset some of the resource availability problems that would emerge. Two of the three models predict a global ecological collapse after the middle of the 21st century, with the third model reaching an equilibrium state. The Report was widely criticized when first released (Bardi 2011), and was long attacked by radical free-market proponent Julian L. Simon (2014). However, recent re-analyses (Meadows, Randers and Meadows, 2004; Bardi 2011) and reviews (Nørgaard, Ragnarsdóttir, and Peet 2010) have been much more favorable.

For his part, Georgescu-Roegen made two related arguments. He was perhaps the first to propose an elaborate explanation which argued that there were natural limits to economic growth imposed by the ecosystem. He also examined how this occurred in relation to entropy, noting that the process of production uses up stored energy (what he called 'low entropy' natural resources) and returns degraded ('high entropy') matter as waste back into the ecosystem. These ideas were extended by his student, Herman Daly, who as an economist for the World Bank popularized the idea of steady state economics. Daly also proposed that economic production has physical limits tied to the ecosystem both as a source of raw materials and as a sink for pollution. In this view, as economic production expands and consumes nature, it accelerates ecological destruction, and Daly argued for the need for state intervention to constrain the deleterious effects of economic expansion on ecosystems, proposing the need for a zero-growth or steady state economy (see also, Costanza et al. 2014).

The ideas found above are also central to other indicators of the tension or contradiction between continuous economic development and ecological disruption and disorganization. One of those measures is the ecological footprint (Rees 1992; Wackernagel and Rees 1997, 1998), which includes an index relating various aspects of consumption of ecological resources (including the pollution of ecosystems) to ecological resource availability. Related to that concept is the development of planetary boundary analysis associated with the work of environmental scientist Johan Rockstrom, chemist, Will Steffen, atmospheric physicist and former head of NASA's Goddard Institute for Space Studies, James Hanson, and, among others, the Noble Prize winning atmospheric chemist, Paul Crutzen (Rockstrom et al. 2009a, 2009b). Unlike other studies which are more critical of the ecological crisis-economic development connection, Rockstrom et al. (2009b, 475) state, 'The evidence so far suggests that, as long as the thresholds are not crossed, humanity has the freedom to pursue long-term social and economic development.'

In contrast to the view of Rockstrom et al. sits the more critical approach of the ecological crisis-economic development nexus taken up by environmental sociologists and ecological Marxists. The first major and extensively developed position on this issue was proposed by Schnaiberg (1980) in his book, *Environment: From Surplus to Scarcity,* which introduced treadmill of production theory. Drawing on Marxist arguments, Schnaiberg proposed that capitalism entered a new phase following World War II, in which production was accelerated by an increased reliance on fossil fuel and chemical energy. In doing so the treadmill of production increased ecological withdrawals (the extraction of raw materials) and ecological additions (the generation of pollution), creating increasing levels of ecological disorganization. Essentially, this argument posits that as the treadmill of production expands globally, and global capitalism expands, ecological disorganization will also expand. This outcome is not always immediately apparent because in the global treadmill of production, ecological additions and withdrawals and hence ecological disorganization, shifts across nations and there is often insufficient global pollution and resource depletion data to be able to precisely illustrate this process empirically (but see various important empirical studies related to this argument by: Jorgenson 2010, 2006; Jorgenson, Austin and Dick 2009; Jorgenson and Burns 2007; Jorgenson, Dick and Austin 2010; Jorgenson and Rice 2015).

Related arguments concerning the adverse connection between economic development and ecological disorganization have also been addressed by ecological Marxists elaborating upon observations made, though not extensively developed, by Karl Marx (Foster 1992, 2000). Important in the development of this argument was O'Connor's (1988) analysis of the contradictions of capitalism, which includes the proposition of a contradiction between capitalism and nature, or the idea that capitalism, as it expands, must destroy nature, an issue that Foster (1992) elaborates[1]. For his part, O'Connor is also critical of the more traditional, orthodox or general arguments linking economic development to ecological crisis (e.g., limits to growth, steady state economics) because in those analyses:

> 'Class exploitation, capitalist crisis, uneven and combined capitalist development, national independence struggles, and so on are missing . . .The results of these and most other modern efforts to discuss the problem of capitalism, nature, and socialism wither on the vine because they fail to focus on the nature of specifically capitalist scarcity, that is, the process whereby capital is its own barrier or limit because of its self-destructive forms

> of proletarianization of human nature and appropriation of labor and capitalization of external nature' (O'Connor 1988, 13).

In other words, those traditional views do not make it clear that the ecological crisis is an outcome of an inherent crisis within capitalism involving the contradiction between economic expansion and ecological stability (Foster 1992). This view is called the 'second contradiction of capitalism,' which Foster (1992, 78) refers to 'the absolute general law of environmental degradation under capitalism.' As Foster noted (1992, 78-79):

> 'this contradiction can be expressed as a tendency toward the amassing of wealth at one pole and the accumulation of conditions of resource depletion, pollution, species and habitat destruction, urban congestion, overpopulation and a deteriorating sociological life-environment' (in short, degraded 'conditions of production').

In Foster's view, it is 'impossible to overthrow' or overcome the second contradiction of capitalism without also overcoming capitalism's first contradiction: 'the absolute general law of capitalist accumulation' (Foster 1992, 77).

While the two approaches above connecting economic development and ecological disorganization do not agree in terms of positing a theoretical explanation for this connection – and as O'Connor and Foster argue, the traditional/orthodox approach does not even attempt to make such a theoretical argument – both views indicate that accelerating economic production expands ecological disorganization, eventually leading to an ecological crisis. Both views also suggest that controlling the ecological crisis requires controlling economic production. However, it is difficult to provide empirical evidence on this latter point because specific economic conditions must first exist – conditions in which production is curtailed – to ascertain if the assumption that limiting production will lead to a decline in ecological disorganization.

Such a condition was presented by the global economic recession in 2008 through 2009. The effects of the recession were seen globally, but also had specific impacts, which affected many aspects of the US economy (Bagliano and Morana 2012; Meyer and Sullivan 2013). These impacts also varied across states (Estevão and Tsounta 2011), with research indicating a differential effect of the recession on air pollution across states (Tong et al. 2015). Indeed, several recent studies have shown that the Great Recession impacted the generation and dispersal of certain air pollutants (Castellanos and Boersma 2012; Lin et al. 2010; Russell, Valin and Cohen 2012; Vrekoussis et al. 2013). Whether the Great Recession, by limiting economic development and the expansion of the treadmill of production, also generated a decline in other forms of pollution is currently unknown.

3. The Current Study

Building on the above theoretical arguments and empirical observations, the current study assesses the effect of the Great Recession on the production of toxic pollution in the United States across states. If, as the above arguments suggest, that economic development and ecological disorganization are linked, then one would expect that the effect of the Great Recession would be to significantly alter the distribution of pollution across time within US states. In Schnaiberg's ToP approach, ecological additions or pollution is identified as one of the deleterious outcomes of production. In the current study, we measure ecological additions employing the US EPA's Toxic Release Inventory (TRI). The TRI includes emission data on more than 650 chemical pollutants, and thus provides a fairly comprehensive indicator of ecological additions.

We have chosen to examine the effect of the recession on toxic releases at the state level because we are interested in the trends in state economies relative to their production policies. Part of the focus of the ToP perspective is how states (e.g. US states, countries) help reduce or fail to reduce pollution; therefore to accurately test this approach, a state-level analysis is necessary. Following the argument about the treadmill of production made by Schnaiberg, we employ toxic releases to measure one of the forms of ecological disorganization he argued resulted from the ToP, namely ecological additions. As Schnaiberg (1980) argued, as the ToP expands and accelerates, ecological additions are expected to increase. During a recession where the growth/expansion of the ToP is constrained, it would follow that ecological additions would also be curtailed. Moreover, research has documented the central role of the state in ToP analysis (e.g. Bond 2007; Stretesky, Long and Lynch 2013a; York 2004). In fact, Schnaiberg (1980, 249) himself, wrote of the importance of the state in "slowing" the treadmill, suggesting that "[i]f the treadmill is to be slowed and reversed, the central social agency that will have to bring this about is the state, acting to re-channel production surplus in non-treadmill directions."

Additionally, research has demonstrated that the intensity of the Great Recession varied across US states (Mian and Sufi 2012), which suggests that analysis of the effects of the recession should be conducted at the US state-level. Martin (2011) has argued for the need to consider location geography in assessing recession effects and a great deal of research examining the impact of the recession has been conducted at the state-level (e.g. Erceg and Levin 2014; Estevão and Tsounta 2011; Fernald 2015).

In our state-level analysis we hypothesize two outcomes linking economic development pathways to pollution and the recession.

H1: In comparison to the pre-recession period, (2005-2007), the effect of the Great Recession period in the US (2008-2009) will be to generate a decrease in toxic emissions measured in the toxics release inventory.

H2: In comparison to the recession period, pollution (measured by TRI emissions) will increase during the post-recession period (2010-2014) within states.

The methods and data employed to address these hypotheses are discussed below.

4. Method

To examine the effect of the recession on pollution we first map changes in TRI emissions within states over the period 2005-2014. Next we estimated fixed-effects panel models based on longitudinal data for the period 2005-2014 for the 50 US states. We control for several competing economic explanations of pollution tied directly to the production process. The variables used in the analysis are described below. The data allow us to examine pollution patterns three years before the recession 2005-07, the two years during the recession 2008-09, and five years after the recession 2010-14.

4.1 Dependent Variable

TRI emissions. To measure pollution, we used data from the US Environmental Protection Agency's (EPA) Toxics Release Inventory (TRI; EPA 2016). TRI contains data on the disposal and release of approximately 650 toxic chemicals in the US. According to the EPA (2017), the chemicals that are included in the TRI are those that cause, "(1) cancer or other chronic human health effects, (2) significant adverse acute human health effects, and (3) significant environmental effects." The primary purpose of the TRI is to inform the public about the types and levels of chemical pollutants that are released into the environment. The TRI was created as a result of the chemical accident that took place at Bhopal, India in 1984 where thousands of people died as a result of the release of methyl isocyanate from the Union Carbide Chemical plant. After the accident, the public demanded more information about toxic chemical releases which prompted the US government to create the TRI (Burns, Lynch and Stretesky 2008). The EPA states that the goal of the TRI is to be a premier source for tracking chemical releases and accessing information on public exposure to toxic chemicals, to provide “a way for citizens to better understand possible sources of pollution in their communities” (EPA 2017). Despite the usefulness and benefits of the TRI data, it does have some weaknesses. The TRI does not cover all toxic chemicals that are released by firms and it does not report quantifiable data on exposure that people may experience from the chemical releases (GoodGuide 2017). While these weaknesses need to be noted, the TRI is one of the most compressive sources of chemical pollution data in the US and therefore we use it in our analyses.

The TRI data measure the total reported chemicals released in metric tons per year for industrial and federal facilities for each state for air emissions, surface water discharges, underground injections, and releases to land. The TRI, then, is a measure of the total annual ecological disorganization that takes place in each state that results from the production process. The mean TRI emissions for states during the time-period is 21,300,000 metric tons (mt) (standard deviation = 37,800,000mt). TRI emissions is highly skewed (9.29), we therefore transform the TRI emissions variable into its natural log (ln) form.

4.2 Independent Variable

Recession. The effect of the Great Recession on pollution is our primary interest in this study. Therefore, we measure the potential effect of the recession over time with a dichotomous variable that indicates whether a year was during the recession (2008 and 2009) coded ‘1’ or a year that was not during the recession (2005-07 and 2010-14) coded ‘0.’ This variable allows us to assess the effect of the recession on pollution, measured by TRI emissions, by comparing TRI levels before/after the recession with during the recession.

4.3 Control Variables

GDP per capita. According to ToP theory and ecological Marxism, ecological disorganization increases are driven by economic growth (Schnaiberg 1980). To measure economic growth, we used GDP per capita measured in $US (Bureau of Economic Analysis 2016).

Population. Research has argued that population and ecological disorganization are linked (Ehrlich and Ehrlich 1970; Sherbinin, Carr, Cassels and Jiang 2007), therefore we control for the total population of each state (US Census Bureau 2017). Population is skewed, so the variable is transformed into its natural log form.

Manufacturing sector. The ToP approach suggests that a great deal of pollution originates in the production process (Schnaiberg 1980). We therefore control for four indicators of the size and productivity of the manufacturing sector of each state, including, *the number of people employed in manufacturing, the manufacturing sector annual payroll ($1,000), the cost of materials in the manufacturing sector ($1,000)*, and *the value of shipments and receipts for services in the manufacturing sector ($1,000)*. All of these data are from various years of the American Manufactures Survey (2016), housed by the US Census. These four variables are skewed, so we transform the variables into their natural logs. We collapse the four variables into a principle component to reduce any effects of multicollinearity on the estimates. The Cronbach's α for the manufacturing index = 0.70.

4.4 Analytic Strategy

We first map the percent change in toxic releases by state (2005-2014) using three maps. The first map examines the 3 years before the recession (2005-07), the second covers the recession years (2008-09), and the third shows the five years after the recession (2010-14). Next, to test our hypotheses that the recession will reduce pollution we used longitudinal data on the 50 US states for the years 2005-2014. We employ fixed-effects panel regression models to estimate the effects of the recession on within-state changes in TRI emissions, controlling for other macro-economic variables related to production that might predict pollution levels. The fixed-effects models control for state characteristics that are not included in the models (i.e. omitted variable bias) though the intercept term. The models do not estimate between state effects.

We estimated four fixed-effects models of the relationship between the recession and TRI emissions to test our hypotheses. The first model includes only the recession variable, the second model adds in GDP per capita, the third adds the population of the states, while the fourth model adds in a principle component of the four manufacturing sector variables. To determine if we could estimate the effects of the four manufacturing control variables separately, we reran the models using Least Squares equations to estimate the Variance Inflation Factor (VIF) values to test for multicollinearity. A model including all the independent variables, control variables and the manufacturing variables separately, had a very high mean VIF value (69.70). When these four variables are collapsed into a principle component index in the full model, the mean VIF = 3.74 which is under acceptable levels. Therefore, we only report the full model with the manufacturing variables collapsed into a principle component.

5. Results

Table 1 reports the descriptive statistics of the variables in the analyses. Figures 1, 2 and 3 are maps of US states and the changes in TRI levels for the states. In states where increases are reported in the maps, this indicates that during the time period covered in the map, TRI emissions increased over that time frame. Figure 1 is a map of the change in toxic releases from

2005 to 2007 by states (before the recession) and shows general increases in TRI emissions across 20 states during that time frame. Figure 2 maps the changes in toxic releases from 2008 to 2009(during the recession) and finds only five states with increases in TRI emissions during that time frame. Figure 3 maps the changes from 2010 to 2014 (after the recession) with 25 states showing increases in TRI emissions during that time frame. Based on these maps, it is clear that fewer states increased TRI releases during the recession compared to the time periods directly before and after the recession.

[INSERT TABLE 1 ABOUT HERE]

[INSERT FIGURE 1 ABOUT HERE]

[INSERT FIGURE 2 ABOUT HERE]

[INSERT FIGURE 3 ABOUT HERE]

Table 2 presents the results of four fixed-effects panel regression models predicting TRI emissions. Based on the results of all four models, the recession appears to negatively affect TRI emissions. The coefficients for the recession are negative and significant demonstrating that the recession years (coded 1) have lower levels of TRI emissions compared to the years before and after the recession. Additionally, as the ToP literature would suggest, increases in GDP per capita are associated with increases in TRI emissions according to Models 2-4. The fact that both the recession and GDP per capita are significant predictors of TRI emissions suggests that in addition to overall economic performance of a state (GDP per capita), there is also a unique effect on pollution of being in a recession. Models 3-4 report mixed findings for population. In Models 3 and 4 the relationship between population and TRI emissions is negative and significant. This suggests that more toxic releases occur in less populated states. Finally, in the case of manufacturing sector size and performance, the effect on TRI emissions of the manufacturing sector is significant and positive (Model 4), suggesting that increases in the size and productivity of the US manufacturing sector are associated with increases in TRI emissions. This finding supports the treadmill of production argument, as the ToP perspective highlights the importance of the manufacturing sector in the generation of pollution.

[INSERT TABLE 2 ABOUT HERE]

6. Discussion

In this paper we found evidence that the recession reduced pollution as measured by TRI emissions. We did this in two ways. First, we mapped TRI levels before, during and after the recession by state. An inspection of the three maps clearly shows lower levels of TRI emissions across states during the recession compared with states before and after the recession. Next, we employed fixed-effects regression equations to model the effect of the recession on TRI emissions, controlling for other macro-economic production-related variables. We found a unique negative effect for the recession on TRI levels controlling for GDP per capita, population and indicators of the size and performance of the manufacturing sector.

Our findings support the ToP and ecological Marxism literatures which suggest that increases in productivity are the primary drivers of ecological disorganization and vice versa, that decreases in production should decrease pollution (e.g. Foster 1992; Lynch et al. 2013; O'Connor, 1988; Schnaiberg 1980; Stretesky, Long and Lynch 2013a). We use GDP per capita as a proxy measure for economic performance and find that increases in GDP per capita are positively related to increases in TRI emissions. However, we also find that there is a unique effect of the recession on TRI levels that is different from economic performance and growth measured using GDP per capita, and size and performance of the manufacturing sector. This is an interesting finding, which deserves the attention of future research.

While unpacking what this recession effect might be empirically is beyond the scope of this paper, we will offer a few possibilities. First, the levels of each chemical recorded in the TRI have a base threshold that must be crossed in order to require reporting. Therefore, during economic downturns like the recession of 2008-09, production decreases which means that toxic releases should also decrease (as the coefficient of GDP per capita demonstrates in the above analysis). In some cases, the reduction in some TRI chemicals during recessionary periods may drop firms below the TRI reporting thresholds, and therefore appears to reduce TRI emissions more than what actually occurred because they are no longer required to report their emissions. Additionally, companies may be more willing to put the effort into reducing TRI emissions below the threshold in times of economic uncertainty because they are worried about staying profitable and therefore do not have to pay costs associated with TRI monitoring and reporting(see also De Marchi and Hamilton 2006). However, during times of economic growth, companies are less likely to worry about the money saved from reporting because the profits generated from increased productivity will dwarf any savings from not having to report to the EPA.

Second, some of the chemicals that get released in production processes may have economic value. During recessionary periods where firms are attempting to stay profitable, the cost of capturing and retaining these chemicals may be mitigated by their value. One result of this process could be a reduction in the levels of toxic chemicals released by the companies and therefore lower levels of emissions reported to the TRI.

Third, treadmill of production theory indicates that the pace of production was accelerated following World War II by increased reliance on fossil fuel and chemical labor.

In theory, and as we suggest our data illustrates, the continued expansion of the treadmill of production as well as its contraction during the recessionary period, affects toxic emissions independently of GDP. Controlling for GDP in this case is important since a large proportion of US GDP is generated by the service sector. In the US, the service sector accounts for approximately 79% of total GDP, with manufacturing/industry/mining/construction/accounting for about 20%, and agriculture about 1% of GDP. Thus, the GDP measure is primarily measuring the impact of the service sector on GDP, and not the specific impact of the treadmill of production.

With respect to the above, it should also be noted that the close connection between the treadmill of production and the fossil fuel sector plays a potential role in the production of toxic waste. As one would expect, during the recession oil consumption in the US declined dramatically, and reached its lowest level at the end of the Great Recession, declining from about 40 quadrillion Btu in 2006, to a low of 35.5 quadrillion Btu by the end of 2008, or to about the same level of oil consumed in 1996. This reflects both a change in the scope of the treadmill of production and personal consumption habits related to gasoline consumption. According to the Energy Information Administration, fuel prices peaked in the US in 2008 during the recession at about $4.10 per gallon, declining sharply during 2009 to around $1.60 per gallon, and rising thereafter as the economy recovered and demand for fossil fuel increased. At the same time, according to the Institute for Energy Research, US oil production was declining prior to the Great Recession, stabilized during the recession, and increased following the recession. Thus, despite stability in manufacturing's share of GDP, and a sharp drop in crude oil and natural gas production in 2009, there were subsequently significant increases in crude oil and natural gas production and prices in the US, which are central components of the treadmill of production's driving mechanism. The sharp rise in post-recession fossil fuel consumption expanded the deleterious effects of the treadmill of production on the ecosystem through increased ecological withdrawals and additions. Evidence of this effect can be seen in Figure 3 in the post-recession period, which indicates that several of the states with increased ecological additions were also states where there is significant oil production and refining.

Unfortunately, it is difficult to provide a precise indicator of the treadmill of production, and instead researchers generally refer to indicators of the treadmill's effects. In order to more precisely estimate whether the treadmill of production affects pollution or other forms of ecological disorganization, a more specific indicator or set of indicators that can be used to measure that concept is needed. Thus, even after controlling for alternative explanations, whether the recession effect noted in this study is a specific measure of the effect of slowing the treadmill of production requires further research that better measures the treadmill of production.

We also believe that our findings have important policy implications, particularly if the results of our study can be generalized to the global world economic system and economic development patterns across nations. In the treadmill approach, nations are linked through the ways in which production, extraction and pollution occur across nations. Consistent with that view and our results, to reduce pollution globally, nations must cooperate to limit forms of economic expansion that contribute to pollution. The recent Paris Agreement on climate change is an example of an international policy that may generate ecologically beneficial results. Given that this new agreement has not yet been implemented, and that compliance with the Agreement is essentially voluntary and lacks externally imposed social control mechanisms, it is unclear whether merely signing the Agreement will induce compliance.

Such issues also take on heightened importance in light of recently published information connecting global pollution and health. For example, the severity of the global pollution problem was recently highlighted by a UNICEF report that noted that globally, one in seven children or more than 300 million children world-wide live in areas where ambient air pollution levels exceed World Health Organization guidelines *by a factor of six or more*, and that 2 billion children live in areas where air pollution exceeds minimum WHO air quality standards. UNICEF estimates that this level of air pollution leads to the death of approximately 600,000 children under the age of five globally each year. For the 3.2 million children born globally each year that died before age six but after the first month of life, this translates into a shocking death rate of 18.75% from air pollution. In 2014, WHO also estimated that globally seven million people die prematurely from air pollution exposure, indicating that air pollution exposure has serious consequences across age groups.

As the global air pollution map (WAQI 2016) indicates, there are a number of air pollution hotspots across the globe where the Air Quality Index (AQI) indicates extensive levels of air pollution. AQI scores of 201-300 indicate heavy air pollution, and scores of more than 300 indicate severe air pollution. On November 9th (10 AM, Eastern Standard Time), several cities recorded extremely high AQI readings of more than 500: 999 in Jinchang, China, Laredo, Texas and Coahuila, Mexico; 895 in Zonguldak and Elazig, Turkey; 880 in Izmir, Turkey; 833 in Morelos, Mexico; 753 in Varanasi, India; 547 in Lucknow, India; and multiple readings over 500 and up to 824 in Delhi, India – locations that are home to more than 34 million people.[2] At issue is whether constraining the expansion of the treadmill of production might help mitigate these high levels of pollution experienced by a large number of people globally.

7. Conclusion

This study focused attention on prior research and theory which suggests that escalating economic production has deleterious ecological impacts, and the implication of those studies that long term economic growth generated by the manufacturing of commodities in particular drives ecological destruction and disorganization. That literature has a long history, and a number of studies indicate that expanding economic production and ecological disorganization co-occur. Positions that support this view range from steady-state economics, limits to growth analysis, de-growth studies, environmental sociology and ecological Marxism, indicating that there is some widespread consensus across different theoretical and empirical views of the economic development-ecological destruction nexus. We argued that these views also imply that one mechanism for controlling ecological disorganization is constraining economic production. We noted, however, that the question of whether a decline in economic production has a clear connection to a reduction in pollution has not been widely addressed, though as noted, a handful of studies examining the effect of the recession on air pollution support that connection. To further address whether a decline in economic production has positive ecological effects, we assessed the effect of the Great Recession across US states on toxic waste emissions recorded in the TRI before, during and after the Great Recession, finding evidence that indeed, a stalled or regressive economic situation reduced toxic emissions. This finding also lends support to various economic/ecological models which suggest a connection between economic production and ecological disorganization/pollution.

The problem this analysis presents is the indication of a trade-off between economic production and economic expansion and the detrimental effects of economic production and expansion on ecosystems and hence the health of species in those ecosystems. Certainly, it would be desirable for economic expansion and ecosystem stability and health to co-exist. This is the hopeful scenario. As early as 1971, William Ruckelshaus (1971), the first Administrator of the US EPA, drew attention to what he called the 'technology gap' related to pollution control, and many have argued that technological innovations will solve the pollution problem associated with manufacturing. Now, forty-five years later, we continue to await technological innovations that will solve the problem of pollution, and in the meantime continue to allow the treadmill of production to expand with minimal efforts to limit its deleterious ecological impacts.

Endnotes

1. The AQI reflects the US EPA AQI, which normally is scored on a scale of 5-500. Some nations, however, use different AQI indexes, generating higher scores on the AQI scale. These score can change throughout the day since portions of those scores are based on changes in hourly readings, while other portions of the scale represent 24-hour averages for some pollutants. As an example of how those scores change throughout the day, we also examined AQI scores on waqi.info at 3 PM Eastern Standard Time on November 9th. At that time, Kashi, China had an AQI of 534; Jiuquan, Baiyin, Lanzhou (four sites), and Zhangye, China reached 999; Dingxi, China reached 580; Pingliang, China had scores ranging from 580 to 884; Hurriyet, Turkey reached 565; Batman, Turkey, 890.
2. While here we combined the views of O'Connor and Foster, there has certainly been some debate about their views and the different implications of each approach to ecological Marxism, which involve theoretical distinctions about the relationship between economic and ecological crises under capitalism. Foster (2002) himself has addressed this issue. As Foster noted, the (external) ecological contradictions of capitalism stem from the (internal) organization of capitalism, and there is thus some debate about how to best explain this relationship between ecology and economy under capitalism. The issues here involve how, in the first instance, capitalism generates ecological crisis (which is not really the center of the debate), and second – and this is where the debate enters – whether the ecological contradictions of capitalism are to be seen as an independent sphere of effect feeding back on capitalism and possibly causing ecological crisis, or whether the ecological ought to be conceptualized as part of the internal dynamic of the operation of capitalism. In O'Connor's view, there are two

“contradictions” (the first view), while for Foster, the two problems are inter-related. The difference between these views also involves whether the view of Marx is interpreted as including a position on ecological crisis connected to capitalism’s crises more generally (Foster), or is posed as a critique and extension of Marx’s view that requires examining the two spheres separately and examining their interactions (O’Connor). Solving this theoretical debate does not, we believe, affect nor is relevant to the argument as used in our approach.

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Table 1 Descriptive Statistics for Variables in the Analyses

Variable	Mean	St. Deviation	Minimum	Maximum	Skewness
TRI emissions	$2.1*10^7$	$3.8*10^7$	53313	$6.4*10^8$	9.29
Recession	0.20	0.40	0	1	-
GDP per capita	46807.3	8671.6	31043	74289	0.73
Population	6141353	6778035	554246	$3.9*10^7$	2.56
Employees	235614.3	238042.2	7620	1448485	2.10
Annual payroll	$1.2*10^7$	$1.2*10^7$	382107	$7.1*10^7$	2.28
Cost of materials	$6.1*10^7$	$7.3*10^7$	3734564	$5.0*10^8$	2.90
Value of services	$1.1*10^8$	$1.2*10^8$	5955627	$7.3*10^8$	2.45

Table 2. Fixed-Effects Regression Coefficients (*b*) and Standard Errors (SE) for Determinants of TRI (ln), 2005-2014

	Model 1		Model 2		Model 3		Model 4	
	b	SE	*b*	SE	*b*	SE	*b*	SE
Recession	-0.10*	0.04	-0.08#	0.04	-0.10*	0.04	-0.80*	0.04
GDP per capita			0.00003***	$7.5*10^{-6}$	0.00003***	$7.5*10^{-6}$	0.00002*	$7.8*10^{-6}$
Population (ln)					-1.82**	0.57	-2.49***	0.59
Employees (ln)								
Annual payroll (ln)								
Cost of materials (ln)								
Value of services (ln)								
Manufacturing index							0.50***	0.13
Constant	15.86***	0.02	14.55***	0.35	42.05***	8.64	52.64***	8.92
N	500		500		500		500	
F	5.93*		9.89***		10.11***		11.76***	
R^2 *within*	0.01		0.04		0.06		0.10	

Note: ****p*<0.001, ***p*<0.01, **p*<0.05, #*p*<0.10 significance (two-tailed)

Fig. 1. Change (%) in toxic releases by state before the recession, 2005–2007

Fig. 2. Change (%) in toxic releases by state during the recession, 2008–2009.

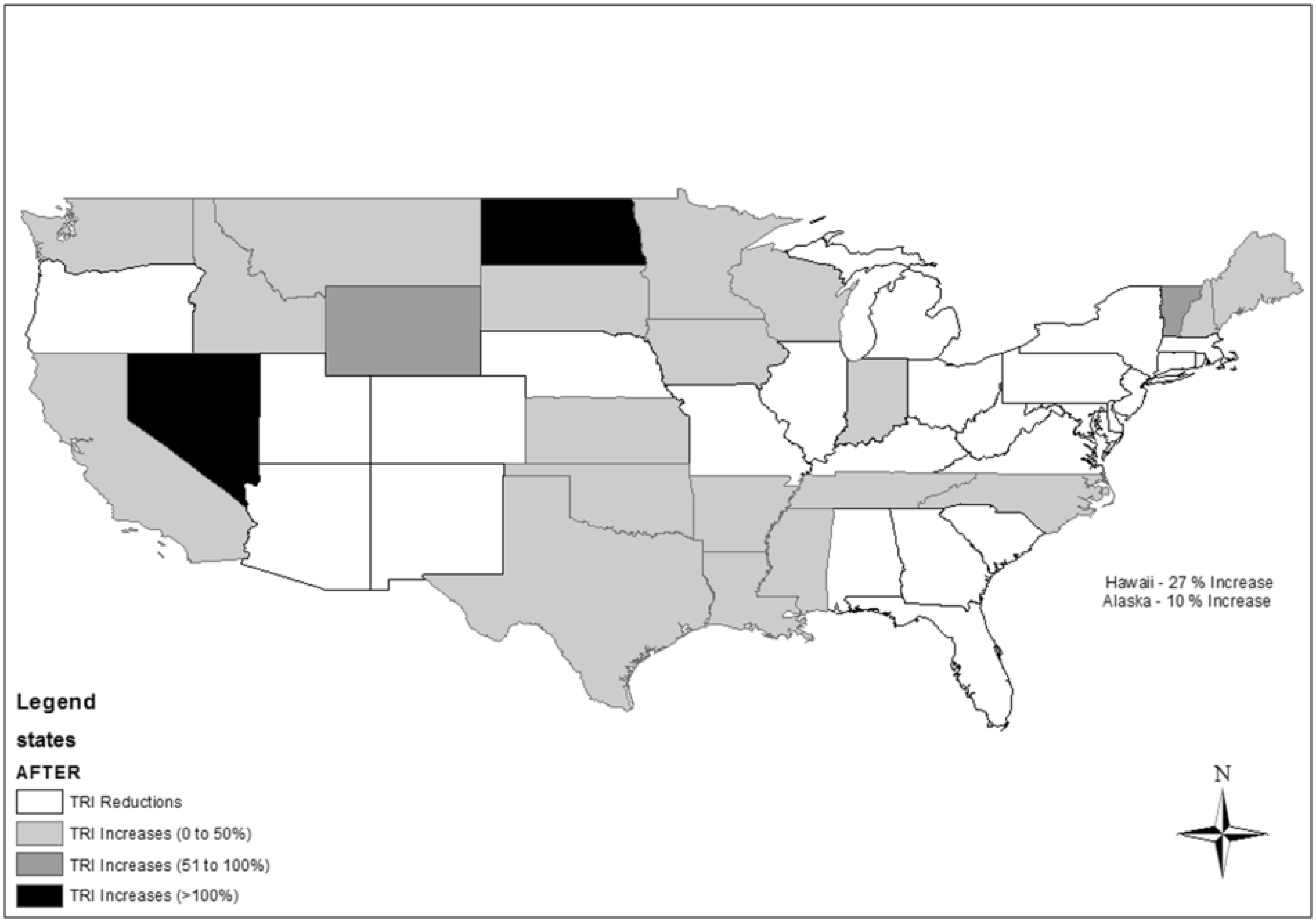

Fig. 3. Change (%) in toxic releases by state after the recession, 2010–2014.