ISSN 0976 - 545X

Journal of Technology Management for Growing Economies

Volume 1 Number 2 October 2010

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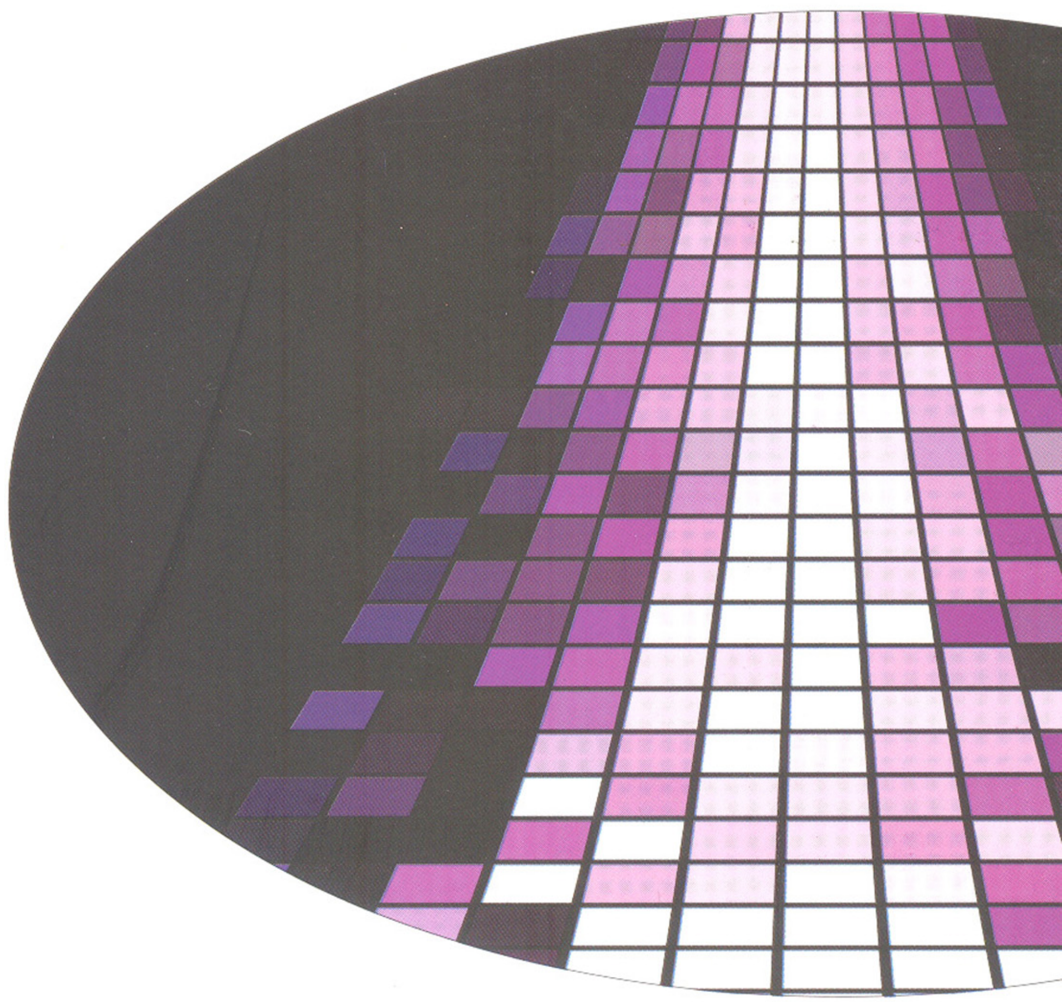

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DOI: 10.15415/jtmge.2010.12011

Technology Leapfrogging: Findings from Singapore's Water Industry

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Abstract

This paper illustrates Singapore's strategy in catching up with global water treatment nations. Water is an important economic resource for Singapore, creating value-added jobs and stimulating research and development in various related technology trajectories. The analysis shows that from a nation lacking in competence in the water industry, Singapore has successfully transformed herself into a global hydrohub, exporting indigenous capabilities and offering consultancy for water projects. With long-term government policies and funding support for initial R&D and subsequent industry R&D inducement by means of the introduction of Public-Private Partnership (PPP) programme, Singapore has been able to build up her competence in waste water treatment. This is probably the first paper that analyses the development of the water industry in Singapore from the management of technology and policy perspectives.

Keywords: *Water industry, Public-Private Partnership, Global hydrohub, Government stimulation Singapore strategy, water treatment.*

INTRODUCTION

The Water Industry in Singapore

The Singapore water industry is very vibrant. Singapore is positioning herself to become a global hydrohub, with activities spanning the entire value chain of R&D, construction, design and operations. The value-added[1] contribution from the water sector was S$0.5 billion (0.3% of DP) in 2003. It is targeted to reach S$1.7 billion (0.6% of GDP) by 2015. Jobs created (directly or indirectly) for this sector are expected to reach 11,000 in 2015 (0.5% of local employment), with a large part of the growth in professional and skilled categories. As of 2008, Singapore's water sources, otherwise known as the four National Taps, include local catchment (50%), imported water (33%), NEWater (recycled water) (7%) and desalinated water[2] (10%) (ADB, 2008).

Under the Singapore Green Plan (the blueprint towards environmental sustainability), published in 2002, the target for the supply of water is to

Journal of Technology Management for Growing Economies
Vol. 1 No. 2
October 2010
pp. 29-47

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have at least 25% of Singapore's water supply derived from unconventional sources by 2012. With advancement in membrane technology, the Public Utilities Board was able to project a higher target that by 2011, NEWater will be able to meet approximately 30% of Singapore's water need.

NEWater Journey

The Singapore Water Reclamation Study (NEWater Study) was initiated in 1998 as a joint initiative between the Public Utilities Board (PUB) and the Ministry of the Environment and Water Resources (MEWR). The primary objective of the joint initiative was to determine the suitability of using NEWater as a source of raw water to supplement Singapore's water supply. NEWater is treated used water that has undergone stringent purification and treatment process using advanced dual-membrane (microfiltration and reverse osmosis) and ultraviolet technologies. NEWater can be mixed and blended with reservoir water and then undergo conventional water treatment to produce drinking water (a procedure known as Planned Indirect Potable Use or Planned IPU). Figure 1 illustrates how the IPU strategy is part of PUB's strategy to close the water loop.

As listed in Table 1, there are currently five NEWater factories in operation in Bedok, Kranji, Seletar, Ulu Pandan and Changi. The NEWater factories at Bedok and Kranji Water Reclamation Plants were commissioned in 2003. In 2004, the third NEWater factory at Seletar Water Reclamation Plant was commissioned. Ulu Pandan is the fourth NEWater plant that started operation in March 2007. This fourth NEWater factory was tendered for a Design, Build, Own and Operate (DBOO) contract.

Since the introduction of NEWater in 2003, its demand has increased rapidly. In addition to the four NEWater factories which have a combined capacity to supply 15% of Singapore's total water demand, the fifth NEWater factory at Changi (completed in May 2010), have a combined designed capacity to meet up to 30% of Singapore's total water demand.

Table 1: NEWater Factories in Singapore

Name of NEWater Factory	Plant Capacity (mgd)	Year Commissioned
Bedok	18	Jan 2003
Kranji	17	Jan 2003
Seletar	5	Feb 2004
Ulu Pandan	32	Mar 2007
Changi	50	May 2010
Sum of Combined Capacity	122mgd (555,000 m3/day)	

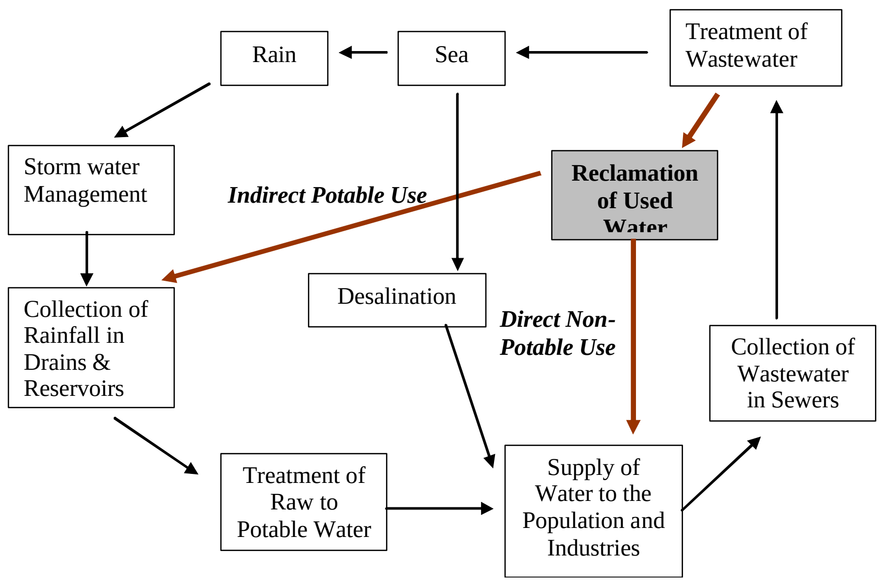

Figure 1: Strategy to Close the Water Loop.

Noteworthy Implications in NEWater Development

An analysis of the NEWater development in Singapore reveals the following noteworthy implications suggestive to technology management for growing economies:

(1)Transformation of a National Security Issue into a Platform for New Innovations

The ability to be more self-sufficient in increasing water supply and less dependent on imported water has been a long-lasting high-priority national target. It is observed that through government stimulation and industry participation, a national security issue has been transformed into a platform for innovations. Measures of these new innovations include the development of indigenous capabilities, the export of these indigenous capabilities via consultancy projects to other counties, the creation of research and development funding for research on water and the environment, building strategic alliances with industry players and the establishment of Center of Excellence (COE) in Singapore.

(2) Technology Substitution for Conventional Water

NEWater is a technology-driven innovative solution to "increasing" the supply of water through recycling wastewater which would otherwise be discharged into the sea. By means of the phenomenon known as "technology substitution", it helps decrease the nation's dependency on imported water by being able to recycle used water for industrial use, thus reducing the demand of potable water by industries. The existing portable water can be solely dedicated for human consumption.

(3) Inducement of Highly Technology Intensive Systems

The four taps that make up Singapore's water supply include local catchment, imported water, NEWater and desalinated water. In terms of the technology, NEWater, besides desalinated water, requires an advanced level of membrane technology. The requirement for the former are higher than the latter as the raw water to be treated is more heterogeneous than seawater. The NEWater production process involves a hybrid system of advanced membrane filtration such as microfiltration, ultrafiltration, reverse osmosis and membrane bioreactors. This use of advanced membrane technology also requires complementary engineering systems such as operation and management and stimulation and monitoring. This has induced technology advancement in other related industries, such as in Information Technology (IT), in particularly software for monitoring the systems, and diagnostic technology which includes products and services for the detection of contaminants.

(4) Unique Stepwise Industrial Policy Leading to a Global Hydrohub

Analysing the industrial policies implemented by the government to become a global hydrohub, the following stepwise trend is observed: from importation and multinational companies dependent to absorption/ assimilation to building an indigenous industrial base to exporting the indigenous capabilities. The knowledge creation cycles does not end with the export of indigenous capabilities. The external knowledge acquired from export activities by means of joint projects with companies with advanced technologies and institutional learning by the receiving party is assimilated and integrated into the existing knowledge pool and disseminated to broad industries leading to the co-evolutionary model of domestication.

Thus, the analyses for this paper focus on three dimensions: market learning, elasticity of substitution and open innovation dynamism aiming at co-evolutionary domestication. This introductory section is followed by a review of existing works on the foregoing three dimensions. Numerical analyses of market learning and substitution dynamism are demonstrated in the next section. The paper also analyses a possible development of co-evolution domestication in open innovation. The last section briefly summarises new findings, policy implications and suggest future works.

REVIEW OF EXISTING WORKS

Market Learning

Experience, knowledge, or insight gained from the use of imported products has played a significant role in improving innovation diffusion (Venkatraman, 1988; Gatignon and Robertson, 1991). However, Jovanovic and Lach (1989) pointed out that the process of diffusion slows down as learning effects rise. Learning by doing (Arrow, 1962) is a phenomenon that begins the moment new knowledge is initially implemented, and lasts throughout the maturation stage, providing opportunities for cost reduction and quality improvements (Gregory, 2006). The dynamics underlining such a phenomenon depends not only on the manufacturer, but also on the economic and technological landscape, as well as on the market structure. That is, market learning can be defined as a series of learning processes spanning across the whole value chain from production to distribution to utilization. Watanabe and Asgari (2004) developed a mathematical model to measure dynamic learning coefficients representing market learning effects, and successfully tested the model's usefulness by determining the diffusion trajectory of Japan's photovoltaic industry. This dynamic learning coefficient can be applied to trace the dynamic change in Singapore's market learning effects in the process of NEWater import, diffusion, utilization and also the shift to indigenous development.

Elasticity of Substitution

Under the circumstances of a constrained economy, it is generally pointed out that most efforts to overcome the constraints have been directed at substituting unlimited production factors for a constrained production factor (Binswanger and Ruttan, 1978). This is similar to an ecosystem in that in order to maintain homeostasis (checks and balances that dampened oscillations), when one species slows down, another speeds up in a compensatory manner in a closed system (substitution), while depending on supplies from an external system leads to dampened homeostasis (complement) (Odum, 1963). This concept of substitution provides information suggestions for a constrained economy. To date, a number of studies have identified a substitution mechanism. Watanabe (1992, 1999) demonstrated Japan's explicit function in transforming external crises into springboards for new innovations by analysing its technology substitution for energy in the 1970s leading to Japan's high-technology miracle in the 1980s. Given that water is a constrained resource in Singapore, similar elasticity of technology substitution can be expected in overcoming this significant constraint.

Open Innovation for Co-evolutionary Domestication

North (1990, 1994), Nelson and Sampat (2001) have carried out analysis on the structure and inducing role of institutions. Watanabe (1999) and Watanabe *et al.* (2006) analysed the trajectory of Japanese economy as an innovation driven economy from the institutional aspects. They postulated a concept of hybrid management fusing the "East" (indigenous strength) and the "West" (lessons from corresponding to a digital economy) to explain the reactivation of the Japanese economy. Chen and Watanabe (2007) studied the self-propagating development in mobile phone driven innovation to illustrate the success of hybrid management. Furthermore, Watanabe *et al.* (2009) analysed the driving force of mobile phone development and identified that functionality development increase induces subscribes to increase, which supports market learning and restores the effects of learning as innovation resources for succeeding mobile phone innovation in a co-evolutionary way. This dynamism can be called co-evolutionary domestication (Williams, Slack and Stewart, 2000). Such a business model, co-evolutionary domestication is crucial for Singapore for its sustainable development.

ANALYSIS & DISCUSSION

NEWater Dependency

Table 2: demonstrates NEWater (NW) dependency in Singapore over the period 2003-2011. As mentioned earlier, it is reported that by 2011, NEWater is targeted to meet 30 percent of Singapore's water needs.

Table 2: Trend in NEWater Dependency in Singapore (2003-2011) – %

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011
NEWater dependency	1.7	3.7	5.3	9.0	16.4	22.2	24.6	27.4	30.4

Table 3 identifies diffusion trajectory representing the trend in NEWater dependency toward 2011 by means of a logistic growth function

$$p(t) = \frac{\bar{p}}{1 + e^{-at+b}}$$

Table 3: Estimated Trajectory for NEWater Dependency in Singapore (2003-2011)

Coefficient	Estimated value	*t*-value	*Adj.* R^2
$\bar{\pi}$	31.0	26.7	0.994
a	0.76	11.0	
b	3.77	13.5	

Figure 2 compares the actual and estimated trend in NEWater dependency in Singapore over the period 2003 – 2011.

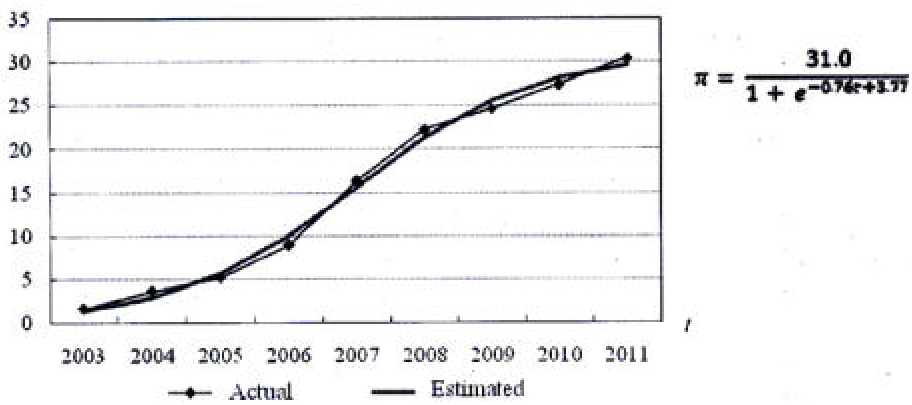

Figure 2: Trend in NEWater Dependency in Singapore (2003-2011): Actual and Estimated (%).

By incorporating quarterly trend (t_q) and quarterly total used water into the estimated function, quarterly trajectory $(p(t_q))$, and the quarterly NEWater production (based on capacity of production) over the period 2003- 2009 were estimated.

Trend in Learning

Utilising quarterly production of NEWater (*NW*) and trend in fixed price of NEWater (P_n), (deflated by manufacturing product price index for manufacturing goods), the dynamic learning coefficient was estimated by the following equation:

$$P_n = A \sum NW^{-l(t)}$$

where *A:* conficent; $\sum NW$ cumulative stock of NEWater production; $l(t)$: dynamic learning coefficient; : coefficients; and t : time trend.

Dynamic learning coefficient $l(t)$ can be depicted by the following equation as a function of time trend t :

$$l(t) = \sum_{t=0}^{n} a_i t^i = (a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + ... + a_n t^n)$$

Taking logarithm, following linear function can be obtained:

$$\ln P_n = \ln A - l(t) \ln \sum NW = \ln A - ((a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + ... + a_n t^n) \ln \sum NW$$

By means of the backward elimination method, following regression result with the highest statistical significance was obtained:

$$\ln P_n = 0.47 - (0.05 + 1.40 \times 10^{-5} l^3 - 4.85 \times 10^{-7} l^4) \ln \sum NW \qquad adj.\ R^2\ 0.938\ \ DW\ 1.27$$

(-3.04) (-6.10) (6.26)

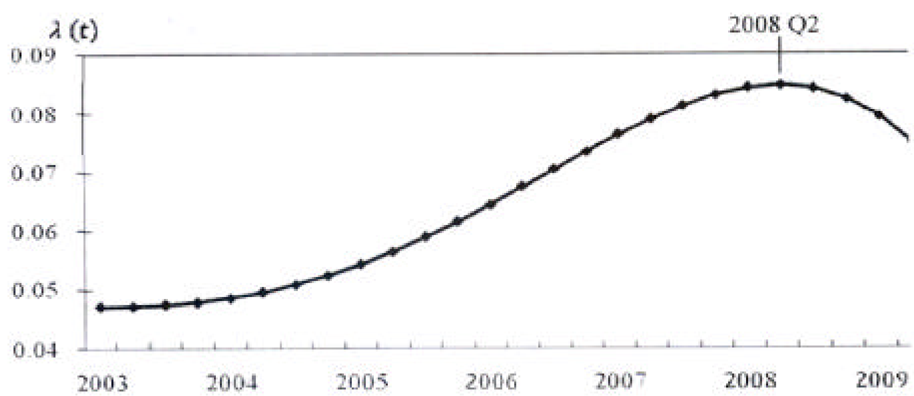

Figure 3: Trend in Learning Coefficient (2003-2009).

Figure 3 illustrates the trend in learning coefficient over the period 2003 – 2009 which demonstrates that the learning coefficient increased steadily from 2003, reaching its peak in the second quarter of 2008 (2008 Q2) and then changed to a decreasing trend since then. This suggests that Singapore's NEWater development has shifted from a period of learning dependent (prior to 2008 Q2) to a period of indigenous capabilities dependent (after 2008 Q3).

Elasticity of NEWater Substitution

Elasticity of NEWater (*NW*) substitution for conventional water (*CW*) was computed using the following equation:

$$\ln \frac{NW}{CW} = a + s \ \ln \frac{P_c}{P_n}$$

where a: coefficient; s : elasticity of NW substitution for CW; P_c: fixed price of CW; and P_n: fixed price of NW. Consumer Price Index and Manufacturing Product Price Index for manufactured goods were used as deflator of CW price and NW price, respectively.

Figure 4 illustrates the trend in the *NW* and *CW* ratio over the period 2003- - 2009. The ratio reflects a steady increase, reaching the target of satisfying 30% of the nation's water supply by 2011. (The 30% target corresponds to the *NW*/*CW* ratio of 43%.)

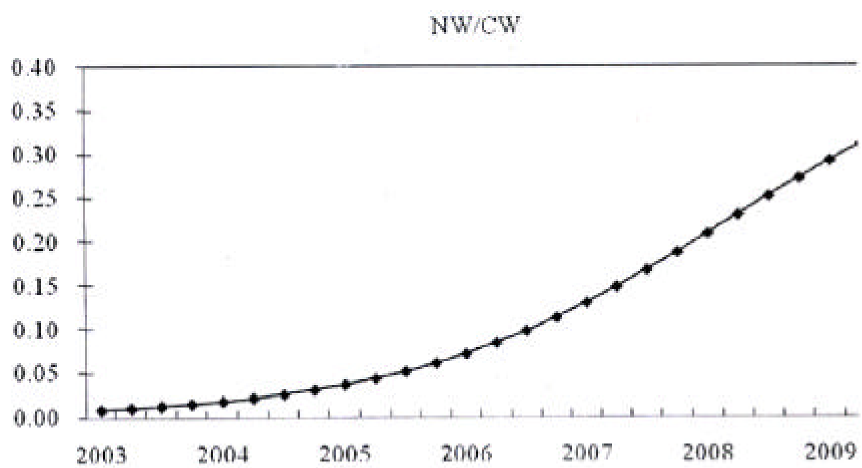

Figure 4: Trend in the NEWater (*NW*) and Conventional Water (*CW*) Ratio (2003-2009).

The result of the analysis is summarized as follows which demonstrates a high statistical significance for the elasticity of substitution of *NW* for *CW* over the period examined.

$$\ln \frac{NW}{CW} = -4.96 + (7.64 - 1.48D_1 + 1.54D_2) \ln \frac{P_c}{P_n} \qquad adj.\ R^2\ 0.924\ DW\ 1.44$$

(-26.30) (9.03) (-2.49) (2.60)

where D_1 and D_2 : dummy variables (D_1: 07Q2-08Q2 = 1, others = 0; D_2 : 08Q3-09Q4 = 1, others = 0).

The elasticity of *NW* substitution for *CW* for 2003Q1 – 2007Q1, 2007Q2 – 2008Q2 and 2008Q3 – 2009Q4 are 7.64, 6.16 and 9.18, respectively.

Figure 5 demonstrates that this substitution can be attributed to the increase of relative prices $(\frac{P_c}{P_n})$ due to *NW* price decrease by learning effects from imported technology up until the first quarter of 2007. While $\frac{P_c}{P_n}$ changed to decrease trend as NEWater development shifted from imported technology period to indigenous technology period from the second quarter of 2007 due to relative increase in *NW* price, $\frac{NW}{CW}$ ratio continued to increase. Similar trend was accelerated after the third quarter of 2008 due to relative increase in NW price through higher functionality and decrease in learning effects as NEWater development shifted to export accelerating period based on indigenous development technology. These sustainable substitutions demonstrate the substantial change in learning to indigenous technology development and also to further functionality development for export acceleration as a driver of *NW* substitution for *CW*. While the level of elasticity of *NW* substitution for *CW* slightly decreased during the transition period from imported technology dependent to indigenous technology development, it increased as higher functionality for export acceleration endeavored.

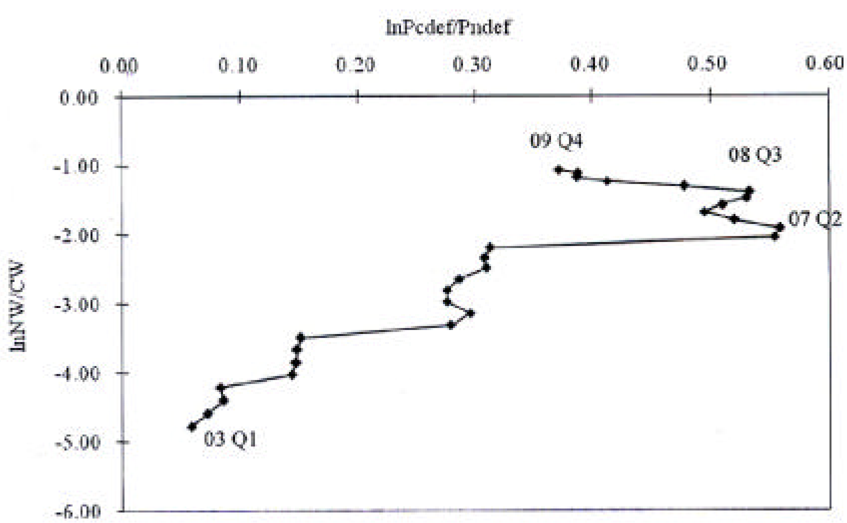

Figure 5: Trend in the Correlation between Prices and Volume of NEWater (NW) and Conventional Water (CW) (2003-2009).

OPEN INNOVATION FOR CO-EVOLUTIONARY DYNAMISM IN NEWATER

Utilising the foregoing learning and substitution analyses by means of quarterly trends in NEWater and conventional water supply as well as corresponding trends in respective fixed prices, open innovation dynamism in the process of NEWater development is analysed.

Singapore's NEWater development trajectory over the last decade can be divided into the following four phases:

Phase 1 (2000 – 2007 Q1): Imported technology dependent period

Triggered by the setting up of the Bedok demonstration plant in 2000 based on imported technology, successive import of advanced reverse osmosis membrane technology primarily from Dow Chemicals and Nitto Denko and extensive learning thereon three advanced NEWater plants were in operation successively: Bedok (2003), Kranji (2003) and Seletar (2004). Table 4 lists Japanese firms supplying membranes for the microfiltration, ultrafiltration and reverse osmosis processes in the production of NEWater. As shown in Table 5, the technologies related to microfiltration and ultrafiltration processes are imported mainly from established industry players in Japan (Asahi Kasei), Europe (Siemens) and the United States (General Electric), while the technologies related to reverse osmosis membranes are imported mainly from industry players in Japan (Nitto Denko and Toray) and Korea (Woongjin Chemcial Co. Ltd.). The technologies used for the ultraviolet disinfection process within the NEWater manufacturing process is imported mainly from establish players from the United States (ITT Water and Wastewater), the United Kingdom (Hanovia Limited) and Canada (Trojan Technologies). Engineering-related capabilities and consultancy services are dependent on French-based companies (Suez and Veolia Environment), US-based companies (Black & Veatch and CH2MHill) and Netherlands-based company (Deltares).

Table 4: Advanced Membranes Introduced by Leading Japanese Firms* in Singapore NEWater Factories

NEWater Factory	Year of Introduction	Microfiltration / Ultrafiltration	Reverse Osmosis
Bedok (Demonstration Plant)	2000		Nitto Denko (10)
Bedok	2003	Asahi Chemicals (73)	Nitto Denko (32)
Seletar	2004		Toray (24)
Kranji	2006		Nitto Denko (40)
Ulu Pandan	2007	Asahi Chemicals (191)	Nitto Denko (156)
Changi	2010		Toray

Figures in parenthesis indicate capacity (thousand m^3/day)

**Japan's membranes occupy 50% of the world market*

Table 5: Country of Origin for Suppliers of Products and Services for Singapore NEWater Factories

Product / Service	Korea	Japan	US	Europe	Canada	France	Netherlands
Microfiltration/Ultrafiltration		*	*	*			
Reverse Osmosis	*	*					
Ultraviolet Disinfection			*	*	*		
Engineering-related Services			*			*	*

During this period, there was intensive learning by local firms as illustrated in the upward trend in Figure 5. One government initiative that facilitated this learning process was the setting up of the Environment & Water Industry Development Council (EWI) by the Ministry of the Environment and Water Resources in May 2006. This Council was tasked to spearhead the development of the environment and water industry in Singapore with the vision to develop Singapore into a 'Global Hydrohub' for business, investment, research and technology. The Council adopted a three-pronged strategy – Capability Development, Cluster Development and Internationalisation to achieve its vision. The Capability Development Strategy involved the establishment and building up of a strong technology base through research and development, thus the potential to develop new technologies to be at the forefront of research. To accomplish this aim, human capital (expertise) is essential and therefore the need to build up research talent for the industry. A S$100 million Environment & Water Research Programme (EWRP) was launched in 2006 to accelerate technological development efforts. The Nanyang Technological University (NTU) partnered consultancy and research firm, DHI to form the DHI-NTU Water and Environment Research Centre and Education Hub. The National University of Singapore partnered Dutch water specialist, Delft Hydraulic to form the Singapore-Delft Water Alliance to advance science and technology in the water sector. The Cluster Development Strategy involved the development of the local water industry by attracting major international companies to anchor their operations (headquarters, engineering facilities or research and development centres) in Singapore. The EWI works closely with the Economic Development Board and the Public Utilities Board and has been successful in attracting General Electric from the United States, Nitto Denko from Japan, Siemens from Germany and Veolia from France.

Phase 2 (2007 Q2 – 2008 Q2): Transition from learning to indigenous technology development period

Based on the preceding learning and assimilation of spillover technology, development dependent on learning shifted to development of indigenous development, which is demonstrated in Ulu Pandan NEWater factory, commissioned in 2007. Facilitating the shift was the introduction of Public-Private-Partnerships (PPP) initiative to spur greater collaboration between the public and private sectors, in particular, the Design-Build-Own-Operate (DBOO) scheme. The Ulu Pandan NEWater factory was the first NEWater factory built under the DBOO scheme. Keppel Integrated Engineering won the DBOO contract in 2004 to design, build, own and operate the plant to supply NEWater to PUB under a long-term contract of 20 years. As illustrated in Figure 6, the DBOO scheme opened opportunities for local firms to develop and apply their indigenous capabilities leading to broader dissemination of core technologies as advanced membranes with complementary engineering systems such as operation and management as well as simulation and monitoring. Initially dominated by international players such as Veolia Water Systems and Suez, the players for the engineering-related services in this second phase increased to include local firms such as Hyflux Limited, Salcon Pte Ltd, Keppel Integrated Engineering and Sembcorp Utilities Pte Ltd. Sembcorp Utilities Pte Ltd won the contract to construct the Changi NEWater factory which was also a DBOO project. Furthermore, this has induced technology advancement in other related industries such as Information Technology (IT), in particularly software for monitoring the system, and diagnostic technology, which induced products and services for the detection of contaminants.

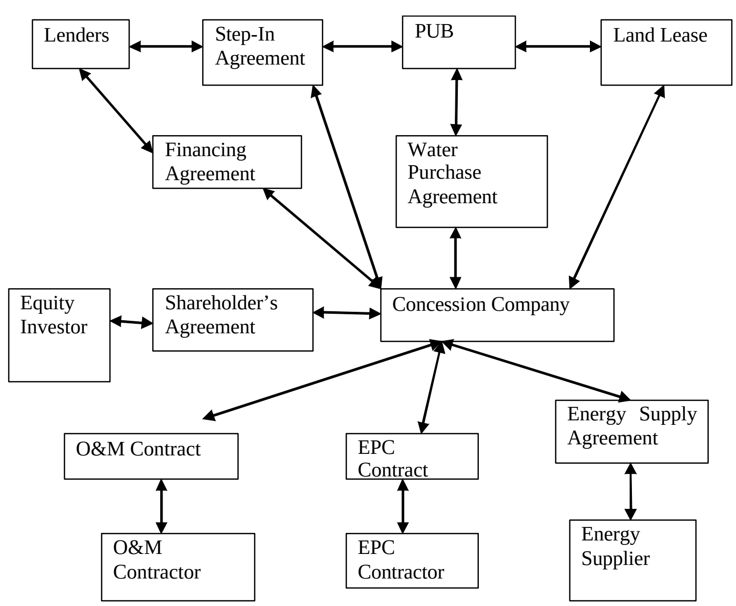

Figure 6: The Design-Build-Own-Operate Model.

Phase 3 (2008 Q3 – 2010): Export accelerating period

Following the development of indigenous capabilities and the success of DBOO projects, firms began to internationalise their businesses by securing projects abroad. This was an indirect way of exporting their indigenous capabilities accumulated throughout the first two phases. According to Milieu (March 2009), 'Algeria Energy Company chose Singapore's Hyflux to design, build and run a seawater desalination plant in western Algeria – a sizable contract worth US$468 million.' The experience gained has enabled local company, Hyflux Limited to internationalise its business into China and the Middle East. The company is currently building the Tianjin Dagang Desalination Plant, China's largest membrane-based seawater desalination plant with a designed capacity of 100,000 m^3/day. The company was also awarded a S$95 million design and construct contract in 2009 for a membrane-based seawater desalination facility for the Salalah Independent Water and Power Project in Oman. Table 6 lists the locations and purposes for which Kristal™ (membrane used for ultrafiltration and microfiltration) manufactured by Hyflux Limited are exported to and the year in which the deals were sealed, while Table 7 lists the capacities of the water plants that the company has secured over the years. It can be deducted that the experience and capabilities developed over the years has enabled the company to secure water plant deals with larger (designed) capacities. Keppel Integrated Engineering, the main contractor for Ulu Pandan NEWater factory testified that '… the DBOO plants in Singapore would enable us (local companies)) to move even more aggressively overseas'.

Table 6: Export Destination of Kristal™ Membranes Manufactured by Hyflux Limited

Country	Industry	Year Deal Was Secured
Middle East & North Africa		
Algeria (Magtaa)	Seawater Desalination	2008
Algeria (Tlemcen)	Seawater Desalination	2006
Dubai	Sewage Treatment	2005
Namibia	Textile Wastewater	2002
Europe		
The Netherlands	Drinking Water	Information not available
China		
Beijing	Ultra-pure Water	2006
Guangdong	Desalination & Wastewater	2005
Tianjin	Seawater Desalination	2004
Southeast Asia		
Indonesia	River Water Treatment	2004
Malaysia	Brine Regenerant Recovery	2000
Malaysia	River Water Treatment	2000

Source: Hyflux Annual Report 2008.

Table 7: Designed Capacities of Water Plants Constructed by Hyflux Limited

Country	Industry	Year Deal Was Secured
Middle East & North Africa		
Algeria (Magtaa)	Seawater Desalination	2008
Algeria (Tlemcen)	Seawater Desalination	2006
Dubai	Sewage Treatment	2005
Namibia	Textile Wastewater	2002
Europe		
The Netherlands	Drinking Water	Information not available
China		
Beijing	Ultra-pure Water	2006
Guangdong	Desalination & Wastewater	2005
Tianjin	Seawater Desalination	2004
Southeast Asia		
Indonesia	River Water Treatment	2004
Malaysia	Brine Regenerant Recovery	2000
Malaysia	River Water Treatment	2000

The Internationalisation Strategy of the EWI involved working closely with International Enterprise Singapore and the Public Utilities Board to help Singapore-based water companies ‘internationalise’ their business. This is facilitated via the creation of networking opportunities through trade missions and conferences; and the signing of bilateral agreements on water research and consultancy projects. To date, bilateral agreements have been signed with the United Arab Emirates, Bahrain and India. Trade missions to the Middle East and China have been organised and local companies that have been invited to be part of the delegation led personally by the Minister for the Environment and Water Resource include Keppel Corporation, Hyflux Limited, Sembcorp Utilities and Salcon. In addition to trade missions, the annual Singapore International Water Week (SIWW), with its inaugural conference held in 2008, is an international conference held together with the World Cities Summit that strategically positions Singapore as a global hydrohub – a nation that the forefront of research and development; a nation with the capabilities in research and development, training, leadership, policy and implementation; a nation where experts all around the world can come together to interact and exchange knowledge.

By 2010, the EWI has seen the success of its Cluster Development Strategy. The WaterHub, a Center of Excellence constructed adjacent to the Ulu Pandan NEWater factory with the vision of being the leading hub for the global water industry is home to water associations such as the International Water Association (IWA) and the Singapore Water Association (SWA), corporate research institutes such as Siemens and Konzen and the Centre for Advanced Water Technology (CAWT). At the regional level, it aims to be the regional water knowledge hub for the water industry. Nitto Denko set up its R&D centre in the WaterHub in June 2008. The above efforts show the government's commitment to encouraging foreign investment in hydro-R&D by providing non-discriminative facilities. These efforts together triggered the export acceleration phrase.

During the third International Water Week hosted by Singapore in 2010, Singapore hosted the second Asia Pacific Hydro Summit and demonstrated that Singapore has become Centre of Excellence (COE) for global water business as Global Hydrohub.

As part if the Capability Building Strategy of the EWI, the Institute of Water Policy was established in June 2008 by the Lee Kuan Yew School of Public Policy as a platform to build up and train the next generation of Asian policy-makers and leaders. The SIWW is strategically held annually concurrently with the World Cities Summit,

Phase 4 (2010 and beyond): Co-evolutionary domestication period

The fusion of external knowledge acquired from export activities by means of joint export with countries possessing advanced technologies, institutional learning by the receiving party and the existing knowledge pool are expected to disseminate to various industries, leading to the phenomenon known as co-evolutionary domestication. An example in the local scene is the plan by local firm, Hyflux Limited, to develop a new Hyflux Innovation Centre and the Hyflux Production Hub in the next three to five years. Also evident are the local engineering, procurement and construction projects that the company had won in 2010 to construct a membrane bioreactor plant and a desalination plant on Jurong Island.

Attractive incentives provided by the government to leading firms to invest and establish their R&D centres in Singapore induced world leading hydro-firms to conduct their business in Singapore and/or with leading Singapore firms such as Hyflux, leading to the acceleration of the foregoing co-evolutionary domestication.

The four phrases are indicated in Figure 7.

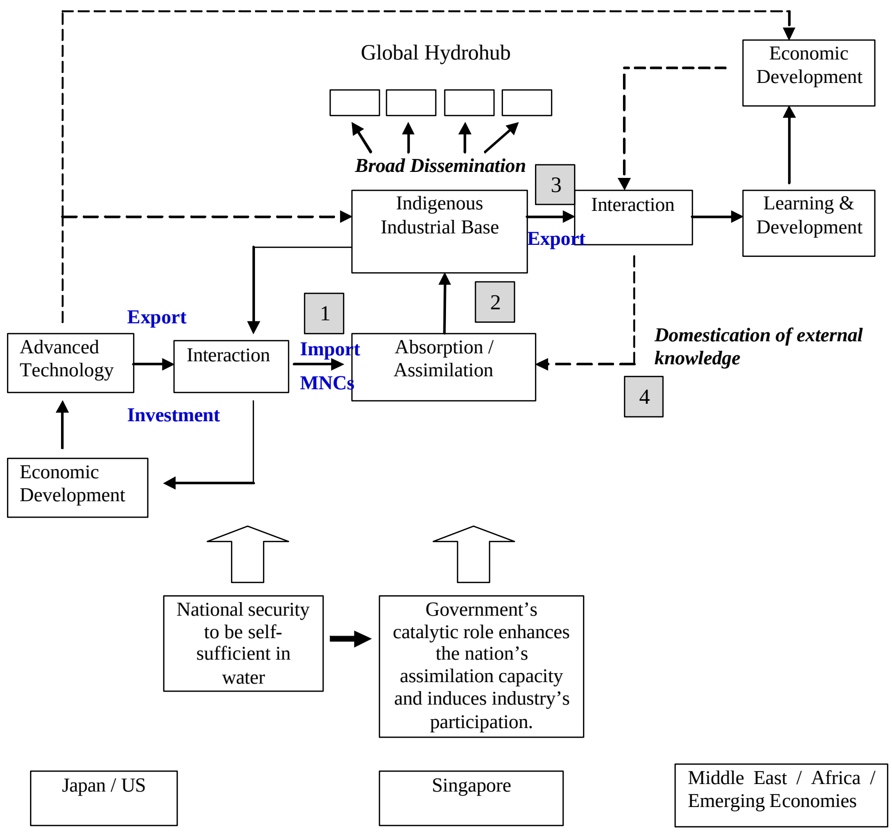

Figure 7: Proposed Framework for Open Innovation Dynamism.

CONCLUSION

Singapore has successfully leapfrogged from a constrained situation with limited capabilities in the water industry to a situation whereby it is now exporting capabilities worldwide. The need to be self-sufficient in water lead to the exploration of increasing water supply via existing (conventional) means and non-conventional means. Focusing the study from the management of technology perspective on NEWater, NEWater is technology-intensive. It is a multidisciplinary field requiring extensive R&D efforts (in areas such as nanomaterials and membrane manufacturing) fully integrated with sensitive systems engineering efforts.

The initial stage involved importing products and capabilities by engaging multinational industry players. As NEWater is R&D / technology intensive, a holistic government industrial policy was implemented to build up the necessary capabilities with the aim of becoming a Global Hydrohub. R&D centres were set up within tertiary education institutions where researchers concentrate on academic research. Centres of Excellence were set up to encourage interaction between private and public sectors, and academics and companies. Also successfully implemented was the initiative to attract major industry players to set up their R&D headquarters in Singapore. Through the government's PPP initiative, the opportunities for technology spillover and learning were enhanced. (In this paper, technology includes knowledge such as know-how.) The knowledge was assimilated and transformed into the development of indigenous capabilities. With the indigenous capabilities developed, local companies won projects overseas, thus creating the opportunity for knowledge transfer to the recipient.

With long-term planning and appropriate and timely government stimulation efforts, this case study is an exemplar of emerging economies can build up indigenous capabilities and attempt a leapfrog in the industry that is identified as an economic pillar for the country.

FOOTNOTE

1. Value-Added (VA) is a measure of the returns to factors of production (including labour, capital, entrepreneurship) and is a one-to-one proxy for GDP. For specific projects, the major contributors are profits, remuneration, depreciation, rentals, etc
2. 47% of desalinated water cost depends on purchased electricity and NEWater cost is 40% that of desalinated water cost.

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