Long-Run Protection:
Determining Key Features of Growth and Sustainability in Northeast Asia

Matthew A. SHAPIRO

Author identification: *Matthew A. Shapiro (matthew.shapiro@iit.edu) is Assistant Professor of Political Science at the Illinois Institute of Technology in Chicago, Illinois. His research interests include East Asian political economy, environmental and energy policies, and science and technology policies.*

I. INTRODUCTION

This chapter attempts to advance understanding of the crucial links among growth, technological change, human capital accumulation, and openness and their impact on greenhouse gas (GHG)-related research and development (R&D) output in East Asia, specifically China, Japan, Korea, and Taiwan. Looking at the 1952-2004 period, I test not only for the impacts of a science and technology (S&T) and innovation set of GHG-output related inputs, but also test for the presence of the Environmental Kuznets Curve (EKC) in terms of the GDP-CO2 emissions relationship. This research builds upon the works of various important growth theorists, including Solow (1956, 1957), Nelson and Phelps (1966), Mankiw, Romer and Weil (1992) and especially Benhabib and Spiegel (1994, 2002). The latter demonstrated the role of human capital on technological development (or more specifically technology catch-up) between 72 and 86 nations over extended periods of time, 1965-85 and 1960-95, respectively. In all of these studies, however, there is a limited role for openness to trade, capital, or technology in explaining variations in growth rates across countries. Nevertheless, and although certainly still controversial, many of the studies that have been done on East Asia and its so-called “economic miracle” argue that it is greater openness to trade, capital flows, and technology that have distinguished the East Asian experience from that of Latin America, Africa or other regions of developing countries.

What is remarkable about Japan, Korea, and Taiwan, and what is a grand qualifier for their “advanced economy” status, is that they have taken a proactive role to establish themselves as high-technology suppliers. In terms of GHG-related R&D, there is a vested interest for these countries to distribute knowledge and products to their neighbors, as the technology-based mitigation of GHGs and airborne pollutants has positive externalities for surrounding environs, particularly if it positively affects economic growth.[1] Technology-oriented partnerships are advanced through opportunities to gain knowledge from more technologically-advanced countries, but technology transfer is typically limited in nations like China which has lax intellectual property laws, weak governance, and a preponderance of corruption. China is a particularly important case because of its current and prospective levels of GHG emissions. Given that climate change is a direct result of GHG levels in the atmosphere, the entire world but especially the countries of the Northeast Asian region can facilitate China in its application of the most advanced technology to mitigate GHG emissions.

There is a disincentive for China, and other developing countries for that matter, to seek out solutions for its environmental pollution and increasing GHG emissions. The EKC model, for example, describes how environmental clean-up efforts limit growth initially. But, the shape of the EKC is affected by a number of factors, including incoming flows of technology from abroad, which can temper the short-run costs of environmental clean-up, if not offset them altogether. Openness to technology from abroad can also limit growth if countries become excessively dependent on trade partners and if manufacturing is emphasized rather than innovation, but all four of the East Asian countries examined in this chapter have policy goals which incorporate innovation and provide the opportunity for sustainable, long-term growth.

To provide evidence of sustainable growth, this paper extends the Nelson-Phelps model of catch-up and shows how Japan, Korea, Taiwan, and potentially China are newly advanced economies. Our revised catch-up model accounts for and highlights the effects of innovations which increase a nation's potential for environmental sustainability and, thus, sustainable growth, rather than adapting general technologies from abroad. The impact of these environmentally-oriented S&T transfers is not different from the original

[1] I do not model the minutiae of the decision-making process for the providers or receivers of this technology.

model: a curvilinear increase in a nation's capabilities to address environmental sustainability, creating a catch-up effect in which a country rapidly acquires capabilities in the near-term and at a diminishing rate over the medium- to long-terms, as the gap with the leading countries is narrowed.

The most important contributor to curvilinear increases in capabilities is the simultaneous growth of a nation's innovative capacity in the area of environmental sustainability with the receipt of such transfers from abroad. In the absence of such a mechanism, there would simply be a level increase of the existing linear trajectory. Of course, a nation's innovative capacity is not predicated strictly on incoming technology transfers but involves domestic efforts to address existing deficiencies and establish targets which were not previously attainable.[2] These domestic efforts typically include a more rigorous focus on the national innovation system, including government funding of key education programs, R&D facilities (both public and private), and the establishment of international economic relations with more technologically advanced countries as well as countries which possess factors of production (labor and capital) to contribute to the generation of the targeted innovations (Nelson, 1993). There is room for improvement in the Northeast Asian countries examined here, but strong evidence is offered below showing that innovative capacity combined with inflows of foreign R&D investment are sufficiently mitigating GHGs.

To address these issues of growth, environmental sustainability, and the Northeast Asian region, we turn next to the EKC model and the extent to which endogenous measures, the international transfer of technologies, and regional cooperation contribute to its shape. The relevant data, empirical methods, and empirical results are then presented, and a concluding section offers policy prescriptions and a call for even more regional integration. As this is a relatively new area of research, a review of the relevant literature is incorporated throughout the chapter.

[2] The Pascha and Mahlich (2007) volume discusses these domestic efforts in Korea and Northeast Asia.

II. THE ENVIRONMENTAL KUZNETS CURVE

The original Kuznets Curve (Kuznets, 1955) reveals the relationship between economic growth and inequality, hypothesizing that inequality first increases with economic growth, levels off, and then decreases. The EKC applies a similar logic to explain environmental quality in an inverted U-shaped relationship with growth. That is, a country's initial development is coupled with decreases in air and water quality and environmental degradation. Over time and with further development, changes are made to limit pollution and environmental degradation, for the sake of the country's citizenry or in response to regional/international pressure. Support for the efficacy and applicability of the EKC is by no means universal.[3]

In the existing empirical literature, there is limited evidence of the EKC. Dinda's (2004) overview and survey of the EKC does not support its widespread presence, although local air pollutants seem to point to an inverted-U relationship between emissions and economic growth. of the cross-country differences at the macro-level by differentiating between income level. Focusing explicitly on energy consumption, which is a legitimate proxy for environmental degradation and/or GHG emissions, the overall picture indicates a positive correlation between energy consumption and income for the middle income group and a negative correlation for the high income group.ibute this difference to greater energy efficiency for countries in the high income group, but it must also be acknowledged that energy efficiency is the result of S&T advances which are much more likely to occur in the high income group.

In their model of the effects of a carbon tax policy in a rich, open economy, (Bruvoll and Foehn, 2006) note that the EKC can be explained in terms of the redistribution of more polluting industries from rich to poor, neighboring countries. In the case of Northeast Asia, such a relocation effort has been occurring, namely from Japan, Korea, and Taiwan to mainland China. A call for transfers of technology to China from these countries can be justified on normative grounds, thus. International agreements

[3] See Dasgupta, et al. (2002) and Millimet, et al. (2003), which offer support, while Stern (2004), Copeland and Taylor (2002), and Arrow, et al. (1995) argue against use of the EKC.

attempt to address this problem, but they must account for the role of region-based technology transfer.

The EKC dovetails with the neoclassical economic approach to assess the determinants of growth, assuming a constant returns-to-scale production function,

$$Y_i = K^{\alpha}(AH)^{1-\alpha}. \qquad (1)$$

This attempt to incorporate the EKC with the Solow growth model is most consistent with Brock and Taylor's (2004) "green Solow model," in which emissions intensities and abatement costs are incorporated into the analysis. They do not acknowledge, however, the role of openness. We pursue two theoretical avenues: (1) a simultaneous examination of the determinants of economic growth and the determinants of environmental sustainability; (2) a claim that the EKC is present in Northeast Asia. The two forms of development are represented by *i*, with economic growth measured by GDP levels and sustainable development measured by CO2 emissions.

Eq (1) presents constant, *A*, capital stock, *K*, and educational attainment, *H*, where the capital share is set at one-third and the labor share *(AH)* is set at two-thirds.[4] As it is commonly expressed in the literature, *A* represents exogenously growing labor-augmenting technology. Educational attainment, *H*, is generally expressed in one of two forms: as a measure of school enrollment or as a measure of average years of schooling attained. Barro and Lee (2000), based on their study of educational attainment, have the relevant data for both of these measures, but our basis of educational attainment is more centered on tertiary enrollment rates and the number of researchers, which is more appropriate when focusing on S&T output.

Capital stock, *K*, is shown in the standard capital accumulation equation,

$$\dot{K} = I_K Y_i - \delta K, \qquad (2)$$

where the change in physical capital stock is the difference between I_K , the amount of investment in physical capital, and δK , the depreciation of capital. If we divide both sides of Eq (1) by *AL*, defining *y*, *k* and *h* as *Y/L*, *K/L* and *H/L*, respectively, we have

[4] These estimates of α and (1-α) conform with Benhabib and Spiegel (2002).

$$\frac{y_i}{A} = \left(\frac{k}{A}\right)^{\alpha} h^{1-\alpha} . \qquad (3)$$

The theoretical specification presented in Eqs (1) – (3) treats technological change, *A*, as exogenously determined, implying nonexcludability and nonrivalry, as specified by Solow (1957). *A*, thus, receives no compensation and may be exploited without limits. Arrow (1962), on the other hand, claims that increases in capital goods, *K*, increase knowledge through "learning by doing."[5] As such, knowledge is treated similarly to that of the Solow model, but, as Romer (1990) indicates, fails to acknowledge the tendency for firms to intentionally invest in R&D. I acknowledge Romer's claims that technological change is endogenous in that it arises from intentional actions made in response to market conditions.

Jones (2002) develops a related theoretical model which replaces labor augmenting technology, *A*, with individual skill level, *h*. Defining "skill" as "the range of intermediate goods that an individual has learned to use,"[6] advanced capital goods are utilized as

$$\dot{h} = \mu e^{\psi s} A^{\gamma} h^{1-\gamma} , \qquad (4)$$

where A^{γ} is the world frontier of technology. Building on the work of Eaton and Kortum (1994), Jones (2002) describes the parameter μ as the productivity of a country using education to learn to use new ideas. In the traditional sense, high values of μ may reflect a high quality education system. Here, however, I expand this parameter to include the productivity of a country based on its degree of openness. If we substitute Eq (4) into our original production function, it will be shown that growth is now not just a function of the ability to use new ideas, but also the ability to productively use incoming capital and technology, especially that which mitigates GHG emissions.

Theorizing in the endogenous growth framework, we are faced with interpretation problems. Econometric estimates, such as Kim and Lau's (1994) analysis of the meta

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[5] "Learning by doing" is the education process which occurs during production. This education may occur in a training facility (college- or firm-based) separate from the production floor, or it can happen in the S&T case by reviewing publications and patents.

production function (MPF), identify the fact that production knowledge is imperfectly available and requires large amounts of tacit knowledge.[7] Second, developed countries' firms may fear that the communication of technology to counterparts in developing countries will lead to future competition in a Schumpeterian sense. Third, a considerable part of learning is local, meaning that knowledge transfer occurs across sectors.[8] Finally, openness measures, embodied by μ in Eq (4), are meant to account for differentiating policies between countries, particularly the rules and regulations pertaining to intellectual property rights (IPRs) and FDI, although IPRs can have different effects, depending on a country's stage of development.

Mansfield (1995) claims that there is a direct relationship between the strength and weakness of a country's IPR regime and the kinds of technology transferred to that country, particularly with regard to high-technology industries. The strength of IPRs is also a focus of Yang and Maskus (2003), who claim that stronger IPRs may discourage innovation and reduce international technology transfer in the preliminary stages.[9] Kim (2003), however, claims that technology transfer increases as the returns to innovation resulting from such IPRs become apparent. These increases are also dependent on international licensing, local wages, and other aspects of absorptive capacity.

There is no consensus as to the effects of openness, at least in the traditional growth literature. Harrison (1996) looks at multiple measures of trade openness, concluding that – for most of the measures –openness is correlated with higher growth. Edwards' (1998) seminal analysis of 93 countries uses nine indices of trade policy to address the complexities of international trade and also lends support for the claim that openness leads to increased growth. Wacziarg (2001) develops this line of discussion

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[6] Jones (2002): 126.

[7] "Tacit knowledge" is defined here, in accordance with Langloi and Nicolai (1997: 17), as knowledge which "can be acquired only through a time-consuming process of learning by doing." (For a definition of "learning by doing", see fn. 11)

[8] For example, the growing share of employment in the service sectors may represent an institutional infrastructure requiring more technology-supporting services, such as the marketing, finance, and transportation of advanced technologies.

further, targeting the sources of gains from trade in a dynamic framework, while Rodriguez and Rodrik (2000) argue that the relationship between trade openness and growth is not settled, primarily because of the aforementioned endogeneity problem, although some (Lee, et al., 2004) do attempt to minimize the potential for endogeneity through two-stage regression analysis.

The endogeneity issue is prevalent for trade openness, but analyses of capital openness typically conflate it with other forms of openness, most notably openness to technology. Findlay (1978), for example, models technology transfer as a function of FDI, among other things, while Wang (1990) shows that both human capital and technology diffusion are positively related to FDI inflows, given institutional shifts within the recipient country. Similar findings are presented by Borensztein, et al. (1998), who examine and show that FDI flows from developed to developing countries over time, but that the degree and effect of technology transfers is dependent upon a country's existing human capital stocks.

Given the mutual effects and endogeneity of forms of openness, it is no surprise that the majority of the macro-level studies cited above make calls for further analysis at the micro-level, the literature of which provides a number of relevant findings. Responding to and supporting Amsden's (1989) claims that growth models for late industrializers must incorporate imports of foreign technology rather than technological innovation, Zhang and Zou (1995) construct a model based on foreign capital imports. By dividing capital accumulation into home-produced capital and imported foreign technology, they show that economic growth rates and foreign technology imports are positively correlated and more significant than domestic accumulation.[10]

Given the aforementioned model and existing literature, the effects of openness, human capital, and physical capital upon economic growth and environmental sustainability are assumed to be positive, shown in Fig. 1 with the EKC framework

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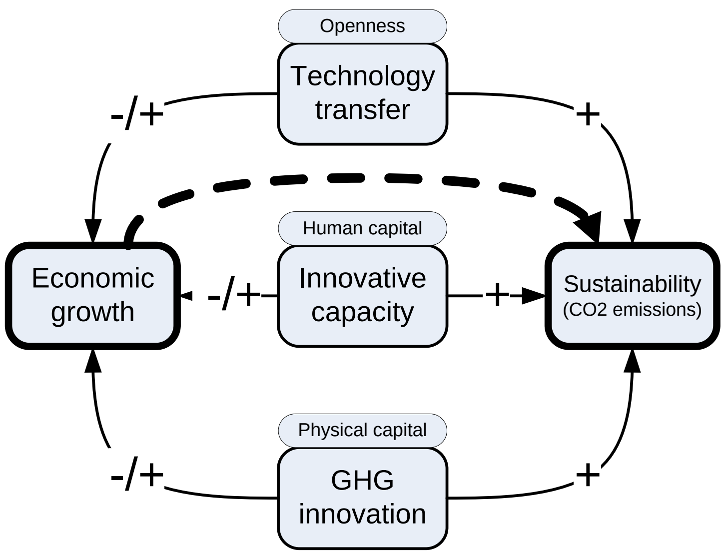
[9] Yang and Maskus also point out that the increase in technology transfer via inward licensing may occur with higher costs per license and possibly higher prices. Ultimately, the economic effects in terms of welfare are uncertain.

[10] The distinction here, it should be noted, is in terms of capital goods imports, not FDI.

(expressed with bold borders and arrows). Yet, as Fig. 1 shows, the traditional variables of the growth model are replaced with proxies relating specifically to sustainability and innovation. The proxies that are offered for openness, human capital, and physical capital are, respectively, technology transfer, human capital measured through innovative capacity, and physical capital measured by returns to investment in GHG-related innovation.

These proxies are not expected to impact economic growth or environmental sustainability uniformly, as technology transfer, innovative capacity, and GHG-based innovation restrain growth in the short-term and bolster growth in the long-run, as described above. This is likely the result of excessive costs from initial investments in the pursuit of these technologies or the orientation of labor away from certain profitable enterprises in less high-technology sectors to more uncertain but potentially rewarding S&T ventures. As well, technology transfer is expected to yield significant increases in growth, but a recipient country which lacks the requisite capacity may waste time and resources, so the impact can be negative in the short-run and positive in subsequent periods. These three variables may not have a uniformly positive effect on growth, but sustainability is expected to increase across the board, with the greatest yields occurring in the long-term.

Fig. 1 Growth-EKC causal diagram and predicted effects



III. CONTRIBUTORS TO SUSTAINABILITY AND THE EKC IN NORTHEAST ASIA

We focus now on S&T output in Northeast Asia which has potential utility for other countries in the region and beyond. There is much promise for technology transfer through specialized regional integration, which is now in its relative infancy with regard to GHG emission reduction efforts. Gross differences in environmental governance, private sector responsiveness, and S&T output continues to present a significant hurdle for a smooth transition to East Asian cohesiveness, to which we now turn.

In Japan, the Ministry of the Environment (MOE) has supported a number of comprehensive measures to treat what it describes as "sustainable society," particularly the reduction of GHGs and the promulgation of a sound material cycle through reduced consumption and increased reuse and recycling of products (MOE, 2006). Japan's S&T efforts currently reflect the third instalment of the Science and Technology Basic Law enacted in 1995.[11] One of the six goals of this law is sustainable development defined by a combination of economic growth and environmental protection. To this end, the largest share of the S&T budget allocations for 2009 are for low-carbon technologies, totalling 164 billion yen (Wada, 2009).[12] The emphasis on low-carbon technologies is also indicative of Japan's long term approach to S&T, exemplified by the goals of the "Innovation 25" guidelines in 2025 and the "Cool Earth 50" proposal (from the 2007 G8 summit) of halving global GHGs by 2050.

Korea also conflates S&T-based efforts to reduce GHG emissions with economic growth. The three elements of "green growth" – minimize energy consumption while pursuing economic growth, minimize GHG emissions, and develop new growth engines – are grounded in commitments of 3.7 billion dollars of 23 billion dollars in government funding over the next five years to be invested in renewable technologies such as photovoltaics and wind turbines (Kim, 2009). The chair of the Presidential Committee on Green Growth reported that the Lee Myung-bak administration has set a goal to reduce GHG emissions by 21 to 30 percent by 2020, in line with international goals to reduce GHG emissions 50 percent by 2050 (Na, 2009).

Taiwan's Agenda 21, the National Environmental Protection Plan, the Sustainable Development Action Plan (Republic of China Executive Yuan, 2004), the Basic Environment Act of 2002 (Article 23), and the institution of the Ministry of Economic Affairs (Bureau of Energy) are all focusing on sustainability and efficiency as core goals of Taiwan's energy policy. The Taiwan Industrial Greenhouse Office (TIGO) under the Ministry of Economic Affairs was established specifically to reach a GHG-reduction goal of ten percent (based on 2000 emissions) by 2015 (Chen, 2008). This is for good reason, as Taiwan is very dependent on fuel imports (98 percent of sourced fuel) (Courtenay, 2007). Despite the fact that Taiwan is not a signatory to the Kyoto Protocol, it adheres to

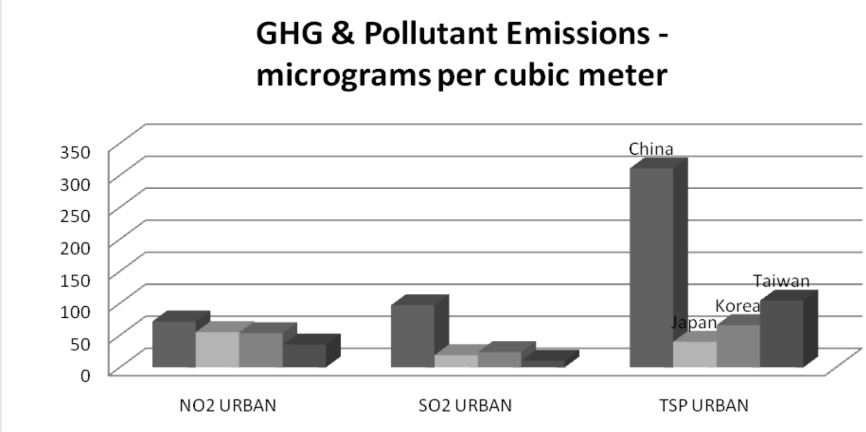
[11] The First Basic Plan (1996-2000) targeted increases in government expenditures and a new R&D system; the Second Basic Plan (2001-2005) focused on increases in the knowledge base and increasing the competition for research funds.
[12] Innovative technologies received 52.3 billion yen, S&T diplomacy received 46.7 billion yen, regional (domestic) system promotion received 69.3 billion yen, and public-private R&D projects received 19.5 billion yen.

the protocol's objectives and emphasizes renewable energy S&T to combat GHG emissions.

In China, there has been a strategy for sustainable development in place since 1996 (Rongping, 2009), efforts to mitigate GHGs are secondary to air and water pollution corrections, as the Chinese Ministry of Environmental Protection (MEP) emphasizes reductions in chemical oxygen demand (COD) and SO2 emissions above all else. These two measures quantify water and air quality, respectively, but NO2 and especially air particulate (TSP) concentrations in China's urban areas are significantly higher than in neighboring countries, presented in Fig. 2. Major efforts are being made to address water and air quality, as eight cities have been banned from engaging in construction which results in increased COD or SO2 emissions (MEP, 2009). There is no indication, though, that CO2 emissions reductions targets are a primary concern for the MEP. As well, China maintains low energy efficiency and outdated technologies, and there are really no measures established to promote energy-saving S&T. Formal legislation, such as the Law on Science and Technology Progress (2007), does not sufficiently emphasize financial support and investment mechanisms (USAID and AECEN, 2008).

However, the 17th National Congress of the CCP in October 2007 presented a plan to coordinate increases in GDP and sustainability (USAID and AECEN, 2008). Subsequent commitments put forth in December 2007 at the 13th Conference of Parties of the UNFCCC amounted to a 20 percent energy savings target by 2012 and a viable GHG-related S&T policy. A proactive role is being played in Beijing to make this a reality, such as the Leading Coordination Committee on Global Environmental S&T and the Law on Science and Technology Progress, the latter of which addresses IPRs (USAID and AECEN, 2008). On the whole, this is a major effort to thread together the disparate agencies and ministries in China and unify the country's S&T goals.

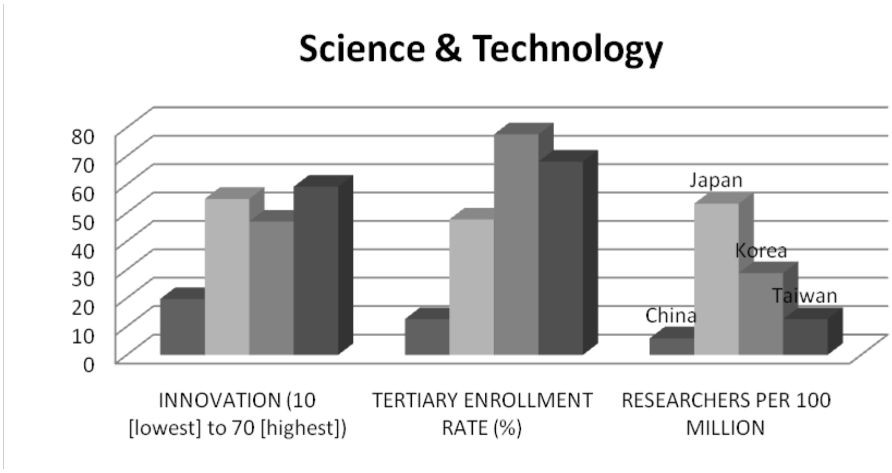
Fig. 2



Source: Esty, et al. (2005).

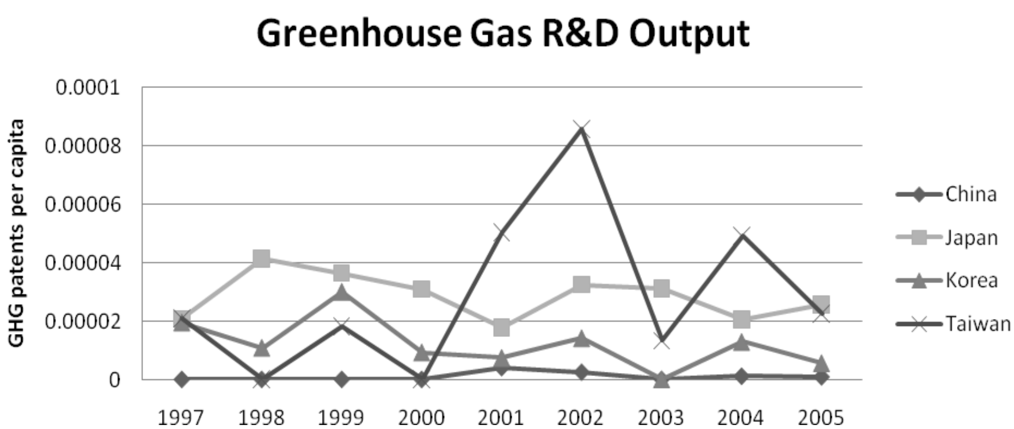
Additional qualitative differences among these four Northeast Asian countries include, as of 2005, disparities in S&T infrastructures. Fig. 3 exhibits the lower levels of innovation, tertiary enrollment rates, and number of researchers per 100 million people in China, relative to its neighbors. GHG-based R&D output for China is also a reflection of differences in S&T infrastructure, shown in Fig. 4. Data collection for patents was done through the online patent search function of the USPTO, with search parameters based on the presence of either "greenhouse effect" or "greenhouse gas" in the patent description or the article's topic. These keywords are by no means all-inclusive parameters to capture the degree of GHG-oriented innovation, but a cursory analysis of a number of keywords over the relevant time period confirms that these two terms are greatest in number and cover the widest area of industry classes. GHG-based patents in China have never really taken off and are noticeably lower than those of Japan, Korea, and Taiwan. Without sufficient technology inflows from these countries to China, the costs of effective CO_2 reductions will remain high.

Fig. 3



Source: Esty, et al. (2005).

Fig. 4



Source: Author's calculations.

Existing regional efforts to treat the absence or deficiency of national efforts to address GHG emissions include the Environmental Cooperation-Asia (ECO-Asia), under the United States Agency for International Development (USAID). This program encourages investment in clean energy technologies, among other sustainability-oriented goals, and it has been involved in China since 2007 to upgrade old coal-fired power plants and reduce CO2 emissions. A total of $109 million will help reduce at least 11 million tons of CO_2 emissions over the lifetime of the affected power plants (USAID and ECO-Asia, 2009). Similarly, the Asia Development Bank (ADB) recently approved an energy policy which provides reliable and affordable energy to all citizens of the region while simultaneously focusing on efficiency and renewable energy projects, such as wind power projects in China (ADB, 2009). There are also efforts to tap the emerging carbon market and fund clean energy projects in Asia through the Asia Pacific Carbon Fund of the ADB (ADB, 2006). This can yield additional returns for those countries and areas which have highly inefficient or antiquated energy infrastructures, much like the rural areas of China.

Also at the regional level, efforts to deal with disparities in environmental governance are facilitated through the Asian Environmental Compliance and Enforcement Network (AECEN), which helps improve environmental compliance and enforcement. Since 2005, thirteen Asian countries have worked in tandem with USAID, the ADB, the US EPA, the OECD, the World Bank, and other organizations to improve compliance through the exchange of policies and practices. The East Asian vision of a sound material cycle society is also embodied in attempts to synchronize efforts across the region, such as the Second Asia 3R Conference, held in Tokyo. This coordination effort extends beyond the reduction of material waste, stressing efficiency in resource use, S&T innovation, and international technology transfer (MOE and Institute for Global Environmental Strategies, 2008). These are crucial advances but must continue at the same pace as sustainability-oriented inputs and technology transfers.

IV. DATA, METHODS & RESULTS

I first test for the EKC in China, Japan, Korea, and Taiwan by examining the relationship between GDP and CO_2 emissions over the 1952-2004 period. GDP per capita data is drawn from the Penn World Table Version 6.2 (Heston, et al., 2006), and CO_2 data is measured in thousand metric tons (mtons) exclusively emitted from fossil-fuel consumption, available from CDIAC (2009). This specific account of CO_2 acts as a control for any changes in its levels which might result from diminishing or expanding carbon sinks, agricultural shifts, and increases or decreases in livestock. Thus, the type of

S&T infrastructure and output in each country affects our CO2 emissions data most directly.

While existing research may not necessarily validate the EKC, there are significant omissions in this literature. For example, the EKC does not fit the environmental efficiency patterns of seventeen OECD countries, based on the 1980-2002 period (Halkos and Tzeremes, 2009), but Korea, Taiwan, and China are excluded from the analysis. A similar study for the 1971-2004 period for 113 countries reaches a similar set of conclusions, although GHGs are not emphasized (Luzzati and Orsini, 2009). When a modified functional form of the EKC is applied, specifically one which accounts for CO2 emissions among different GHGs,[13] the EKC is confirmed for OECD countries but not for non-OECD countries (Galeotti, et al., 2006); yet, others have found that the EKC for CO2 is not well supported (Romero-Avila, 2008) or that innovation and S&T to mitigate GHG emissions must accompany any analysis of the EKC, such as the Clean Development Mechanism (CDM) (Huang, et al., 2008). Failures to treat the EKC at the macro-level also indicate the need for case-specific analyses, and this chapter is one of several attempts to bridge this gap. Existing work on China examines city levels of SO2 pollution, supporting the EKC and concluding that China is able to "tunnel through" the EKC with application of S&T advancements (Brajer, et al., 2008), which is consistent with Huang, et al. (2008).[14]

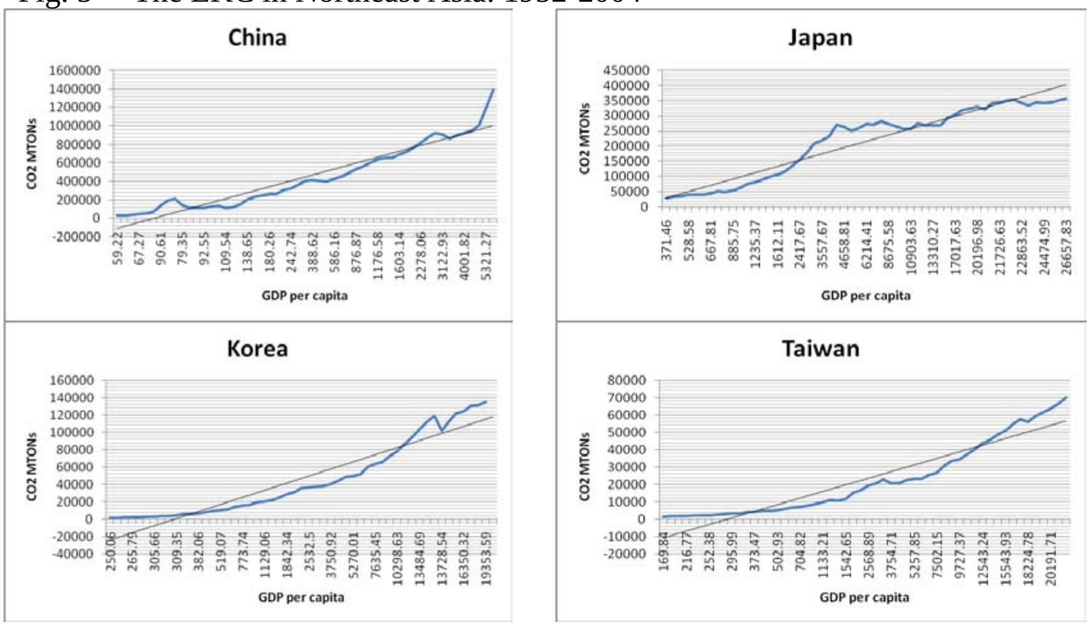
A first look at the EKC for these four countries in Fig. 5 largely reveals a standard rather than an inverted U-shaped curve. Japan is the exception, which I attribute to its position at the world's technology frontier and its lengthier exposure to CO2 emissions, as emissions in year-one were nearly 28,000 metric tons, while Korea and Taiwan only reached such levels in the early 1970s and mid-1980s, respectively. Despite clear confirmation of the EKC in Japan, I believe that China, Korea, and Taiwan are on the

[13] For example, SO2, NOx, and CO2.

[14] Others examine pollution in the form of sewage discharge in China, which is peripheral to our discussion of GHG emissions, but they conclude that technical progress tends to reduce the amount of industrial wastewater pollutants (Gu, et al., 2009). Another China-based case study looks specifically at how the EKC in China also focuses on the country's first special economic zone (SEZ). In Shenzhen, for example,

verge of plateauing. CO_2 emissions in Korea in 2005 and 2006 (not presented in Fig. 5) show a four percent decrease and a negligible two-tenths of a percentage increase from 2004 to 2005, respectively. Emissions in China and Taiwan also decreased year-on-year 2004-2005 and 2005-2006.

Fig. 5 The EKC in Northeast Asia: 1952-2004



Source: Author's calculations based on Heston, et al. (2006) and CDIAC (2009) data. GDP per capita measured in thousands of dollars.

Statistical analysis confirms that the inverted U-shaped EKC curve is present for these four countries. Table 1 presents regression results from a GLS fixed effects model, which is used to control for unexplained country-specific variation among these four countries. GLS modeling techniques control for heteroskedasticity (Greene, 2002) which could be important in the present context. Models 2 and 3 represent quadratic and cubic functions, respectively, indicating that CO_2 emissions increase with low levels of GDP and decrease with higher levels of GDP. The cubic function (Model 3) is particularly noteworthy given the second increase in CO_2 emissions from even higher levels of GDP,

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production-induced pollutants were found to support the EKC, although consumption-induced pollutants did not (Liu, et al., 2007).

although the coefficients are difficult to interpret given correlations among the explanatory variables.

Table 1 Regression (fixed effects) output: EKC

	(1) CO2	(2) CO2	(3) CO2
GDP	8.702872***	39.21955***	141.9126***
	(2.464924)	(7.812042)	(13.22694)
GDP squared		-0.0011607***	-0.0104762***
		(0.002842)	(0.0010971)
GDP cubed			2.36e-07***
			(2.73e-08
Constant	203812.4***	76176.94	-180294.9***
	(29111.27)	(41276.13)	(42801.04
N	100	100	100
r2	0.365	0.720	0.691
F-stat	12.47***	15.60***	43.55***

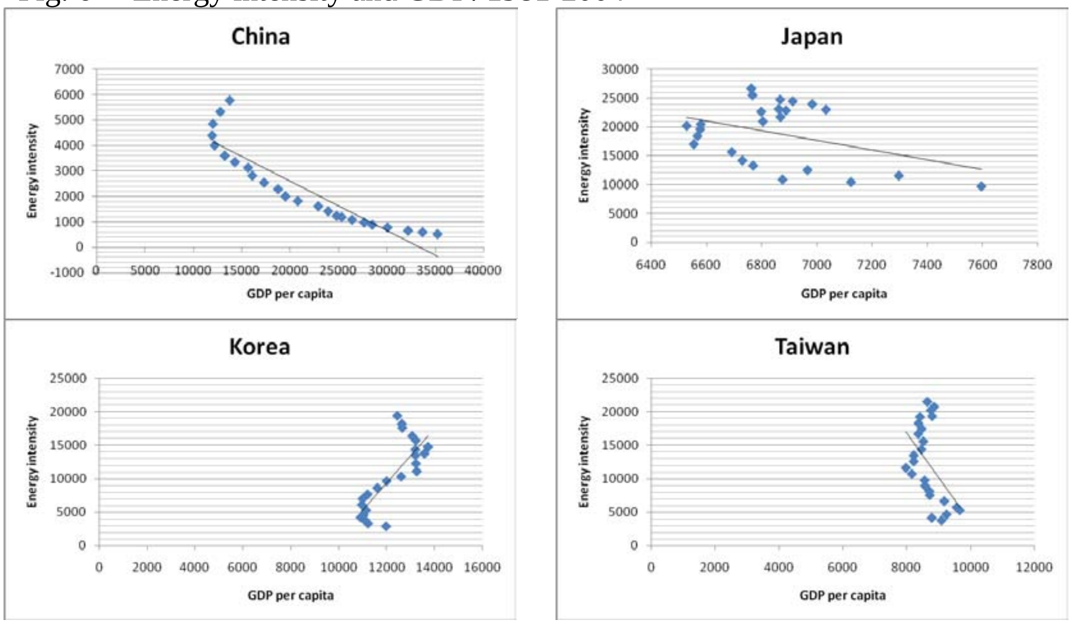
Standard errors in parentheses.
* p<0.05, ** p<0.01, *** p<0.001

Before turning to the endogenous growth/environmental sustainability models, an exploratory comparison of energy intensity data (EIA, 2009) and GDP per capita levels offers some important insight into the sustainability-related changes in these four countries. Energy intensity, measured in British thermal units (btu), quantifies the total primary energy consumption per dollar of GDP using purchasing power parities.[15] Energy intensity should be decreasing with increases in GDP per capita, given increases in S&T infrastructure and increasing economies of scale, which is the case in China, Japan, and Taiwan, shown in Fig. 6. In Korea, however, two periods of decreasing intensities border a period of increasing intensities from the late 1980s to the 1997-98 financial crisis, creating a semblance of a backward S-shaped curve. The post-financial crisis period, represented by the uppermost scatter plot points, indicates a revitalized attempt to keep energy costs down. This backward S-shaped curve is partially identified in Taiwan, and, in China, there is a clear shift towards higher energy intensities in the

[15] This measure is used as one of two proxies for GHG-based innovation in the subsequent regression analysis.

most recent high-growth period, effectively establishing the bottom turn of the backward S-shaped curve.

Fig. 6 Energy intensity and GDP: 1981-2004



Source: Author's calculations based on Heston, et al. (2006) and EIA (2009) data.

When assessing the impacts of our proxies for openness, human capital, and physical capital, I again use the GLS model to control for heteroskedasticity and unexplained country-level variation. Our proxy for growth and sustainability is GDP per capita and carbon dioxide emissions, respectively. The proxy for openness is the share of investment in business R&D from foreign sources and the proxy for human capital is the number of full time researchers, both of which are taken from the OECD MSTI (2009) database. GHG-based innovation is measured in two ways, GHG-oriented patents and energy intensity, both of which have been described above. To test for the combined effects of incoming technology transfer and domestic capabilities to contribute to economic growth and environmental sustainability, a foreign R&D-FTE researchers interaction term is included. In total, eight fixed effects regressions are run to determine these variables' effects on economic growth and environmental sustainability, the results of which are presented in Table 3. Summary statistics for these variables (and the EKC model variables) are presented in Table 2.

Table 2 Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
GDP	100	10755.43	7596.582	452.28	26657.83
GDP squared	100	1.73e+08	1.88e+08	204557.2	7.11e+08
GDP cubed	100	3.24e+12	4.46e+12	9.25e+07	1.89e+13
CO2 emissions	108	315310.1	349345.3	20504	1664589
GHG patents	36	0.0000176	0.0000188	0	0.0000859
Energy intensity	104	12110.06	6500.395	6492.5	35241
Foreign R&D funding	43	0.4727209	0.7630702	0.002	3.985
FTE researchers	56	435783.1	311279.1	45778	1223756
For. R&D*FTE interaction term	43	327311.8	657410	119.3129	2769822

Regression output for the endogenous growth model (Table 3, models 1-4) is largely consistent with our predicted effects described in Fig. 1. GHG-related innovation, measured first as GHG-related patents and then as energy intensity, has a positive effect on GDP per capita, although not at a statistically significant level. Innovation capacity, or the number of FTE researchers in each country, has a positive and statistically significant effect on growth, as does openness to technology from abroad, based on the amount of foreign funding for local firms' R&D. There is no significant effect, though, of the interaction term, which counters much of the existing literature. To recapitulate, both indigenous and foreign efforts play an important role for growth in Northeast Asia, but GHG-related innovation does not.

Table 3 Regression (fixed-effects) output: determinants of growth and sustainability

	(1) GDP	(2) GDP	(3) GDP	(4) GDP	(5) CO2	(6) CO2	(7) CO2	(8) CO2
GHG patents	11823604.426	12181648.321			-1.572e+08	-6.376e+07		
	(12153673.20)	(12618384.15)			(1.96e+08)	(1.38e+08)		
Energy intensity			0.744	0.669			29.358*	24.765
			(0.75)	(0.86)			(11.82)	(13.09)
Foreign R&D funding	2982.417***	3274.165	4141.629***	3762.336	-93259.080***	-13650.848	-58018.957***	-78118.480**
	(751.12)	(1729.99)	(751.72)	(2154.14)	(10161.22)	(17251.81)	(12762.66)	(27381.83)
FTE researchers	0.041***	0.041***	0.046***	0.047***	0.781***	0.558***	0.961***	0.937***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.08)	(0.07)	(0.06)	(0.06)
For. R&D*FTE interaction term		-0.001		0.001		-0.195***		0.030
		(0.00)		(0.00)		(0.04)		(0.04)
Constant	1764.627	2199.790	-8600.328	-8023.525	97483.862*	195184.694***	-321730.771*	-268018.291
	(2979.93)	(3592.97)	(7571.49)	(8291.61)	(34205.76)	(31920.95)	(122102.13)	(138634.08)
N	26	26	35	35	30	30	43	43
r2	0.621	0.622	0.721	0.722	0.970	0.986	0.947	0.948
F-stat	10.40***	7.41***	24.17***	17.51***	246.33***	388.61***	214.96***	160.00***

Standard errors in parentheses.

* p<0.05, ** p<0.01, *** p<0.001

These results are partially reflected in those of the environmental sustainability model (Table 3, models 5-8), as an increase in the number of GHG-related patents decreases CO2 emissions from the consumption of fossil fuels. The coefficient, however, is not statistically significant and, more importantly, our second proxy for GHG-based innovation – energy intensity – actually increases CO2 emissions. This is likely due to the existence of a gap between energy consumption through fossil fuel generation and energy intensity improvements, a phenomenon which is present in the reverse S-shape relationship between growth and energy intensity. Regarding the other determinants of CO2 reductions, foreign R&D funding again contributes to sustainability by reducing CO2 emissions by 93,259 and 58,018 mtons for each percentage share increase to local firm R&D efforts. Expansion of human capital stock for R&D – the number of FTE researchers – also contributes to an expanding supply of CO2. This offers evidence in support of Esty, et al.'s (2005) conclusion that S&T efforts and the ecological footprint are positively correlated. Finally, the combined effects of openness and domestic R&D capabilities significantly lower CO2 emissions in the model which accounts for GHG patents (Table 3, model 6).

V. CONCLUSION

This discussion has confirmed that, for environmental sustainability in Northeast Asia, openness is more significant than local efforts to innovate and increase absorptive capacity. The number of researchers in a country does, however, play a significant role, while investments in GHG-related innovation do not. This has been shown through an expanded neoclassical growth model which acknowledges that economic growth or environmental sustainability are functions of the ability to use new ideas as well as the ability to productively use incoming capital and technology. There are indications, though, that local efforts and capabilities combined with incoming technology are important in reducing CO2 emissions, which is consistent with the claims of Borensztein, et al. (1998). Also evident for Northeast Asia is a consistent and inverted U-shaped EKC. Absent from the above analysis, though, is a two-stage empirical procedure in which the growth function itself (including its determinants) is a function of CO2 emissions. This was not possible, however, given the correlation between CO_2 emissions and the determinants of growth, as explained in the theoretical section above.[16] All the same, innovation and S&T in pursuit of solutions for GHG emissions is crucial, and there are a number of curvilinear effects involved with efforts to reduce GHG emissions. Our exploratory analysis of energy intensity, for example, revealed its non-linear relationship to economic growth. The reverse S-shaped curve indicates that China is following in the footsteps of Korea and, to a lesser degree, Taiwan.

China dominates the discussion of country-specific analyses of the EKC, as it is the veritable hinge upon which climate change policy swings. This is true in both the immediate and near-term sense, as India and other developing countries will ultimately follow international standards which address China's present and future GHG emissions. China is also a common case study for the EKC hypothesis in light of its rapid industrialization, large geographic size, problematic governance structures (also correlated with growth), and lax legislation to address GHG emissions. Given that technological openness is a positive predictor of both growth and environmental sustainability, China must establish closer ties within the region, particularly as Korea plans to devote nearly its entire basic R&D budget to green S&T pursuits.

A major challenge to China's adoption and application of technologies from within the region is the availability of such technology elsewhere. Recently, Vice Premier Li Keqiang met with U.S. Energy Secretary Steven Chu and Commerce Secretary Gary Locke to discuss bilateral cooperation on clean energy and related technologies (MEP, 2009), but it is likely that the relationship will be affected by China's adherence to the principle of "common but differentiated responsibilities." This refers to the distinction between developed and developing countries in reducing GHG emissions: developed countries are largely responsible with the existing stock of GHGs and thus should shoulder the responsibility of GHG reductions more than countries of the developing world, where per capita emissions are still relatively low. On these grounds, China

[16] Future work on endogenous growth in an EKC framework should attempt to examine the determinants of growth which are uncorrelated with CO_2 emissions. Such efforts may still be plagued with endogeneity

opposes unilateral adoption of GHG emissions reduction targets and, in response, the U.S. is unwilling to share key GHG-related S&T output with China without compensation. Whether or not future empirical research is able to verify the regional-versus-international benefits of openness to GHG-related technology transfer, laborious and lengthy negotiations at the international level can be avoided. These four countries are on track to coordinate, given revived emphasis on climate change-mitigating policies and innovation efforts.

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