Technological Capacity and Environmental Performance: A Research Note Using Country Level Data

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ABSTRACT: This research note examines, at the macro level, the impact of corporations' technology capacity on environmental performance. Technology capacity is loosely defined as the ability of corporations in a country to acquire or develop new technologies. Building on the IPAT equation from industrial ecology, this note proposes that technological capacity is the main channel for environmental performance improvement emerging from corporations. The analysis reveals that generally, technological capacity is linked with aggregate performance indicators and more particularly with higher degree of eco-efficiency. However, it appears that when looking at the absolute value of ecological stress, technological capacity is detrimental.

Keywords: *environmental management, aggregate data, technology*

INTRODUCTION

Many organizations have integrated principles of corporate social responsibility in their decision-making and strategy. Within these responsibilities, corporations are expected to make a fair use of the natural resources and to manage their assets in a way that reduces the ecological stress caused by their operations and products. Paradoxically, corporations are often cited as being the main contributor to ecological damages, while simultaneously, they are also viewed as the catalyst for new solutions. For example, through both hard and soft technologies, corporations can significantly reduce their impact on the environment (Thoumy & Vachon, 2012).

To date, the substance of the corporate environmental management literature is on environmental strategies (Bansal, 2005; Hart, 1995; Russo & Fouts, 1997; Sharma & Vredenburg, 1998), green manufacturing (King & Lenox, 2002; Klassen & Whybark, 1999; Melnyk, Sroufe, & Calantone, 2003), and green supply chain (Seuring & Müller, 2008; Simpson, Power, & Samson, 2007; Simpson & Power, 2005; Vachon & Klassen, 2006a, b; Zhu & Sarkis, 2004) but less attention has been devoted to the capacity of corporations to provide or to adopt technical solutions to address environmental challenges.

In this note, the linkage between technological capacity and environmental performance is explored using country level data. Technological capacity is defined as the ability for corporations to acquire or develop new technologies. While some studies have addressed specifically environmental technologies innovation (Brunnermeier & Cohen, 2003; Horbach, 2008), it is important to clarify that this research note is about technical innovation capability in general. As such, the concept comprises corporations' capacity to capture technological knowledge outside their boundaries, and their ability to internally develop new technologies which are not necessarily linked to environmental management. Therefore, this note is building upon recent studies exploring absorptive capacity and knowledge management which are argued to be linked to environmental management (Gavronski, Klassen, Vachon, & Nascimento, 2012). Thus, the main research question underlying this note is: Does corporate technological capacity contribute positively to a country's environmental performance?

UNDERLYING THEORETICAL PREMISE: THE IPAT EQUATION

The association between technology and environmental performance, or conversely environmental pollution, has been a central point of contention among scientists since the early 1970's (Chertow, 2001). Ultimately, "technology" became a key factor in what is known as the IPAT or master equation of industrial ecology (Graedel & Allenby, 1995). Equation 1 presents the IPAT equation in its most generic form. The basic premise, while widely contested in the literature (Chertow, 2001), is that aggregate pollution level (I for 'impact') is a product of the population level (or 'P'), the gross domestic product (GDP) per capita (or 'A' for affluence), and pollution per unit of GDP (or 'T' for technology) (Zagheni & Billiari, 2007). Simply put, the level of pollution is determined by the level of population, the affluence, and/or technology.

Looking at the equation one can affirm, without speculating, that corporations have very little influence on the population level. On the other hand, corporations can certainly influence the GDP per capita. Within the current economic paradigm however, it is very difficult to conceive that corporations would diminish their production in order to reduce the GDP. In fact, despite all the rhetoric regarding the triple bottom line (Elkington, 1998), the wealth of a nation remains heavily measured by the level of GDP and its growth. Therefore, the key factor in the IPAT equation for which the corporations can be central and play a substantial role is the technological term.

TECHNICAL INNOVATION AND ENVIRONMENTAL PERFORMANCE

When looking closer at the technological term of the IPAT equation, the implications of eco-efficiency becomes obvious. A clear way for corporations to contribute positively to the aggregate environmental welfare is to reduce the ecological stress generated while producing a unit of GDP (or a unit of wealth). Interestingly, the literature related to the concept of eco-efficiency is found predominant in environmental management. In fact, it is fundamental to the Porter Hypothesis (Porter & van der Linde, 1995) which suggests a positive link between innovation and environmental management. Specifically, the Porter Hypothesis denotes that corporations facing new regulation that are designed without a command and control scheme and with market incentives will innovate and find new and better ways to address the environmental issue. Another significant outcome of the Porter Hypothesis is that environmental innovation can be leveraged to improve other facets of the operations, such as costs and quality. For instance, the adoption of the pollution prevention technologies (i.e., tackling the pollution at the source) were linked to improved manufacturing and financial performance (King & Lenox, 2002; Klassen & Whybark, 1999). Furthermore, pollution prevention activities in the supply chain were also linked to better quality, flexibility, and delivery performance (Vachon & Klassen, 2006b). Using country-level data, Vachon and Mao (2008) found a relation between a country's supply chain strength and environmental performance such as the recycling rate (positive relation) and the level of greenhouse gas emissions (negative relation).

The complementarity between environmental management and other aspects of operations has also attracted the attention of scholars over the years. For example, the entire 'lean and green' literature suggests that lean principles can be found in the pursuit of better environmental performance (Florida, 1996; Hajmohammad, Vachon, Klassen, & Gavronski, 2012; Yang, Hong, & Modi, 2011). After all, pollution is a form of waste (Porter & van der Linde, 1995) and waste elimination is a cornerstone of lean management (Shah & Ward, 2003). The primary argument of this segment of the literature is that organizations that have implemented lean management practices, have developed capabilities that can easily be leveraged for effective environmental management (Hajmohammad et al., 2012). This argument also stands for quality management (Curkovic, Melnyk, Handfield, & Calantone, 2000; Pil & Rothenberg, 2003) and safety management systems (Taubitz, 2010). Using a similar rationale, technology capacity taking the form of capability to (i) absorb external knowledge, (ii) perform research and development activities, and (iii) collaborate with research institutions can be refocused for environmental innovation.

Studies pertaining to environmental innovation are more popular in the policy and economic literature (Horbach, 2008; Jaffe & Palmer, 1997; Lanjouw & Mody, 1996; Popp, 2006). The literature indicates that stricter environmental regulation is linked to environmental innovation (Brunnermeier & Cohen, 2003; Lanjouw & Mody, 1996). For instance, Horbach (2008) found that lagged general technological development activities were positively linked to environmental innovation. To synthesize, technological capacity is proposed as a source of capability that can be leveraged for environmental innovation, which in turn leads to better environmental performance.

The definition of environmental performance is a key element for the purpose of this research note. Several previous studies have taken the level of pollution (e.g., toxic emissions) as a proxy for environmental performance (Hunt, 2006). For example, the benchmark of emissions data from the toxic release inventory (TRI) to a firms' financial performance, has been central to multiple papers (Hamilton, 1995; Khanna & Damon, 1999; King & Lenox, 2002). Furthermore, greenhouse gas emissions often used in both energy sector and climate changes studies are extremely popular (Aldy & Pizer, 2008; Zhang, 2008). In addition to air emissions, water effluent pollution is also used as an environmental performance indicator (e.g., total suspended solids or TSS) (Barla, 2007). In this study, the notion of pollution is also used as basis for environmental performance. Finally, measures benchmarking the countries (e.g., by comparing a series of environmental indicators either pollution based or environmental-friendly metrics such as the percentage of protected areas) are used.

Research proposition: Higher level of aggregate corporate technological capacity in a country will positively be linked to environmental performance.

METHODOLOGY

This study uses archival data from varied sources. First, technological capacity was measured using five items from the Executive Opinion Survey (World Economic Forum) as reported in the Global Competitiveness Report 2012-2013. The Executive Opinion Survey covers 144 countries with a total of 14,059 respondents representing about 100 respondents per country on average (details of the respondents are provided in chapter 1.3 of the Global Competitiveness Report 2012-2013).

Technological capacity was measured using the items presented in Table 1. The five items show good reliability for the scale to be measured with a Cronbach's alpha of 96%. All items loaded on a single factor that accounted for 87% of the variance. The average of the items was computed and retained as a measure of technological capacity. Because the concept of technological capacity is very close to innovation capacity, a validity check was done using the number of patents applications (under the Patent Cooperation Treaty) for 2008-2009 as reported in the Global Competitiveness Report 2012-2013. The correlation between technological capacity and the number of patent applications was 75% (p-value < .001).

Table 1 Factor Analysis: Technological Capacity[1]

Items	Factor Loading
1. To what extent are the latest technologies available in your country? (1 = not available, 7 = widely available)	.919
2. To what extent do businesses in your country absorb new technology? (1 = not at all, 7 = aggressively absorb)	921
3. In your country, how do companies obtain technology? (1 = exclusively from licensing or imitating foreign companies, 7 = by conducting formal research and pioneering their own new products and processes)	.939
4. To what extent do companies in your cointry spend in R&D (1 = do not spend on R&D, 7 = spend heavily on R&D)	946
1. To what extent do business and university collaborate on research and development (R&D) in your country (1 = do not collaborate at all, 7 = collaborate extensively)	.948
Other statistics	
Bartlett's test of sphericity: Approximate Chi-square = 1087 (df = 10, p-value < .01)	
Kaiser-Meyer-Olkin measure of sampling adequacy = .787	
Eigenvalue = 4.368, variance explained = 87.4%	
Cronbach's alpha = .962	

[1]These items are from the Executive Opinion Survey conducted by the World Economic Forum as reported in the Global Competitiveness Report 2012-2013 (http://www.weforum.org/reports).

Three further sources provide key indicators of environmental performance for each country: (i) the Environmental Performance Index (EPI) computed and reported by the Yale Center for Environmental Law and Policy (Yale University) and the Center for International Earth Science Information Network (Columbia University), (ii) the Global Footprint Network, and tiii) the Sustainable Society Foundation.

From the Environmental Performance Index data (2012), three indicators are considered. The first two are direct measures of emissions: (i) the level CO2 emissions divided by the GDP and (ii) the level of SO2 divided GDP. The CO2 emissions are the predominant contributor to greenhouse gases which are the leading cause of climate change. The SO2 emissions are usually associated with acid rain. Both types of emissions are also closely connected with industrial and logistical activities making them relatively good indicators for corporate-based pollution. In both cases, the absolute measured was divided by the GDP in order to be consistent with the IPAT equation and to have a better sense of the degree of pollution per unit of economic wealth. The third indicator from the Environmental Performance Index (EPI) was the overall assessment of the environmental performance of the country which includes several indicators such as environmental health (e.g., water and air emission impact on human health), the state of the natural resources (e.g., pesticide use in agriculture, protected land) and climate change and energy (which includes the CO2 emissions). It should be noted however, that the CO2 emissions and SO2 emissions used in this study composed only about 10% of the final EPI score for each country.

Two further indicators are the carbon footprint and the bio-capacity. Both of these measures are taken from the Global Footprint Network (footprintnetwork.org) with the most recent calculation being for 2008 (as of May 2012). The carbon footprint is measured as the amount of land and sea area needed to sequester the carbon produced in a country. Therefore, it is a measure of ecological stress from the country's activities. Similarly, the bio-capacity is the difference between the ecological demands and the availability of resources to absorb these demands within a country: a positive difference is viewed as a country's resource capacity to be superior to the demands put upon it. ? A negative bio-capacity index therefore signifies that a country is using more resources than it actually has, putting it on the path of unsustainable development.

The final indicator is an aggregate measure coming from the Sustainable Society Foundation (www.ssfindex.com). The Foundation present a sustainable society index (SSI) for which 9 measures out of 24 are environment-related and constitute the environmental wellbeing dimension of the SSI. This indicator is similar to the one computed for the EPI.

There are two control variables that are included in the analysis. The population is a measure used to capture the size of the country and is also a variable included in the IPAT equation. The GDP per capita also appears in the IPAT equation and provides an indication of the level of economic wealth in a country. Given that both of these measures present long tails, the natural logarithmic transformation was taken for analysis.

RESULTS

Bivariate correlations between all variables are presented in Table 2. It is noteworthy that the correlation between the GDP per capita and technological capacity is high and significant at 74%. This might be an indication for collinearity: the variance inflation factors were less than 2.4 which is well below the critical threshold of 5 reported in the literature, (Hair, Anderson, Tatham, & Black, 1998) thus suggesting that collinearity should not be an issue.

Table 2 Correlations Table[a]

Variables	1	2	3	4	5	6	7	8
1. CO2 emissions/GDP[b]	–							
2. SO2 emissions/GDP[b]	.35**	–						
3. Environmental Performance Index[c]	-.36**	-.63**	–					
4. Environmental Wellbeing (SSI)[d]	-.69**	-.17†	.34**	–				
5. Carbon Footprint[e]	.43**	-.19†	.24*	-.63**	–			
6. Bio-Ccapacity[e]	-.18†	**.07**	**.03**	**.36****	**-.41***	–		
7. Population[f]	-.14	-.04	-.17†	.04	-.07	-.11	–	
8. GDP per Capita[f]	.28**	-.33**	.52**	-.47**	.78**	-.18*	-.17*	–
9. Technological Capacity	-.02	-.42**	.53**	-.47**	.66**	-.26**	.08	.74**

[a] Number of observations varies 108 to 125 due to missing data. **: p-value < .01, *: p-value < .05, †: p-value < .10.
[b] Natural logarithmic transformation of the actual measure. A lower value is environmentally beneficial.
[c] Environmental performance index for 2012 as reported by the Yale Center for Environmental Law and Policy (Yale University): a higher value is environmentally beneficial.
[d] The environmental dimension of the Sustainable Society Index (2010) as report by the Sustainable Society Foundation: a higher value is environmentally beneficial.
[e] The carbon footprint and the bio-capacity indices for 2008 as reported by the Global Footprint Network. For the carbon footprint, a lower value is environmentally beneficial. For the bio-capacity a higher level is environmentally beneficial.
[f] Natural logarithmic transformation of the actual measure.

Linear regressions using ordinary least squares were performed for each of the six environmental performance indicators. It is important to note that the indicators CO2 emissions, SO2 emissions, and the carbon footprint are negatively correlated with environmental performance: hence an increase is detrimental to the environment. The results from the regressions are presented in Table 3.

Table 3 Regression Resultsa

	CO2/GDP[b]	SO2 / GDP[b]	EPI[c]	Environmental Wellbeing[d]	Carbon Footprint[e]	Bio-Capacity[e]
Population[f]	.049	-.053	-.123	-.071	-.048	-.027
GDP per capita[f]	.691**	-.075	.207†	-.661**	.620**	-.180
Technological Capacity	-.532**	-.361**	.377**	.238*	.208*	-.100
R-square	.200	.178	.327	.250	.622	.070
R-square	9.42**	8.21**	18.34**	13.98**	66.39**	2.965*
Number of observations	117	118	117	130	125	123

[a] Standardized betas reported. **: p-value < .01, *: p-value < .05, †: p-value < .10.
[b] Natural logarithmic transformation of the actual measure. A lower value is environmentally beneficial.
[c] Environmental performance index for 2012 as reported by the Yale Center for Environmental Law and Policy (Yale University): a higher value is environmentally beneficial.
[d] The environmental dimension of the Sustainable Society Index (2010) as report by the Sustainable Society Foundation: a higher value is environmentally beneficial.
[e] The carbon footprint and the bio-capacity indices for 2008 as reported by the Global Footprint Network. For the carbon footprint, a lower value is environmentally beneficially. For the bio-capacity a higher level is environmentally beneficial.
[f] Natural logarithmic transformation of the actual measure.

We note that the R-squares were all above 17% with the exception of the bio-capacity for which none of the variables were significant. Looking at the emissions divided by GDP, technological capacity was negatively linked to both the CO2 emissions ($p < .01$) and the SO2 emissions ($p < .01$) which supports the research proposition. These results were inconsistent with the carbon footprint for which the estimated coefficient was positive and significant ($p < .05$) meaning that a higher level of technological capacity was detrimental for the environment. The relation of technology capacity with more exhaustive indicators was positive and environmentally beneficial. More specifically, the coefficient with the EPI ($p < .01$) and the environmental well-being from SSI ($p < .05$) were both significant. Overall, there is strong evidence that technology capacity is positively linked to environmental performance with the exception of the results pertaining to the carbon footprint.

The population appears to have no impact on the environmental performance (when controlling for economic wealth and technology capacity). This is interesting as population was historically believed to be a key ecological stressor (Chertow, 2001). The GDP per capita is generally associated with the deterioration of the environment as indicated by the positive link with the CO2 emissions ($p < .01$) and the carbon footprint ($p < .01$). It was also negatively linked to environmental well-being ($p < .01$). The positive, yet only marginally significant, linkage with the EPI is relatively puzzling. Overall, the economic wealth of a nation is negatively linked to its environmental performance.

DISCUSSION AND CONCLUSION

Looking back at the results, we can conclude that technology capacity taking the form of a corporations' ability to absorb external technologies, to interact with scientific institutions, and to develop new technology internally, is positively linked to environmental performance.

Specifically, corporate technological capacity appears to be a determinant of eco-efficiency as indicated by the results pertaining to the CO2 and SO2 emissions per unit of GPD. The results however, also indicate that corporate technology capacity increases the carbon footprint. Furthermore, it is noteworthy, although not significantly, that the link between technological capacity and the bio-capacity was directionally consistent with the results found for the carbon footprint. The Global Footprint Network provides an absolute measure of ecological stress rather than a relative measure (for instance EPI is a composite score reflecting the relativity among the countries). Therefore, technological capacity might imply that corporations are generating more production and hence more pollution aggregately (i.e., not in a per-unit of production basis). In other words, while the emissions per unit of GDP are reduced the global level of emissions increases: this is not necessarily sustainable. This finding might be partially explained by the strong correlation between technological capacity and the GDP per capita. Because the GDP per capita is positively associated with carbon emissions, the indirect effect of the technological capacity is negative on the level of emissions (i.e., technological capacity generates more wealth per capita which consequently affects the level of emissions).

Corporations try to improve business processes in order to reduce cost or to expand revenues (i.e., increase profits). What really matters is not necessarily the amount of waste produce in a year, but rather the unit cost (or the unit margin). It is the idea of productivity rather than volume that matters. In regards to technology capacity leading to environmental innovation (as indicated in the literature) it may be that the capabilities developed through R&D are for efficiency purposes only! After all, there is a clear link between energy consumption which can be a significant cost item for many corporations and CO2 and S02 emissions: a reduction of energy consumption would be categorized as eco-efficient. On an encouraging note, technological capacity was positively linked to more general, multi-dimensional, environmental indicators such as the environmental well-being of a country and the EPI. Future research, particularly at the corporate level, should aim to compare the impact of environmental management efforts to the eco-efficiency (a productivity type of measure) and the total footprint or total waste generated.

A better understanding of the underlying causes of eco-efficiency gains is needed to better predict if these gains might lead to an unsustainable path. Interestingly, a new paradigm might be needed in Operations Management. Since the 1990's a new mindset is gaining momentum and downplaying the concept of eco-efficiency by encouraging the concept of eco-effectiveness (McDonough & Braungart, 2002; Rossi, Charon, Wing, & Ewell, 2006). The tenets of eco-effectiveness suggest to direct efforts into developing new technologies (particularly in the product design) in a way that it is benign for the environment: this gives way to a new maximizing mindset (more is better) rather than an approach to minimize undesirable outcomes (eco-efficiency).

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