

The Development of the Clean Technology Industry: A Conceptual Framework

Nir Kshetri

The University of North Carolina at Greensboro

Abstract

The evolution of an industry changes the competitive climate faced by individual firms as well as nations. Many analysts consider the clean technology (CT) industry as a game changer for businesses' and nations' competitiveness in the 21st century. From a theoretical standpoint, the CT industry contains many idiosyncratic features, which affect the nature of entrepreneurial opportunities and roles in this industry. The issues of the evolution of the clean technology industry and nations' competitive advantages in this industry area critical but little-examined problem in the social science research. We contribute to filling this research gap with an analysis of the entrepreneurship in the global CT industry. Specifically, this paper proposes a framework to examine the development of the CT industry and assesses some major economies in terms of the major dimensions in the framework. We also present a case study of entrepreneurship in the Chinese CT industry.

Keywords: Clean technology, disruptive innovations, solar cells, China, venture capital, externality mechanisms

1. INTRODUCTION

The evolution of an industry changes the competitive climate faced by individual firms as well as nations (Utterback 1996). The rapidly evolving clean technology (CT) industry is touted as a potential source to bring changes in businesses' strategic orientation as well as significant changes in the global economic and political power structures. Despite their current small size, some CT sectors such as solar and wind energy are the fastest growing forms of electric power (Kennard 2008).

Facing the trend toward CT, some companies have developed new competences and capabilities that have the potential of being clean and sustainable. To take an example, DuPont has shifted its portfolio away from its traditional core competencies and is developing new internal competences and capabilities compatible with the recent global green movement (Hart 2005).

One can present convincing arguments to show that the current universal drive toward CT¹ is likely to be a long-term trend rather than a fad or hype². Reflective pieces from the popular press as well as academic articles have illustrated influential arguments regarding the CT industry's likely powerful impacts. Many observers in the U.S., for instance, think that despite the Silicon Valley's leadership in technology, it is doubtful that it will be a CT leader (Wadhwa 2010). Additionally, part of the fascinating character of CT is that compared to other industries, innovation per se is likely to make a smaller, independent contribution to success in this industry. For one thing, the CT industry inherently requires the whole new systems instead of merely developing individual technologies (Johnson and Suskewicz 2009). For instance, while Japan has been a global epicenter for the advanced CT innovations, analysts have forcefully argued that the innovations alone may not be sufficient to develop the CT industry (Dickie 2010).

The all-encompassing nature of the CT industry has created new opportunities as well as threats for organizations in diverse industries and settings. Managers may benefit from ensuring that they redefine their actions to better reflect the global trends towards the CT industry. Hart (2005) argues that being more innovative in the long-term requires companies to develop internal capabilities and resources to address the trend toward CT and eco-effectiveness.

There are several indications that policymakers have been persuaded by the economic, environmental, and national security arguments. Governments worldwide are competing to develop CT industries. French finance minister, Christine Lagarde noted: "[CT] is a race and whoever wins that race will dominate economic development. The emerging markets are well-placed" (Bennhold 2010). In April 2009, U.S. President Obama warned: "The nation that leads the world in 21st-century clean energy will be the nation that leads in the 21st-century global economy". In February 2010, he further noted: "Countries like China are moving even faster. . . . I'm not going to settle for a situation where the United States comes in second place or third place or fourth place in what will be the most important economic engine in the future" (cf. Mufson and Pomfret 2010).

From a theoretical standpoint, the CT industry contains many unusual and idiosyncratic features. The issues of the evolution of entrepreneurship in the CT industry and nations' competitive advantages in this industry are a critical but little-examined problem in the social science research. Gibbs (2009) notes: "...the concept of a sustainable entrepreneur may remain as much of a 'black box' as sustainable development itself" (p. 65). We contribute to filling this research gap with an analysis of the global CT industry. Specifically, this paper proposes a framework to examine the development of the CT industry and assesses the world's major economies in terms of the important elements in the framework. We also present a case study of the Chinese CT industry.

In the remainder of the paper, we first provide a review of the CT industry. Then, we discuss our proposed model to examine the development of the CT industry. Next, we classify major economies in the world in terms of the framework. The final section provides discussion and implications.

¹In the U.S., CT was the only sector that received more VC in 2009 compared to 2008, which experienced a 52% increase to \$2.7 billion (Zaborowski 2009).

²While the CT market has been growing since the 1970s (solar panels and wind energy have had a small but loyal consumer), investment in this sector is taking off in recent years (Gangemi 2007).

2. A note on the CT industry

One of the most striking features of the CT industry is its all-encompassing nature, which touches diverse industries and settings. CT requires re-engineering an economy that has run on fossil fuels since the Industrial Age. The transportation infrastructure, for example, encompasses comprehensive network of energy production and distribution that have been shaped by a century of investment and innovation in oil drills, pipelines, tankers, refineries and gas stations (Harris 2010; Johnson and Suskewicz 2009). Parker and Youngman (2009) have rightly pointed out: “[C]leantech is not a sector in the traditional sense (like IT or biotech), more a theme”.

Most innovations developed by biotechnology ventures are typically disruptive in nature (Thomassin and Cloutier 2001). Despite initial inferior performance, disruptive innovations tend to be “cheaper, simpler, smaller, and more convenient to use” (Christensen, Raynor and Anthony 2003). They either create new markets by targeting non-consumers or compete in the low end of an established market.

While some innovations in the CT industry might have disruption potential (Parker and Youngman 2009), they might not be so in the same way as in other industries. As noted above, most disruptive innovations tend to be cheaper (Christensen, Raynor and Anthony 2003). To the contrary, while the costs of solar and wind energy have reduced significantly, they remain more expensive than coal-generated electricity (Walet 2010). The CT industry is thus unlikely to follow Moore's Law³ of cost-improvement curve (Karlgaard 2010).

Instead of focusing on a particular economic sector, CT entails the development, manufacturing, deployment, and sustainment of technologies that help improve the economic productivity and environmental performance of many sectors of the economy and improves national security (Ernst & Young 2007; Parker and Youngman 2009). The development of the CT industries depends upon reducing the costs of products based on existing technologies instead of creating new low-cost products.

CT's development depends upon emotional rather than rational behaviors of consumers and businesses. CT industry's success thus requires a fundamental shift in behaviors of consumers and businesses. Likewise, companies' responses to the global trends toward CT are also functions of factors such as contribution to international/ national security and environmental protection in addition to profit maximization. Some CT leaders, for instance, are likely to be consumer companies that are “de-materializing” and are seeking to improve resource efficiency (Parker and Youngman 2009).

Green capitalism is not likely to work in the same manner as in traditional industries. Wallis (2010, p. 33) notes: “At a conceptual level, it is clear that “green capitalism” seeks to bind together two antagonistic notions. To be green means to prioritize the health of the ecosphere, with all that this entails in terms of curbing greenhouse gases and preserving biodiversity. To promote capitalism, by contrast, is to foster growth and accumulation, treating both the

³ The well-known Moore's Law states that the number of transistors on a chip doubles every 18 to 24 months, driving exponential growth rate of computing power. Over the past 40 years, Moore's Law has been found to be remarkably accurate. For instance, the number of transistors on a single chip increased from 2,300 on the 4004 chip developed in 1971 to 42 million on the Pentium IV processor developed in 2000 (Hamilton, 2001). Moore (2001) was confident that his law 'will be true for another 20 years'. A corollary of Moore's Law is that the cost of computing declines by about 35% every year (Palem 2001).

workforce and the natural environment as mere inputs". A corollary of the above observation is that the traditional venture capital (VC) model that worked for IT may not work for the CT industry. A BusinessWeek article quotes a VC attorney, a CT specialist: "The scale and the risks are much greater". For this reason, some advocates of CT industry maintain that the government needs to act as a source of patient capital.

3. A proposed framework to examine the development of the CT industry

The development of the CT industry in an economy can be understood in terms of three main building blocks (Figure 1)⁴. In this section, we briefly discuss the elements of the building blocks.

Figure 1 about here

3.1. Impacts of CT

Impacts of CT reflect the national welfare created by the CT industry and are the ultimate objectives that policy makers want to accomplish (Ahmad and Hoffmann 2008). The reason perhaps most often cited for policymakers' preference for CT development concerns the shift towards a new form of "capitalist development" that can address concerns related to negative environmental impacts such as global warming and climate change (Gibbs 2009). In addition, CT may also contribute to the economic and national security. In the U.S., for instance, in addition to climate change related concerns, factors such as increasing oil prices, growth of emerging markets and perceived national security implications of energy dependence on foreign countries have been major drivers of the CT industry (Ernst & Young 2007).

3.2. Performance of the CT industry

Performance indicators are CT related actions that are instrumental in delivering the desired impacts. Put differently, target indicators used in measuring CT performance tell the progress towards achieving the ultimate objectives. Various indicators related to the development of the CT industry can be used to measure the performance. Businesses' and consumers' CT awareness, attitude and preferences are tightly linked to the CT industry's performance. It is argued that companies in Japan have a "non-political, long-term view" of energy (San Miguel 2010). In some countries, consumer perceptions are often the biggest roadblock for the development of the CT industry. For instance, due to efficiency and cost-effectiveness of conventional energy in the U.S., consumers have failed to see the benefits of CT (Johnson and Suskewicz 2009; Wadhwa 2010).

Production of CT and CT adoption levels of businesses and consumers are also important performance indicators. The width of CT adoption or the number of different uses of CT, and the depth of CT adoption or the amount of usage of a particular CT can also be used to assess a country's CT performance. Other indicators include entrepreneurship and emergence of competitive local firms in the CT sector, export of CT related products and CT related innovations.

3.3. Determinants of CT development

⁴ This framework draws upon Ahmad and Hoffmann (2008).

Determinants of CT development are the factors that affect CT performance. The left box in Figure 1 presents interdependent and mutually reinforcing elements that determine the development of the CT industry.

Government incentives, supports and strategic regulations that favor the local CT industry

As is the case of any industry, the development of the CT industry is a function of the level of priority and focus of national industrial and technological policies on fostering and strengthening the industry (National Academy of Science 1985). Trade policy and other strategic regulations also affect the CT industry's growth (Tilton 1971). Strategic regulations provide frameworks and processes required for CT related actions that may lead to the planned and targeted results (Medley 1994).

Some argue that the market mechanisms do not work perfectly and are associated with various imperfections and impurities. Prior research indicates that the government can take various measures to overcome businesses' myopia, greed, and economic power (Hart 1998). Government intervention is thus necessary to correct the failure of the market forces (Dahlman 1979). Indeed, some go even further to argue that government intervention may be desirable (Hvistendahl 2009).

Different theoretical contributions and various empirical studies have led to the accepted view that the government can attack barriers to the development of an industry such as those related to skills, information, market and infrastructures by legal and non-legal influences. Scholars examining the development of information and communications technology (ICT) industry have identified these influences in the form of new laws, investment incentives, foreign technology transfer, and other supply-push and demand-pull forces (King et al. 1994; Montealegre 1999). For instance, Singapore has developed itself as an ICT hub of Asia by providing attractive infrastructure, skilled workers and a stable labor environment which attracted a large number of ICT firms to locate there (Kraemer et al. 1992; Wong 1998). Similarly, strong university-industry linkages and a large pool of highly trained scientists and engineers have driven the development of ICT industries in Israel (Porter and Stern 2001).

In most cases, CT products such as solar power tend to be more expensive than conventional alternatives (Galbraith 2009). CT startups often need to make huge investments in R&D and wait for a long time to develop a business plan. Developing expensive production facilities and scaling them up may prove to be a challenge of another magnitude (Wadhwa 2010). A consultant noted that a CT company could take up to nine years to become profitable (Gangemi 2007).

Moreover, some CT sectors such as solar panel manufacturers are facing dropping profits. During 2007-2009, the price of solar panels reduced by more than half (Asia money 2009). The CT industry thus faces non-price barriers. One way to overcome such barriers would be to increase public sector investments and provide substantial subsidies or other incentives, which is likely to play a key role in stimulating entrepreneurship in such technologies. In sum, government incentives are more important for CT industry compared to other industries.

3.4.R&D and innovation profile

An observation is that deployment rather than scientific breakthroughs is critical in the development of the CT industry (La Monica 2010). However, there may be equally compelling arguments regarding the importance of innovations in the CT industry. Innovation undoubtedly contributes to national competitiveness in CT (NSF 2010). Innovation is especially important in the high-end segments of the CT industry. For instance, consider

China's showcase of high-tech renewable energy in Ordos City, Inner Mongolia. Due to a lack of local high quality photovoltaic installations manufacturers, China is importing photovoltaic panels from U.S.-based First Solar for a 2,000-megawatt power plant in Ordos (Mufson and Pomfret 2010).

3.5. Adverse environmental and health impacts of conventional energy sources

Relative advantage is perceived benefits of a technology over previous technologies and the extent to which it is better than the idea it supersedes (Rogers 1962 1983 1995). In this regard, adverse environmental and health impacts of conventional energy sources would lead to a perception of higher relative advantage of CT and encourage its adoption.

3.6. Forward and backward linkages

Of special interest is the development of related and supporting industries (Porter 1990). Efficient channels for forward and backward linkages, labor mobility and stimulation of knowledge and technology transfer affect the development of the CT industry (Markusen and Venables 1999).

3.7. Market size and economies of scale

Market size and economies of scale affect an industry's growth (Tilton 1971). Economies of scale are more important for the CT industry than most other industries. Some analysts argued that even the world's biggest markets such as China and the U.S. lack the scale required to succeed in the CT industries (Woetzel 2009).

3.8. Availability of CT related skills, and labor and natural resources

The diffusion of a technology is influenced by the nature of inputs (Linder 1961; Vernon 1966). In this regard, CT related skills, and labor and natural resources are critical ingredients for the success of this industry.

4. Determinants and drivers of the CT industry: Assessing major global economies

For accelerating the growth of CT industry, Johnson and Suskewicz (2009) have proposed a framework with four elements: (a) an enabling technology, (b) an innovative business model, (c) a careful market-adoption strategy, and (d) a favorable government policy. A close reading of the literature suggests that the development of enabling technology and government policy are probably the most important factors affecting entrepreneurial performance and national competitiveness in the CT industry. The OECD/EUROSTAT framework for entrepreneurship indicators, for instance, has six categories of determinants: Regulatory Framework (related to (a)), Market Conditions, Access to Finance, R&D and Technology (related to (d)), Entrepreneurial Capabilities and Culture (Ahmad and Hoffmann 2008). Indeed, the government's involvement is critical in discovering an appropriate business model and a market-adoption strategy (b and c in Johnson and Suskewicz 2009).

We would thus argue that government policy and development of enabling technology influence international heterogeneity in entrepreneurial performance and national competitiveness in the CT industry. Figure 2 provides a 2 x 2 matrix that classifies major economies in the world on these two dimensions and illustrates how they are positioned to benefit from the global trend towards CT.

Figure 2 about here

Dimension 1: Government incentives, supports and strategic regulations that favor the local CT industry

Solomon (2009) noted the emergence of two primary strategies in the CT arena: a top-down approach, which involves the government imposing regulations that force companies to embrace CT and a bottom-up approach in which CT entrepreneurs come up with solutions for the marketplace (Solomon 2009). Because of the all-encompassing nature of CT and the importance of the development of a whole system, the latter approach is less likely to be effective in the CT industry.

As noted above, government incentives matter in stimulating entrepreneurship in the CT industry (Hvistendahl 2009). In this regard, a 2009 study by Deutsche Bank (DB) 'Global Climate Change Policy Tracker: An Investor's Assessment', which ranked 109 countries, Germany, China and Japan present the lowest risks for green investors and CT firms (PRLog 2009). In particular, there have been direct and targeted public investments in Asia's "clean technology tigers"—China, Japan and South Korea. Substantial and well-targeted incentives and greater public investments have attracted private capital flows in these. These three countries are projected to invest a US\$509 billion in CT during 2009-2013 compared to the U.S. investment of US\$172 billion (Issues in Science and Technology 2010). Likewise, German government policies have made the country a CT leader (Altman 2010).

The United Arab Emirates (UAE) is another high profile example of an economy which is characterized by government incentives, supports and strategic regulations in the CT industry. Masdar City set up the Abu Dhabi government will run entirely on CT (Johnson and Suskewicz 2009). The US\$22 billion zero-emission, zero-waste city was launched in 2006 and is scheduled to be completed by 2016 (Singh 2010).

In this paper's context, strategic regulations are regulations that are developed and applied strategically to provide a framework or process for actions that lead to planned CT results. It is worth noting that the literature is often plagued with claims and counter claims regarding the potential benefits to firms from environmental regulations. Porter and van der Linde (1995) observed that environmental regulations foster innovations and thus benefit firms. Palmer, Oates, and Portney's (1995) models, on the other hand, demonstrated that regulations impose costs on firms, and firms can offset only a portion of those costs through innovation. Mohr and Saha (2008) provide various theoretical examples that are consistent with the Porter and van der Linde's assertion. They consider various possible scenarios associated with environmental regulations and discuss some mechanisms by which firms may benefit from environmental regulations. Specifically, they argue that under some conditions, regulations impose costs that can be fully offset via induced innovation (Mohr and Saha 2008). In addition, Mohr and Saha (2008) also point out the possibility that a regulation itself is beneficial even without innovation. Firms may get additional benefit from innovation. It is quite possible that the cost of regulation is passed along to the consumer in the form of a higher price.

Dimension 2: Innovation and R&D profile

As discussed earlier, innovation per se is likely to make a smaller contribution to success in the CT industry (Johnson and Suskewicz 2009). Innovations, however, undoubtedly contribute to national competitiveness in CT (NSF 2010). For instance, Masdar City is planning to use 100% renewable energy and most of the innovations will be generated on-site (Johnson and Suskewicz 2009). Our second dimension is thus the degree of innovations in the industry. Table 1 presents some important indicators related R&D and innovations profiles of some major economies in the world.

Table 1 about here

One way to understand inventive entrepreneurial activity around the world would be to look at the distribution of patents awarded to inventors in the U.S. Traditionally inventors in the U.S., the European Union (EU) and Japan produced most patents. According to the U.S. National Science Foundation, Taiwan and South Korea have intensified patenting activities in the U.S. in recent years. Chinese and Indian inventors' patenting activities, on the other hand, remain modest (NSF 2010). According to The European Patent Office (EPO), the number of CT patents increased significantly after the Kyoto Agreement. Germany, Japan, the UK, the U.S., South Korea and France have been the countries with the most CT patenting activities (cpaglobal.com 2009).

Classifying some major economies in terms of the two dimensions

We assess some of the major economies in terms of the two dimensions discussed above.

Cell I: South Korea

In 2008, South Korean government set "green growth" as the national vision. In 2009, it announced that US\$31 billion of its US\$38 billion stimulus package would be spent in the CT industry. The package was second only to China in terms of percentage of 2008 GDP (3.4 %) and the world's largest as a percentage of the stimulus package (81 %) (Morrison and Yoshida 2009). The package covered various economic sectors and was expected to create about 1 million green jobs. In 2009, a five-year plan was also announced, which aims to spend 2 % of its GDP in the development of environmentally friendly businesses and projects. In July 2009, an additional US\$85 billion stimulus was announced for CT industries, which is expected to create about 1.81 million jobs in five years (Morrison and Yoshida 2009).

In January 2010, the president signed the Basic Act on Low Carbon Green Growth. The law mandates the government to establish a national strategy for green growth and set national and corporate targets for carbon emissions. The law also provides legal grounds for state investment in CT (Jang-jin 2010). The country's presidential committee selected 10 green technologies to promote as new growth engine businesses for 2010. By 2012, the country will add 28,000 environment-friendly buses and provide incentives to reduce food waste by 20 % (Jang-jin 2010). It has set an explicit goal of increasing South Korean companies' share of the global CT export market by 8 % points (Atkinson 2010).

As noted above, South Korea has intensified patenting activities in the U.S. in recent years. South Korea is also among the top 6 countries in the world for CT patenting activities (cpaglobal.com 2009).

Cell I: Japan

The Japanese government announced in the early 2010 that it would provide US\$33 billion incentives for the CT industry. The targeted deployment would be in solar, hybrid-electric vehicles, and energy-efficiency technologies. The government also announced plans to spend an additional US\$30 billion by 2015 on achieving price and performance improvements of the CT industry (Atkinson 2010).

Japan's innovation profile in CT is advanced. Japan leads the world in CT patents (Parker and Youngman 2009). Between 2002 and 2006, Japan applied for 60,261 patents for environmental technology compared to 25,047 applied by the U.S. (Fuller 2010). For clean-coal technology, the top six holders of patents are Japanese.

Cell II: The U.S. and the U.K.

The U.S. and the U.K. historically were the most popular destinations for global private CT investors (Atkinson, 2010). From 2000 to 2008, the U.K. and the U.S. attracted high levels of green capital investment --\$17 billion and \$52.1 billion respectively (PR Log 2009). In 2008, however, China overtook the U.S. in CT related private investments. In 2009, China gained in its global share of VC in CT, while North America lost its share. North America's share of global CT VC funding declined from 72 % in 2008 to 62 % in 2009 (Red Herring 2010).

According to the Deutsche Bank mentioned earlier, the U.K. and U.S. have a high risk policy and CT investment environment (PR Log 2009). According to the report, the U.S. primarily relies on "volatile market incentive approach". The recent trend of private investment reveals a declining confidence in the U.S. CT industry.

Critics blame the U.S. for "wavering policies, complex permitting, and a skittish financial community" (LaMonica 2010). The American Clean Energy and Security Act was passed by the U.S. House of Representatives in 2009. The Act arguably includes too few proactive policy initiatives and allocates relatively little funding to support R&D, commercialization and production of clean-energy technologies (Atkinson, 2010). Current U.S. energy and climate policies focus on stimulating domestic demand primarily through indirect demand-side incentives and regulations.

Analysts argue that the proposed U.S. climate and energy legislation may not close the CT investment gap. Some analysts argue that one of the biggest problems facing the U.S. CT concerns a political system. Powerful interest groups and the society arguably have acted as barriers to CT friendly policies (Parker and Youngman 2009). Wadhwa (2010) noted: "The Valley may develop some breakthrough technologies, but without government help these are unlikely to translate into global leadership".

While the U.S. has a R&D and innovation profile, the country overall lags behind Japan on CT patents. However, U.S. firms lead in some clean tech sectors. For instance, U.S. firms hold two-thirds of the patents on carbon-capture technology. While the U.S. runs a CT trade deficit of over \$6 billion (Gerwin 2010), some U.S. companies such as First Solar are exporting high-end CT products.

Cell III: China

CT sectors that were prioritized by the government actions have experienced rapid growth (Parker and Youngman 2009). David Sandalow, a U.S. assistant secretary of energy for policy and international affairs—a CT expert recently put the issue this way: "China's investment in clean energy is extraordinary. Unless the U.S. makes investments, we are not competitive in the CT sector in the years and decades to come" (Lean 2010).

China is behind the U.S. and other industrialized countries in terms of CT innovations. According to Chatham House, no Chinese companies is among the top CT patent holders. For instance, there is no Chinese company among the top 20 holders of patents for clean-coal technology. Most Chinese players are concentrated in the low end of the CT industry. For instance, while China has a large number of players in the solar devices sector, most focus on low-tech rooftop water-heaters or cheap, low-efficiency photovoltaic panels (Mufson and Pomfret 2010). Likewise, quality levels of China's wind-turbine manufacturers lag far behind those of General Electric, Vestas and Siemens (Mufson and Pomfret 2010).

Cell IV: India

In June 2009, the Indian National Solar Mission announced that it had set a target to reach 20 GW installed solar capacity by 2020, which was more than the entire world's solar generation

capacity for 2009. India, however, expects to pay for the US\$20 billion plan primarily through international financing (Peace 2009). As of July 2009, India's total fiscal stimulus was US\$6.5 billion (0.5 % of GDP) compared to China's US\$586 billion (Fuller 2009).

According to Chatham House, no Indian company is among the top CT patent holders. In general, India's innovation and R&D profile has been low (Table 1).

5. Discussion and conclusion

This article disentangled the mechanisms behind the development of the CT industry. Disruptive innovations are quite possible in the CT industry, especially when there is a sizable segment of the population adopting this technology. As in other disruptive innovations, the incumbents (e.g., the industrialized nations-based firms) may lack the ability to play the new game in the field of CT (Christensen, Raynor and Anthony 2003). As noted above, companies such as DuPont have entered into a completely new game of CT (Hart 2005). Chinese CT firms' internationalization activities may be the latest sign to suggest that Chinese firms may emerge as winners in the global CT race.

The case study presented in this paper also suggested that the Chinese CT industry is more sophisticated than first meets the eye. The government is playing an influential role to drive the Chinese CT industry. The Chinese government is counting on the CT to enhance its image. The Communist Party expects that a richer and greener economy might help increase respect for it. There has already been some results. In recent years, air quality has improved in some Chinese cities (Bureau of East Asian and Pacific Affairs 2007).

While the Chinese CT industry performs well in the government's incentives and support as well as strategic regulation, its R&D and innovation profile has been low. To achieve various objectives related to economic, environmental and national security (impacts of CT), China needs to slip into a higher gear. Lampton (2005) noted that "China can be weak and strong simultaneously". And so can its CT industry. China continues to gain strength in CT industries. Government's measures are the key to China's success. Of particular interest are the proposed regulatory measures, which are further likely to drive the growth of this industry.

More than a decade ago, Koo (1998) noted that the "progress in China has been scarcely noted in the Western media and overshadowed by the focus on the human rights abuses as perceived by the West". This observation remains generally true today as well. Several analysts have warned that Western managers may have underestimated the innovation taking place in China (Rein 2010). The Western media have neglected to pay enough attention to transformations undergoing the Chinese CT industry. Brian Fan, senior director of research at the Cleantech Group noted: "A lot of people underestimate how focused China is on becoming a global leader in CT" (Mufson 2009).

Some analysts argue that neither China nor the U.S. has the scale required to succeed in the CT industries (Woetzel 2009). The above discussion indicates that China can achieve better economies of scale and has various mechanisms to build it. However, China and the U.S. have complementary characteristics. For instance, China's low cost advantage in the CT industry can be combined with the strengths of the U.S. such as innovation and VC.

Our framework also allows us to examine international trade and factor mobility in the CT industries. As noted above, Japan is ahead of the U.S. in CT innovations. The fact that China has already overtaken the U.S. as Japan's biggest trading partner makes China-Japan

collaboration in Green technology more likely than U.S.-Japan collaboration(economist.com 2010).

REFERENCES

Ahmad, N., and Hoffmann, A. N. (2008). A Framework for Addressing and Measuring Entrepreneurship, OECD Statistics Working Paper, January.[http://www.oilis.oecd.org/oilis/2008doc.nsf/LinkTo/NT000009FA/\\$FILE/JT03239191.PDF](http://www.oilis.oecd.org/oilis/2008doc.nsf/LinkTo/NT000009FA/$FILE/JT03239191.PDF)

Altman, P. 2010. Who Says U.S. Businesses are Pulling Back on a Climate Bill?. Natural Resources Defense Council, February 24, 2010. http://switchboard.nrdc.org/blogs/paltman/who_says_us_businesses_are_pul.html.

Anderson, A.R. 1998. Cultivating the Garden of Eden: Environmental Entrepreneurship. Journal of Organizational Change Management 11, no. 2: 135-44.

Ankori, M. 2008. Cleantech connections, 22 September 08. <http://www.globes.co.il/serveEN/globes/docView.asp?did=1000384413&fid=1724>.

Asiamoney. 2009. Renewable Energy, China Supplement, 8.

Atkinson, R. 2010. America Risks Missing Out in CT: Asia's 'Clean-Tech Tigers' are out-investing the U.S. in renewable power and energy efficiency. http://www.businessweek.com/innovate/content/jan2010/id20100122_369263.htm February 3, 2010.

Bloomberg, M. R. 2008. A Race We Can All Win; The American system still has inherent advantages, but we can't slow down. Newsweek 151, no. 1: 58.

Bureau of East Asian and Pacific Affairs. 2007. Background Notes on Countries of the World: People's Republic of China, Background Note: China, Bureau of East Asian and Pacific Affairs, the U.S. State Department, October, 2007, 1-23.

Business Week. 2007. Venture Capital's Clean Dreams for China, November 2, 2007. http://www.businessweek.com/globalbiz/content/nov2007/gb2007112_376549.htm?chan=top+news_top+news+index_global+business.

Christensen, C.M., M.E. Raynor, and S.D. Anthony. 2003. Six keys to building new markets by unleashing disruptive innovation. <http://hbswk.hbs.edu/item.jhtml?id=3374&t=innovation&noseek=one>.

cpaglobal.com. 2009. EPO to preview clean-tech study at the Climate Change Conference in Copenhagen. http://www.cpaglobal.com/ip-review-online/4234/epo_preview_cleantech_study_cl.

Dahlman, C.J.1979. The Problem of Externality. Journal of Law and Economics 22: 141 - 162.

Demsetz, H. 1967. Toward a Theory of Property Rights. The American Economic Review 57, no. 2: 347-359.

Dickie, M. 2010. Japan to focus on green technology, January 31 2010. <http://www.ft.com/cms/s/0/54773666-0e99-11df-bd79-00144feabdc0.html>.

economist.com. 2010. Japan's love-bubbles for China: Hatoyama's advances to China raise fundamental questions about regional security, January 28, 2010. http://www.economist.com/world/asia/displaystory.cfm?story_id=15393357.

- Energy Technology. 2009. Breakthrough Generation, August 25, 2009. <http://breakthroughgen.org/2009/08/25/indian-prime-minister-says-india-must-invest-in-clean-energy-technology>.
- environmentalleader.com. 2010. Clean Tech Investment Plummets 33% in 2009, January 7, 2010. <http://www.environmentalleader.com/2010/01/07/clean-tech-investment-plummets-33-in-2009/>.
- Ernst, and Young.2007. Global Venture Capital Insights Report. [http://www.ey.com/Global/assets.nsf/International/SGM_Global_VC_Insights_2007/US\\$file/Global_VC_Insight_Report_2007.pdf](http://www.ey.com/Global/assets.nsf/International/SGM_Global_VC_Insights_2007/US$file/Global_VC_Insight_Report_2007.pdf).
- Ernst, and Young. 2008. Global IPO trends report 2008. http://www.ey.com/GL/en/Services/Strategic-Growth-Markets/SGM_IPO_Trends_2008.
- Fuller, B. 2009. All eyes on China. *Engineering & Technology* 4, no. 13: 69-71.
- Fuller, T. 2010. Global warming and green technology: Is China eating America's lunch?, *Environmental Policy Examiner*, February 6. <http://www.examiner.com/x-9111-Environmental-Policy-Examiner~y2010m2d6-Global-warming-and-green-technology-Is-China-eating-Americas-lunch>.
- Galbraith, K. 2009. Companies Call Government Incentives the Key to Green, November 18, 2009. <http://www.nytimes.com/2009/11/19/business/energy-environment/19CLEAN.html?pagewanted=1&r=1>.
- Gerwin, E.d. 2010. In it to Win it, February 24, 2010. http://www.huffingtonpost.com/ed-gerwin/in-it-to-win-it_b_475441.html.
- Gibbs, D. 2009. Sustainability Entrepreneurs, Ecopreneurs and the Development of a Sustainable Economy. *Greener Management International*, Winter, 55: 63-78.
- Hamilton, J. 2001. No breaking Moore's law. *TechTV News*, 24 May. <http://www.techtv.com/news/computing/story/0,24195,3329182,00.html> accessed 29 June 2001.
- Hamilton, T. 2009. Venture capitalists make business case for going green. *The Toronto Star*, December 29, B01.
- Harris, S.D. 2010. Cleantech: Silicon Valley's next great wave of innovation, January 20, 2010. http://www.mercurynews.com/business/ci_14224228.
- Hart, D.M. 1998. *Forged consensus: Science, technology, and economic policy in the United States. 1921-1953*, Princeton, NJ: Princeton University Press.
- Hart, S.L. 2005. Innovation, Creative Destruction and Sustainability. *Research Technology Management*, Sep/Oct2005, 48, no. 5: 21-27.
- Hvistendahl, M. 2009. Asia Rising: Countries Funnel Billions Into Universities, *Chronicle of Higher Education*, 10/9/2009, 56(7), A1-A29.
- Issues in Science and Technology. 2010. Rising Tigers, Sleeping Giant, 26, no. 2: 81-84.
- Jang-jin, H. 2010. Seoul to use taxes to fight climate change, February 6. http://www.koreaherald.co.kr/NEWKHSITE/data/html_dir/2010/02/04/201002040043.asp.
- Johnson, M.W., and J. Suskewicz. 2009. How to Jump-Start the Clean Tech Economy. *Harvard Business Review*, Nov, 87, no. 11: 52-60.
- Karlgard, R. 2010. New Decade, Huge Questions. *Forbes* 185, no. 2: 17.

- Kennard, B. 2008. The Wrong Energy Agenda. BusinessWeek Online, September 2, 2008, 17.
- King, J.L., V. Gurbaxani, K.L. Kraemer, F.W. McFarlan, K.S. Raman, and C.S. Yap. 1994. Institutional factors in information technology innovation. *Information System Research* 5, no. 2: 139-169.
- Koo, G. 1998. The real China. *Harvard International Review* 20, no. 3: 68-71.
- Kraemer, K. L., V. Gurbaxani, and J. King. 1992. Economic development, government policy, and the diffusion of computing in Asia-Pacific countries. *Public Administration Review* 52 (2): 146-56.
- LaMonica, M. 2010. In clean energy, U.S. needs more steel in ground, February 6, 2010. http://news.cnet.com/8301-11128_3-10447548-54.html.
- Lampton, D.M. 2005. Paradigm Lost: The Demise of "Weak China". *The National Interest*, no. 81: 73-80.
- Lean, G. 2010. Did China block Copenhagen progress to pave way for its own dominance in cleantech?, January 22, 2010. <http://www.grist.org/article/2010-01-22-did-china-block-copenhagen-to-pave-way-for-dominance-in-cleantech/>.
- Linder, S.B. 1961. *An Essay on Trade and Transformation*. Uppsala: Almqvist and Wiksells.
- Markusen, J.R., and A.J. Venables. 1999. Foreign direct investment as a catalyst for industrial development. *European Economic Review* 43, no. 2: 335-356.
- Martin, C., and J. Efstathiou. 2010. China's Labor Edge Overpowers Obama's 'Green' Jobs Initiatives. <http://www.businessweek.com/news/2010-02-04/china-s-labor-edge-overpowers-obama-s-green-jobs-initiatives.html>.
- Medley, T.L. 1994. A regulatory perspective on harmonization of regulations and public perception. In *Biosafety for Sustainable Agriculture, Sharing Biotechnology Regulatory Experiences of the Western Hemisphere*, ed. A. Krattiger and F. Rosemarin. ISAAA-International Service for the Acquisition of Agri-biotech Applications SEI-Stockholm Environment Institute. http://www.isaaa.org/resources/publications/Downloads/Biosafety_bk.pdf#page=89.
- Mohr, R.D., and S. Saha. 2008. Distribution of Environmental Costs and Benefits, Additional Distortions, and the Porter Hypothesis. *Land Economics*, Nov, 84, no. 4: 689-700.
- Montealegre, R. 1999. A temporal model of institutional intervention for information technology adoption in less-developed countries. *Journal of Management Information Systems* 16, no. 1: 207-232.
- Moore, G.E. 2001. The continuing silicon technology evolution inside the PC platform. <http://developer.intel.com/update/archive/issue2/feature.htm>.
- Moresco, J. 2009. Record Year for Global Clean Tech VC. *Red Herring*, January 6, 2009, 4.
- Morrison, G., and P. Yoshida. 2009. China, United States, Korea Take Lead In Clean Energy and Low-Carbon Initiatives. *Research Technology Management*, Nov/Dec2009, 52, no. 6: 2-4.
- Mufson, S. 2009. Asian Nations Could Outpace U.S. in Developing Clean Energy; American Markets' Slump Feeds Worry. *The Washington Post*, July 16, 2009, Suburban Edition, A14.
- Mufson, S., and J. Pomfret. 2010. There's a new Red Scare. But is China really so scary?, February 28, 2010. <http://www.washingtonpost.com/wp-dyn/content/article/2010/02/26/AR2010022602601.html>.

- National Academy of Science. 1995. *Allocating Federal Funds for Science and Technology*. Washington, D.C.: National Academy press.
- NSF. 2010. National Science Board Releases Science and Engineering Indicators 2010. January 15, 2010. http://www.nsf.gov/news/news_summ.jsp?cntn_id=116238&org=NSF&from=news.
- Palem, K. 2001. *Designing pervasive computing environment*. <http://www.crest.gatech.edu/courses/dpce.pdf>.
- Palmer, K., W.E. Oates, and P.R. Portney. 1995. Tightening Environmental Standards: the Benefit-Cost or the No-Cost Paradigm?. *Journal of Economic Perspectives* 9, no. 4: 119-32.
- Peace, J. 2009. Indian Prime Minister Says India Must Invest in Clean Energy Technology. *Breakthrough Generation*, August 25, 2009.
- Porter, M. 1990. *The Competitive Advantage of Nations*. London: Macmillan.
- Porter, M.C., and C. van der Linde. 1995. Toward a New Conception of Environment-Competitiveness Relationship. *Journal of Economic Perspectives* 9, no. 4: 97-118.
- Porter, M.E., and S. Stern. 2001. Innovation: Location matters. *Sloan Management Review* 42, no. 4: 28-36.
- Potter, P.B. 2004. Legal reform in China: institutions, culture, and selective adaptation. *Law and Social Inquiry* 29, no. 2: 465–95.
- PR Log.2009. Germany And China Ranked Best Countries For Clean Tech Investors, October 30. <http://www.prlog.org/10395026-germany-and-china-ranked-best-countries-for-clean-tech-investors.html>.
- Red Herring, 2010. Global Cleantech VC Down 33 Percent, 1/8/2010, p1-1
- Rein, S. 2010. Chinese Companies Can't Build Brands? Think Again. *BusinessWeek Online*, January 27, 2010, 18.
- Rogers, E.M. 1962. *Diffusion of Innovation*, 1st edition. New York: Free Press.
- Rogers, E.M. 1983. *Diffusion of Innovation*, 3rd edition. New York: Free Press.
- Rogers, E.M. 1995. *Diffusion of Innovation*, 4th edition, New York: Free Press.
- San Miguel, R. 2010. Tech Titans Lend Credibility to Bloom Box Hype. *TechNewsWorld*, February 24, 2010. <http://www.technewsworld.com/story/Tech-Titans-Lend-Credibility-to-Bloom-Box-Hype-69418.html>.
- Singh, M. 2010. Masdar for early completion of Masdar City 03/01/2010, <http://topnews.ae/content/21668-masdar-early-completion-masdar-city>
- Solomon, S.D. 2009. Clean Tech: Force It or Fund It?. *Scientific American Earth* 3.0 19, no. 1: 22-23.
- Technology Review. 2009. Venture Capitalists Struggle with Renewables, 112, no. 5: 98.
- Thomassin, P.J., and L.M. Cloutier. 2001. Informational requirements and the regulatory process of agricultural biotechnology. *Journal of Economic Issues* 35, no. 2: 323–333.
- Tilton, J.E. 1971. *International Diffusion of Technology: The Case of Semiconductors*. Washington, DC: Brookings Institution.

UNDP (2008). 2008. Human Development Report 2007/2008: Fighting climate change: Human solidarity in a divided world, United Nations Development Programme (UNDP), http://hdr.undp.org/en/media/HDR_20072008_EN_Complete.pdf.

Utterback, J.M. 1996. Mastering the Dynamics of Innovation. Cambridge, MA: Harvard Business School Press.

Vernon, R. 1966. International investment and international trade in the product cycle. Quarterly Journal of Economics 80: 190–207.

Wadhwa, V. 2010. Will China Eat America's Lunch in Cleantech?, January 30. <http://www.washingtonpost.com/wp-dyn/content/article/2010/01/30/AR2010013001016.html>.

Walet, L. 2010. ANALYSIS - China's green tech revolution, January 29, 2010, <http://in.reuters.com/article/technologyNews/idINIndia-45812720100129>.

Wallis, V. 2010. Beyond "Green Capitalism". Monthly Review: An Independent Socialist Magazine, Feb, 61, no. 9: 32-48.

Woetzel, J. 2009. China and the US: The potential of a clean-tech partnership. McKinsey Quarterly, 2009, no. 4: 88-92.

Wong, P.K. 1998. Leveraging the global information revolution for economic development: Singapore's evolving information industry strategy. Information Systems Research 9 no. 4: 323-341.

Zaborowski, J. 2009. Opportunities in a recession. Economic Development Journal 8, no. 1: 42-48.

Table 1: R&D and innovations profiles of some major economies in the world

	Patents granted to residents (per million People) 2000–05	Receipts of royalties and license fees (US\$ per person) 2005	Research and development (R&D) Expenditures 2000–05	Researchers in R&D (per million people) 1900–05
Japan	857	138.0	3.1	5,287
The U.K.	62	220.8	1.9	2,706
The U.S.	244	191.5	2.7	4,605
South Korea	1,113	38.2	2.6	3,187
China	16	0.1	1.4	708
India	1	0	0.8	119

Source: UNDP (2008)

Figure 1: A framework for understanding CT related Indicators

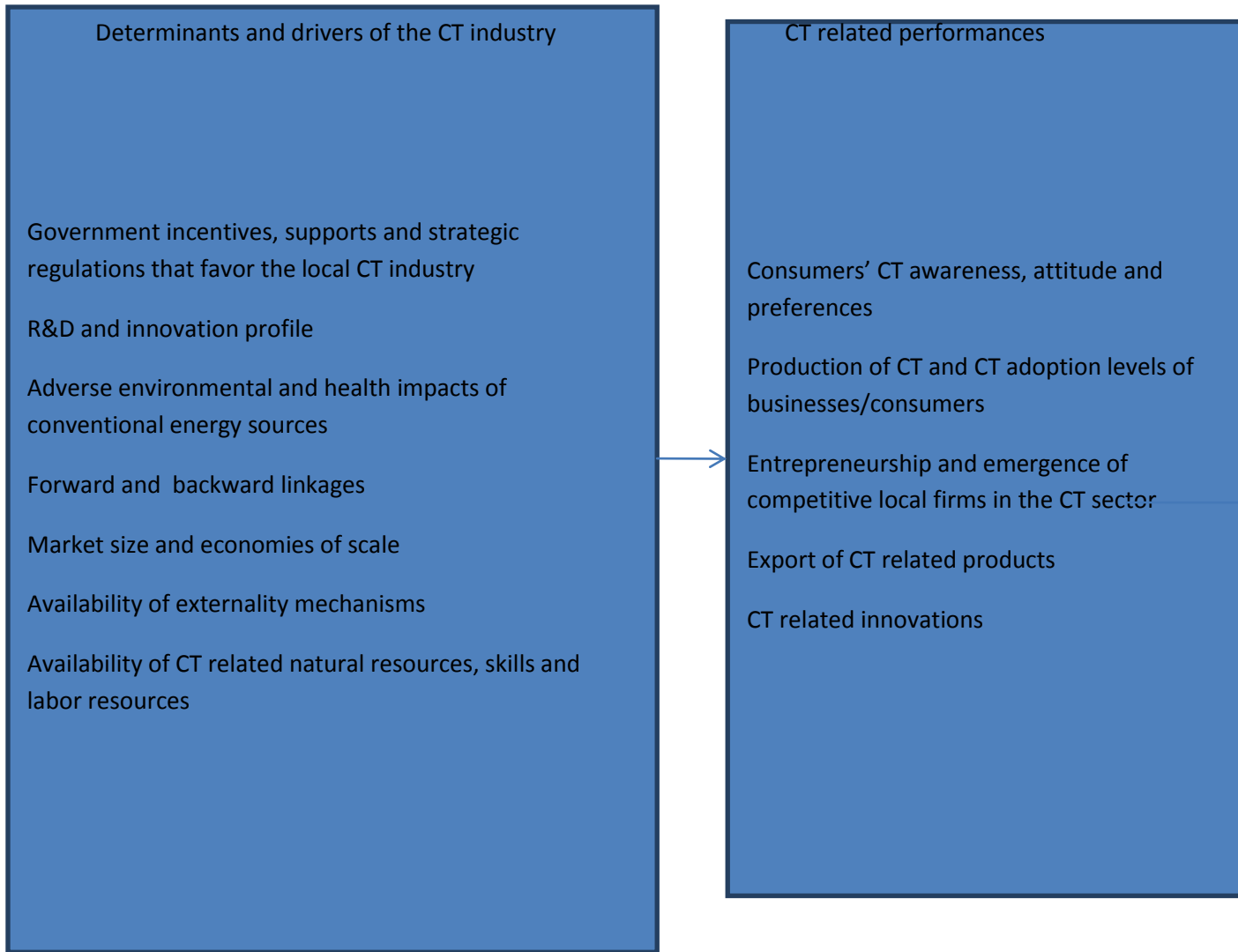


Figure 2: Assessing major world economies in terms of some determinants of CT development

		Degree of government incentives and support	
		High	Low
Degree of R&D and innovation	High	[I] Japan South Korea Germany	[II] The U.S. The U.K.
	Low	[III]	[IV]

		China The UAE	India
--	--	------------------	-------

Notes:

In the U.S., CT was the only sector that received more VC in 2009 compared to 2008, which experienced a 52% increase to \$2.7 billion (Zaborowski2009).

5ii While the CT market has been growing since the 1970s (solar panels and wind energy have had a small but loyal consumer), investment in this sector is taking off in recent years (Gangemi2007).

iii The well-known Moore's Law states that the number of transistors on a chip doubles every 18 to 24 months, driving exponential growth rate of computing power. Over the past 40 years, Moore's Law has been found to be remarkably accurate. For instance, the number of transistors on a single chip increased from 2,300 on the 4004 chip developed in 1971 to 42 million on the Pentium IV processor developed in 2000 (Hamilton, 2001). Moore (2001) was confident that his law 'will be true for another 20 years'. A corollary of Moore's Law is that the cost of computing declines by about 35% every year (Palem 2001).

iv This framework draws upon Ahmad and Hoffmann (2008).