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Technology-based design and sustainable economic growth

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ABSTRACT

This paper seeks to analyze how design creates economic value. The literature on knowledge-based economic development has primarily focused on innovation as the analytical lens, whereas design is the original action that leads to innovation. Despite the fundamental importance of design, existing design research has offered few insights and little guidance for national strategies due to the lack of focus on and analysis of design in an economic context. This paper addresses such gaps by linking design research and economic development theory. We first elaborate on the relationship among design, invention and innovation, describing the necessity of design activity for invention and innovation. Our analysis of the fundamental characteristics of design across contexts sheds light on the strategic importance of the accumulative nature of *technology-based design* for sustaining economic growth. Through the lens of technology-based design, we further quantitatively compare Singapore and three similarly-sized countries (South Korea, Finland and Taiwan). Based upon interview data, we also qualitatively examine Singapore's national strategy focusing on design. The quantitative and qualitative results align well with the Singaporean government's use of design as a strategic lever to pursue innovation-driven economic growth, and also reveal its achievements and shortfalls which indicate possible directions for strategic adjustment.

1. Innovation, invention, and design

Innovation is the critical driver of economic growth (Schumpeter, 1934; Solow, 1956), especially in advanced economies which have approached the frontier of knowledge and thus face limited opportunities to adapt exogenous technologies for production (Porter, 1990). Because of its clear importance, there have been numerous studies of how regions and nations can foster innovation through managing such factors as R&D manpower and spending (Mowery and Rosenberg, 1998; Griliches, 1998), industrial environment and competitive dynamics (Rosenberg, 1963; Porter, 1990), government policy and institutional environment (Lundvall, 1992; Nelson, 1993; Freeman, 1995), etc. In particular, the growing body of research on design has added greatly to our knowledge of the innovation process (Baldwin and Clark, 2000; Dym et al., 2005; Weisberg, 2006).

However, despite their relevance and importance, the findings and theories from design research have been overlooked in innovation policy and economic development studies (Hobday et al., 2012). This paper supplements the preceding economic development studies on innovation alone by addressing design as the specific activity which results in innovation. In doing so, we build upon prior work which treats design as the process through which innovations emerge (Aubert, 1985; Walsh, 1996), and focus on technology-based design for its specific advantage over other types of design in sustaining economic growth. To our best knowledge, we are the first to link design research and economic development theory. In so doing, the work leads to new insights for national strategies for an innovation-driven economy.

Innovation, as defined by Schumpeter (1934), is "new combinations", and also – in the language of economics – "the setting up of a new production function." Schumpeter's concept of innovation includes technical, marketing and organizational activities. According to Solow (1957), technology-based innovation accounts for more than 80% of long term economic growth and has been the emphasis of most studies on "innovation". Technology innovation refers to the introduction of a new product, improvement in quality, and a new method of production, etc. (Hagedoorn, 1996). Innovation comes after invention and is invention that has successfully diffused in use, achieving real economic and social impact.

Both invention and innovation emerge through a design process. Design is defined herein as *a human process that uses knowledge to produce novel objects that are appreciated by or are useful to other humans*. Inventions are creatively *designed* by humans with new mechanisms and/or new functions. The most

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recognizable inventions historically, such as the steam turbine, the electric generator, the light bulb, the car and the computer, were all "designed" and are thus "design output". However, not all design efforts will necessarily result in invention, as some efforts result in less novelty than judged necessary for the label of invention. In a similar sense, not all inventions (despite their useful novelty) have sufficient benefits or are communicated in a way to result in adequate efforts to achieve diffusion and thus become an innovation. The relationship between innovation, invention and design output is shown in Fig. 1. Design activities create the possibilities for invention and innovation, but do not guarantee them. The design output may be inventions or not, and in turn inventions may become innovations or not.

However, innovation scholars on occasion overlook the design process, largely because the design process is difficult-to-anticipate and even difficult to recognize objectively. In contrast, the term "design" is used more often than "innovation" and "invention" by technologically-based practitioners, simply because design is the specific action which humans pursuing innovation actually perform. Thus, when one thinks about enhancing innovation, promoting design activities is more actionable than the narrative focus of innovation. In turn, design capability enables continual delivery of new products, services, and solutions, so is important as a strategic asset for a firm, region or nation to build up in order to compete in a knowledge-based global economy. Mastering it will give firms or regions sustainable competitive advantage (more detailed explanations are in Section 2.3). Therefore, focusing on promoting design activities and building up national design capability as explicit national strategies allows one to be more specific about what can be done for innovation.

When considering "design", many studies combine various kinds of design in questionable ways; for example combining engineering design with industrial or aesthetic design (Candi and Saemundsson, 2008) and sometimes combining what "CAD (Computer Aided Design) technicians" do with engineering design (Walsh, 1996). This ambiguity has limited the potential for effective actions to be taken. Following a survey and synthesis of the broader deign research literature in Section 2, we link design to an economic context as is necessary for innovation, and doing so allows "technology-based design" to appear fundamentally most valuable for driving and sustaining economic growth. We use "technology-based design" instead of an equivalent term "engineering design" (Dym et al., 2005) in order to explicitly emphasize the intensive use of scientific and technological knowledge and techniques in such processes.

On that basis, we further use "technology-based design" as the analytical lens to examine national attempts to move towards an innovation-driven economy. We particularly examine Singapore, assisted with a comparison with Taiwan, Korea and Finland. All four of these countries have been heavily involved in moving into

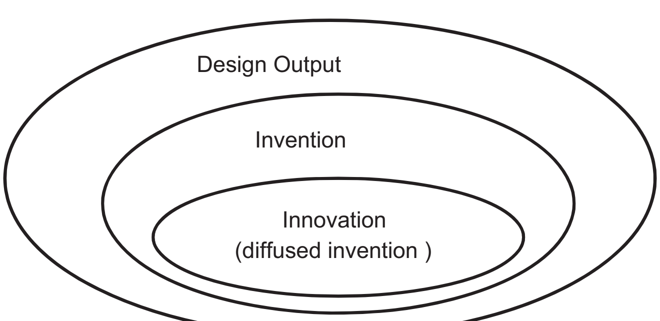

Fig. 1. Relationship between design output, invention, and innovation.

higher value-added activities and thus improving their design capability. The emphasis on Singapore arises because it is the only country, to our best knowledge, whose national strategy has explicitly emphasized the promotion of "design"-related activities for sustaining the nation's economic growth. We conducted on-site semi-structured interviews at a number of organizations that participate in design-related initiatives in Singapore, in spring 2011, and report the interview results in this paper.

Our analysis at the national level has important similarities to national innovation studies (Lundvall, 1992; Nelson,1993; Freeman, 1995), which emphasize the active roles played by specific institutions (companies, universities, government agencies, intermediary organizations, etc.) and government policies, and their interaction in nurturing innovations in specific countries (see Dosi, 1988 and Nelson, 1993 for comprehensive reviews of the perspectives in the national innovation system literature). In this paper, we also examine the incentives and behaviors of different kinds of institutions and their interactions in a national system. In addition to that, we believe that emphasizing knowledge development in technology-based design in the examination supplements what national innovation system studies have been able to conclude.

The paper is organized as follows. Section 2 reviews design research broadly and then design in an economic context which narrows the emphasis to technology-based design. Section 3 discusses potential metrics to assess national design capability. Section 4 uses such metrics to compare Singapore and three other three countries quantitatively, and Section 5 further examines Singapore's national design strategy using interview data. The final section concludes and discusses directions for future research.

2. Fundamentals of design: Survey and synthesis

In much academic literature and common language, design is diversely defined. This can hinder the effective use of "design" as a lens to develop strategies and action plans for economic growth. There is a body of knowledge that is commonly referred to as "Design Research" or "Design Theory" (a branch of which can be labeled "*engineering design research*") where some care in definitions has evolved (Simon, 1996; Dym, 1994; Walsh, 1996; Baldwin and Clark, 2006; Purao et al., 2008; Hatchuel and Weil, 2009; Hobday et al., 2012) and where extensive research has been done. This section attempts to review this literature in order to identify the strategic focus for design-based strategy for actions and policies relative to moving to the knowledge or innovation economy.

2.1. Design process

In the existing literature, the term "design" has been used as either a verb (i.e., activity/process) or noun. When used as a noun, the term "design" often means the output of a design process. Baldwin and Clark (2006) defined design as "the instructions based on knowledge that turn resources into things that people use and value". Treating design as a noun has led to important understandings on product architecture (Eppinger and Ulrich, 1995; Baldwin and Clark, 2000), organizational structure (Ulrich, 1995; Sosa et al., 2004), industry structure (Abernathy and Utterback, 1978; Suárez and Utterback, 1995; Tushman and Murmann, 1998; Baldwin and Clark, 2000), and the functional performances of technologies as output of design (Moore, 2006; Martino, 1970; Nordhaus, 2007; Koh and Magee, 2006, 2008). While useful, such studies are naturally limited in explaining how design output arises, i.e., the process through which knowledge is turned in to valuable artifacts.

A separate and much more extensive set of research findings results from looking at "design" as a human process, rather than its outcome. In a paper that most acknowledge was formative to the field of design research (Simon, 1996), a fairly simple but broad definition treating design as a verb was given—"design is the transformation of existing conditions into preferred ones." To design is to transform existing knowledge and conditions into an artifact that meets certain human needs either directly or indirectly, either functionally or aesthetically. Moreover, the intensity of design activities as opposed to other economic and cultural activities may signal the extent to which a knowledge economy has been developed.

As stated in Section 1 where we gave our elaboration of Simon's definition, the present paper will focus on design as a process in order to understand more concretely what is done to create novel and valuable artifacts. Indeed, there have been increasing numbers of scientific studies on the design process (for intermediate summaries, see Antonsson and Cagan, 2001; Dym et al., 2005). Such studies have illuminated some commonalities of design processes (which include the characteristics of the people who successfully design) across varied contexts, while acknowledging that understanding of the design process is still incomplete (Magee and Frey, 2006; Brooks, 2010).

Numerous kinds of design activities are conducted by humans working in different domains to fulfill different needs and desires. As examples, engineers design products (software, materials or hardware) and services, engineers and other stakeholders design large-scale socio-technical systems, architects and others design buildings, managers design organizations and processes, government leaders design policies and regulations, and artists design poems, musical compositions, sculptures, etc. These specific design processes are vastly different, but all embed some characteristics in common at an abstract level, spanning designs of any form, scale, and scope, simply because they all follow a process to achieve appreciated novelty (Simon, 1996; Walsh, 1996; Purao et al., 2008). In contrast, our use of the term "design" excludes such activities as the development of embodiments such as prototypes or drawings because they lack the necessary novelty/creativity in their processes, whereas they are often also called "design".

In addition to the broad range of practice domains, interest in design research, generally conceived, has been shared by many scholars from different fields, such as cognitive psychologists, economists, engineers, architects, and others. Some of this work is focused on invention (or more generally creativity) but can with little effort be translated into the design framework we are using. Thus, we first seek to highlight the fundamentals of the design process that are common across contexts.

2.2. Fundamentals of design, broadly considered

Since design creates the world that has not existed previously, it is always creative (to a certain degree), regardless of domain. Creativity is important for design successes and arises through a system of interrelated forces operating at multiple levels, such as individuals, organizations and culture (Hennessey and Amabile, 2010). Creativity distinguishes design from production or service delivery processes where repetition is an essential element. While production requires factors such as labor and capital, a factor that design further requires is knowledge of various kinds, including scientific principles, understanding the latest realizations in various domains, and expertise in actual design practices.

A consistent theme of much research in the area has emphasized the importance of deep expertise as the key enabler of successful creative design. Many case studies have verified the need for expertise across all fields including artistic and scientific novelty (for an excellent summary see Weisberg, 2006). The "10 year experience rule" (de Groot, 1965; Chase and Simon, 1973; Chi et al., 1981; Ericsson, 1999), for individuals to continually build up necessary knowledge and experience so as to be able to achieve useful novelty, applies across diverse fields.

Knowledge and the ability to use knowledge to derive novelty are the two essential linked elements of design expertise. A successful designer has deep knowledge and extensive experience in his or her domain of practice. This domain knowledge includes substantial appreciation of past design activities and design output, as well as detailed understanding of the latest developments, techniques and theories concerning designs in the domain (Weisberg, 2006). Of some importance is that the experience and knowledge must be kept "fresh" as infrequent experience can lead to forgetting what was learned previously and so result in little knowledge accumulation (Argote, 1999).

Knowledge of the design process is also held by leading practitioners with this knowledge being viewed as highly nonstructured (Brooks, 2010). The design process is a set of activities that begin with abstraction and end with useful novelty. Such activities include conception, problem definition, prototyping, generation and evaluation of alternatives, experimentation, and refining but overly structured organization of these activities has been shown by empirical and theoretical research to lead to less success than more flexibly structured processes (Frey et al., 2009). The importance of iteration between divergent and convergent thinking (Dym et al., 2005) and succeeding through failure (Petroski, 2006) has been emphasized and are embedded in a flexibly structured design process.

The most fundamental cognitive sub-process used in design is analogical transfer (Weisberg, 2006; Wood et al., 2009), elements of which have also been identified as "Generative Metaphors" (Schon, 1983). Analogical transfer involves the way designers explore the new or unknown using known exemplars and principles. Designers use analogical transfer during various design activities such as conception, evaluation, problem definition, etc. Given that analogical transfer means that new artifacts are developed by extension of existing knowledge, the known importance of deep knowledge of the field (more possible starting points) in successful design is well aligned with analogical transfer as the key sub-process used in design.

Recent research has also begun to elucidate how designers structure knowledge to be able to most effectively translate existing knowledge to useful novelty (Linsey et al., 2008). Abstractions such as functional thinking (Wood et al., 2009) seem particularly well suited to serve as knowledge structures that are easy to use in analogical transfer. Continuing research on knowledge structures may be expected to eventually further unpack the concept of expertise but cognitive psychologists have confirmed that experience leads to greater use of abstractions and an ability to avoid unnecessary details in problem solving of various kinds (Reyna, 1996).

2.3. Design in an economic context

Hobday et al. (2012) recently argued that a gap of understanding remains between design thinking and innovation policies, while promoting design for more effective innovation and national economic growth has become a key policy aim of many nations and governments, including the United Kingdom, Singapore and China. It is still unclear how design research can provide guidance to economic growth and policy making. Our purpose in briefly surveying aspects of the design research literature above is to connect the field of design (and design theory) more specifically to the field of innovation and economic growth.

The most important issue that arises from considering design in the context of national economic growth is how to sustain and grow design expertise and the outcome of design practices. The prior design practices and experience that do not strongly relate to or enable future success tend not to be economically viable and sustainable. Compared to non-technical designs (e.g., aesthetic design, industrial design, etc.), technology-based designs can bring the advantages of "accumulation", which sustains growth. Studies of the functional performances of technology-based design output (among many examples are Moore, 2006; Martino, 1970; Nordhaus, 2007; Koh and Magee, 2006, 2008) have generally shown that performance increases exponentially over time at varying rates depending upon the domain studied. Because of the cumulative nature of technology progress, knowledge of recent advances in a given technology allow one to design things continually better and better—that is, sustainable growth. In turn, these performance increases are the result of continual design efforts over time. Technology-based design activities enable the designers' capabilities to accumulate and be used to do the next things (cumulative again), thus gives them sustained advantages.

In addition, following the resource-based view of the firm (Barney, 1991), if a design process and its outcome are difficult to imitate, competitive advantage from it may be sustained for a longer term. Thus, the designers are more likely to produce difficult-to-imitate products and services when the most advanced (and continually advancing) scientific knowledge and technologies are intensively used in the design process.

Therefore, although Simon's parsimonious definition on design does not include "technology-based", it is clear that having this element enter a broad definition of design is important in an economic sense. Many technology-based design processes focus on finding new mechanisms, embodiments, and forms to fulfill existing or slightly extended functions. Examples are the ongoing design of airplanes, automobiles, computers, data storage devices, medical devices, semiconductors and materials, and large engineering systems such as electrical grids, telecommunication networks, and transportation networks. Alternatively, design may focus on the question of what/why ("function, fitness or adaption"). Such designs can be built on existing technologies but focus on finding new functions, new applications, or new markets based upon the emerging technological possibilities. Examples might include designing Yahoo.com and Facebook.com both of which are built on the rapidly evolving Internet/world wide web infrastructure. In some important cases, new functions and mechanisms arrive together. These can be related to "translations" of new scientific and technological research (such as lasers) or new technical developments that support a (largely) new function ("car phones" in the 1970s).

The focus on function is the core of design efforts oriented toward users, which adapts the functions of products or service to the users' culture, taste, and habit, etc. Such designs based upon deep understanding of users can provide customers new reasons or meanings to buy the products, with well-fitted functions but little-changed technology and utility inside. Such a design orientation may lead to market successes, as shown in many examples (Utterback et al., 2006; Verganti, 2009). However, such design processes are not cumulative because success in one time or one place does not necessarily increase the likelihood of success later or at other places. In particular, adaptation to discovered user preferences can be made in designs that follow the technological improvement path and thus "user-oriented only designs" can be surpassed in relatively short times. Thus, design oriented toward fitting functions or interfaces to users may achieve temporary or regional successes but hardly contribute to overall phenomenal and long-range GDP growth, like those from the successful design of the steam turbine (first industrial evolution), electricity (second industrial evolution), and computing technologies (information age). More importantly for our purposes, this kind of design activity is not likely to lead to *long-run sustainable* design leadership in any domain.

2.4. Key learning from design research literature

In brief, the design research literature establishes the following insights. Basically, deep design expertise is the key enabler of usefully creative design, and can only result from continual knowledge- and capability-building efforts over time. Specifically, technology-based design efforts, as opposed to design more broadly defined, best enable the designers' capabilities to accumulate and gives them sustained advantages. Because of the cumulative nature of technology progress, technology-based design is most valuable for *sustaining* economic growth. The sharper focus on technology-based design (and the need for continual efforts to accumulate design capability), will allow for a more actionable strategy for sustaining economic growth. Therefore, our analysis hereafter will focus on technology-based design and related capability-building efforts to examine national attempts for knowledge-based and innovation-driven economic growth.

3. Assessing design capability

Now we turn to the capability to conduct the desired technology-based design activities outlined above. Design capability operates to create economically valuable novelty and is thus distinct from "research capability" that uses knowledge to create knowledge, and "productive capability" that accurately and economically replicates the results of design. Design capability defined in this way enables new, creative and better products, services and solutions to continually emerge, thus allows the firms, nations or regions that possess the design capability to sustain and grow in an evolving environment.

From many aspects, design capability can be viewed as a specific kind of "dynamic capability", which allows one to respond to the changing environment (Teece et al., 1997), or proactively create changes (Eisenhardt and Martin, 2000), and a rather actionable dynamic capability. However, it is important to view any of these dynamic capabilities – particularly design capability – in an evolutionary economics perspective (Nelson and Winter, 1982). Design capability is an accumulated learning capability that is built incrementally. As a capability, design capability in real-world situations is often a matter of degree, rather than dichotomous (Winter, 2000).

Capabilities generally cannot easily be bought but must be built because their creation and evolution are embedded in organizational learning processes shaped by the past asset positions and evolutionary paths of the firms, nations or regions (Nelson and Winter, 1982). Therefore, design capabilities are naturally heterogeneous across the boundaries of organizations or nations. Heterogeneity is one issue that must be considered when assessing design capability in different countries. Assessing design capability is also not something that can be accomplished without a temporal viewpoint since it is clear we are examining an evolutionary path-dependent process. What one is trying to understand is how successfully the evolution is occurring. Heterogeneity occurs across time since there are numerous paths potentially available for evolution to world-class design capability.

Paths can include long gestation periods with protection (Japan and Korea for automotive design). Another path can apparently involve competition from the low end—design of smaller/cheaper variants and movement up the cost/complexity chain (Brazil for airplanes). A third path that has apparently also worked has involved moving to higher and higher manufacturing capability and then to design of manufacturing systems and eventually to design of the product (Taiwan for computers and smart phones). There is no guarantee that a path taken will end with sustainable design capability as many examples of non-success exist (for example, Taiwan, Malaysia, and others in automotive design). Indeed, design capability in a domain can be lost over time if sufficient expertise is not nurtured to maintain competitiveness (for example, UK automotive). In this paper, we will be focusing on countries that are attempting to develop design capability and will not further consider loss of existing capability.

In all of these and other paths that one can imagine, there are numerous related conditions and context that will either enable or disable the evolution towards design capability. A potentially important path with many important contextual conditions is one that starts with a new technological/scientific discovery and that pursues the formation of profitable companies such as the semiconductor sector in Silicon Valley. Some of the context in the Silicon Valley case is the existence of prior electronics startups (Sturgeon, 2000), unhindered employee moves between firms (including important new startups such as Fairchild, Intel and National Semiconductor), open, inexpensive legal help and others well documented (Saxenian, 1991, 1996; Klepper et al., 2009; Klepper, 2010). Nonetheless, the evolution of a very strong design capability for Integrated Circuits was an essential part of the formation of Silicon Valley story.

Despite the heterogeneity among design domains, the path dependence of any specific evolutionary case and the many important contextual factors, it is still useful to attempt to measure design capability based upon the fundamentals in Section 2. Table 1 is an attempt to measure design capability, starting from "ideal" metrics not all of which are available.

Items 1 and 2 in Table 1 are potentially the most direct measures but items 3–7 are indicative and generally are more available. In the case of item 1, the idea of such a metric is that one could measure the total economic impact of a design but doing so would mean that not only licensing fees but also all other economic impacts such as company profits, employment, wage differences, export success, etc., would have to be estimated. To do this with full reliability, it would be best to make such assessments in the nation/region with and without specific designs. The counterfactual situation is not knowable and thus this measure is conceptual and not realizable. We put it first on the list to inspire further analysis. Item 2 is a possible way to assess the impact and attempts to do so by looking at the economic impact of firms within a nation that have benefits beyond their own company in the sense of Michael Porter's analyses of nations (Porter, 1990). Unpacking design from other economic activities (such as manufacturing, service delivery and resource exploitation and utilization) would be necessary and to our knowledge has not been done.

The number of engineers/scientists employed in technology-based designs (item 3) is a very good measure of our concept of design capability emphasizing deep design expertise. This is because, if such employment is long-term, it signals the ability to economically recover high costs of technology-based design. Actual engineering employment (item 6) is more general and not as good a measure but it is not easy to classify employment of engineers as design employees. Research, manufacturing, service delivery and other work is done by engineers in addition to design. However, a decent metric to estimate item 3 is total private R&D spending as this eliminates all work except that on basic research and design (as we are broadly defining it in this paper). Thus, we will use R&D spending (normalized by GDP) as one assessment of design capability in our analysis in Section 5. A limitation of this metric is that it is not domain-specific as usually measured. However, we believe this is the best input metric to consider for now so we will use it below.

As an output of global world-class technology-based design, what we propose in item 4 is to assess the number of United States patents granted to the country of interest. Patent data has been extensively used to study national innovation capacity in the innovation literature (Furman et al., 2002; Huang, 2010). Even though this is also our best output metric, it has three important limitations: (1) some technically-based domains are not as oriented to patents as others and (2) the measures we have are generally not domain specific and (3) US patents only imperfectly reflect global technical leading designs. Our second best output metric is given in item 5. The number of technologically significant publications indicates that the proper kind of technical knowledge and expertise is building and thus it is also used in Section 4. The last two metrics in Table 1, Employed Engineers (Item 6) and Education of Engineers (Item 7), have been used by others and may on occasion be worth reviewing but they added nothing to our analyses and so are not reported here.

In addition to the metrics, the issue of the emergence of globally significant technologically-based companies is quite relevant to assessing the emergence of national design capability. Thus, qualitative assessment of the emergence of such companies and qualitative evaluation of the patenting organizations are also undertaken in the empirical analysis in Section 4. These qualitative studies and use of metric 5 in Table 1 are the additions to standard "national innovation studies", introduced by our technology-based design perspective. If this design-centric perspective continues to

Table 1
Possible metrics for assessing the evolution of a nation or region toward world-class design capability.

Metric	Rationale/comments	Possible units
1. Economic impact of successful designs	Direct measure of end-point/data not likely to be obtainable	% of GDP (regional or national) derived from designs created
2. Scale (total) of companies achieving global-level designs	Potentially close to direct measure/difficult to obtain meaningful data	% GDP due to companies doing globally-competitive design (export % may be meaningful as well)
3. Employed engineers and scientists in technology-based design	Should be related (over longer term) to a direct measure	Fraction of workforce of engineers and scientists doing technological-based design. *R&D spending as a fraction of GDP.*
4. Patents	A good measure of significant technology-based design output (for areas where patents are important)	Number of United States patent grants
5. Technologically significant publications	Evidence for the fundamental knowledge base needed for world-class design	Number of engineering journal papers
6. Employed engineers	Necessary for technology-based design	Fraction of graduate engineers in workforce
7. Education of engineers	Basis for future of technology-based design	Fraction of graduated engineers in each cohort

be utilized, metrics related to items 1 and 2 in Table 1 will bring even more supplements to the standard approaches.

4. Assessing design capabilities of four countries

Singapore, South Korea, Taiwan and Finland are chosen for the comparative assessment of design capability, because they are similar in that (1) they are relatively small; (2) their economies developed rapidly in the past three decades; (3) they are striving to develop knowledge-based economies.

4.1. Economic development

All four countries have achieved phenomenal economic growth in the past few decades, but through different paths. Korea's economy and growth has been historically dominated by *Chaebols*, i.e., the large family business groups such as Samsung, Hyundai, LG, etc. The Korean government restlessly protected *Chaebols* from domestic and foreign competition during their early years, and allowed them to grow in size and capital strength rapidly, through contract manufacturing and imitated products for exports. Finland's recent economic success largely relied on the success of Nokia. The momentum of Taiwan's economy came from contract manufacturing of semiconductors, electronics components and computers for American fabless firms. The successful growth of Taiwan's IT sector was related to the modularization trend of computers and electronics products since the 1980s, which drove component outsourcing and vertical disintegration in IT-related industries (Baldwin and Clark, 2000; Strojwas, 2005).

Singapore's economic development results from successful large-scale logistics activities ("Entrepot plus"), from finance and from other services such as airlines and real estate. In addition, it was driven by multi-national corporations' operations located in Singapore. This last item successfully happened due to the government's massive investments in physical infrastructure and human capital (through education/training), and business-friendly policies and services (Lee, 2000). Singapore's Economic Development Board (EDB) played a central and successful role in attracting global multi-national corporations to operate in Singapore (Schein, 1996; Lee, 2000). The multi-national corporations (MNCs) first brought in labor-intensive low-cost manufacturing jobs in the 1970s and then capital-intensive and high-skill engineering activities in the 1980s. The successes to the present have already made Singapore the country with the highest GDP per capita in Asia in 2010 (well above Japan). Fig. 2 shows that Singapore has constantly achieved significantly higher GDP per Capita than the others in the comparison group since the early 1990s.

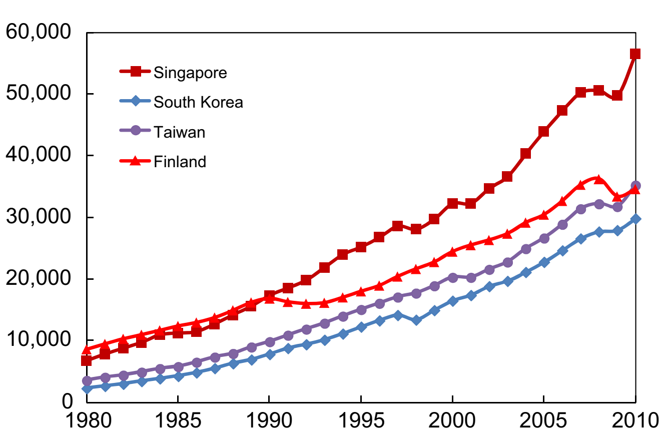

Fig. 2. Per Capita GDP based on purchasing-power-parity (PPP) (Current International Dollars).
Source: IMF World Economic Outlook Database

4.2. R&D expenditure

Past economic successes have led (and allowed) all four countries to heavily and increasingly invest in R&D, shown in their continually growing R&D expenditure as a percentage of GDP (Fig. 3a). In contrast to its far-leading GDP per Capita, Singapore's R&D expenditure intensity lags behind those of the other three comparators. Breakdown of R&D expenditure shows the private-public divide of R&D expenditure is quite similar across these countries, with 70–80% of total spent by the private sector in recent years (Fig. 3b).

4.3. R&D output

All four countries rank well in science and math education (Tan and N, 2005) and all have developed a technologically-relevant knowledge base. Singapore has achieved a significantly higher number of engineering journal articles per capita (Fig. 4a) than the other countries. In this metric, South Korea lags possibly raising an issue about the depth and flexibility of their technological base. Taiwan and Finland are quite comparable to one another and rank clearly between Singapore and South Korea.

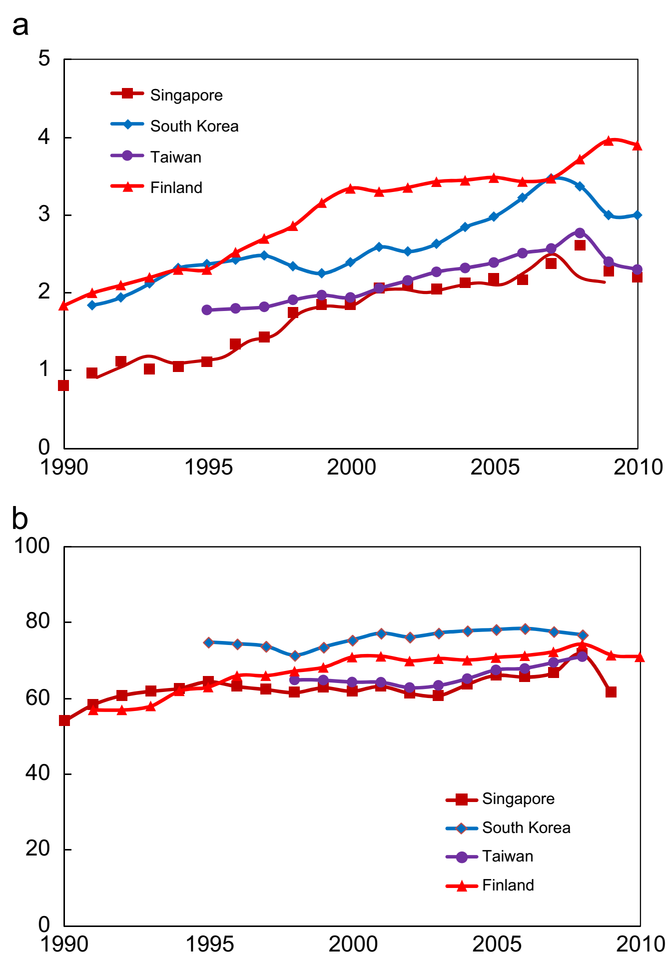

Fig. 3. R&D expenditure. (a) R&D expenditure as percentage of GDP and (b) private sector R&D expenditure as percentage of total R&D expenditure.
Source: Data is compiled from multiple sources, including OECD iLibrary, Finland Statistics Press Releases, A*STAR National Survey of R&D, World Bank Development Indicators, Taiwan National Statistics, and Battelle Global R&D Funding Forecast (2001).

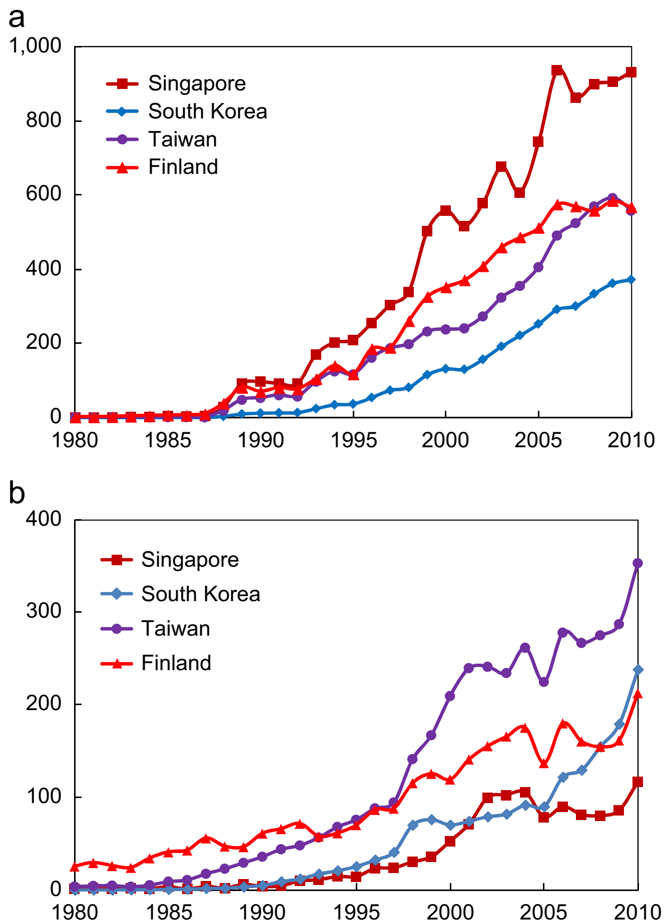

Fig. 4. R&D output. (a) Engineering journal articles per million people and (b) US patents per million people.
Sources: authors' calculation based on publication data from Compendex (searching only journal articles), patent data from United States Patent and Trademark Office (USPTO), and population data from IMF World Economic Outlook Database.

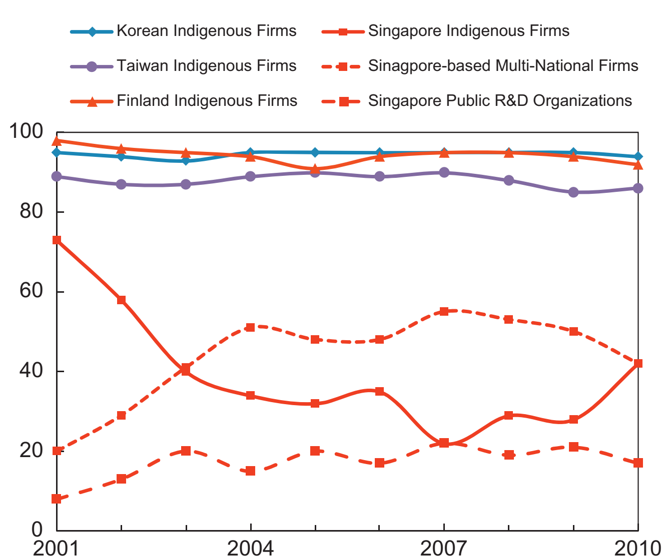

Fig. 5. Percentages of patents from the top 20 organizations receiving the highest numbers of patent grants by organization type.
Source: authors' calculations based on data from USPTO Statistics.

In practical inventive output, Fig. 5b shows a very different ranking when patents per capita instead of publications or GDP per capita are compared (Fig. 4b). In this aspect, Taiwan is most prolific with Korea and Finland in the mid-range and now Singapore the clear laggard. Taiwan's strength in filing patents and mediocrity in publishing papers is distinctly different from the pattern of Singapore. These two countries have clearly demonstrated different abilities for turning demonstrated technological knowledge into commercially-oriented inventions, indicating different design capabilities.

A breakdown of patents by organization makes further distinctions among the group. The majority of "Singaporean patents" (i.e., the patents whose first-named inventor is a resident of Singapore) grants actually go to MNCs, public research agencies and universities (Fig. 5), while patents dominantly are produced by indigenous firms in each of the other countries. This distinction indicates MNCs' major role in building up Singapore's technology-based design capability. The patenting scenario in Singapore has changed over time—indigenous firms experienced a decline in early years but are now apparently equal to MNCs at ~40% each, whereas the public sector has rather stably contributed about 20 percent of patent filing overtime.

Table 2 lists the top five patenting organizations in each country and globally: the four countries have demonstrated clearly different patterns of patenting. A cluster of firms actively patenting in the electronics-related domains has occurred in both Korea and Taiwan. Through continuous learning by doing, the *Chaebols* have become Korea's leading technical inventors and among the best in the world. For instance, in 2010, Samsung received 4,259 patents (only IBM with 5,866 patents received more) and LG received 1450 patents (9th place in the world). Taiwan differs by having a far larger number of patenting firms and firms patenting in a small volume (see Table 3), than any of the other countries, and having ITRI (Industrial Technology Research Institute), a public R&D organization, receiving 464 US patent grants in 2010—the second largest patenting organization in Taiwan. Finland's patents primarily go to the single giant – Nokia, whose patents grants in 2010 are 554 (not including the numbers of Nokia-affiliated firms), which is 20 times more than the second place – Metro Paper, Inc. The patenting activity of Singapore-based organizations is at a magnitude about 1/50 of the organizations in Korea, or 1/7 of those in Taiwan. Based upon these patent results, design capability focusing on the broad but related electronics domain may have already been established in Korea and Taiwan, while Finland's capability is de facto built in a single firm and there is little indication of strong design capability building up in Singapore.

4.4. Creation of technology-based companies

In addition, these four countries have also shown very different patterns of creating technology-based firms. In Korea, *Chaebols* are the main actors that invest in design and profit from design, and some of them have built strong design capability indicated by world-leading patenting records. The Finish government has a strategy to stimulate startups and turn lab/research results into commercial products, and particularly TEKES is charged to nurture technology startups in the form of venture capital. Many of the successful companies, such as Nokia, which grew on TEKES's investment, later became institutional investors of TEKES. However, no other firms than Nokia has achieved globally-competitive design capability so far. For a small country of five million people, the success of a single firm may be sufficient to elevate the national economy, whereas the dependence on a single firm also casts doubt on a sustainable future. In Taiwan, building on their early success in contract manufacturing and electronic components, the Taiwanese firms have also gradually invested in design and intellectual property, and several previous contract manufacturers have been able to design sophisticated products. Moreover, Taiwan

Table 2
Top five patenting organizations in four countries.
Source: USPTO Statistics data. In USPTO statistics, the list for all countries gives different numbers from those specific countries. We use the original data from USPTO so discrepancies appear for Samsung in the table here.

	Rank	Organization	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Singapore	1	Stats Chippac	0	0	0	0	3	3	6	20	30	85
	2	Agency for Science Technology and Research	0	0	1	3	14	26	38	27	31	44
	3	Marvell International	1	2	1	0	2	4	13	22	31	37
	4	Chartered Semiconductors	108	125	92	73	45	56	36	25	22	34
	5	Micro Technology	2	6	21	34	32	35	37	26	24	33
S. Korea	1	Samsung Electronics Co.	1378	1274	1253	1514	1569	2306	2583	3325	3394	4259
	2	LG Electronics Inc.	245	335	404	474	461	683	665	774	1044	1450
	3	Hynix Semiconductors Inc.	4	96	244	331	353	438	400	435	584	972
	4	LG Display Co.	0	0	0	0	0	0	0	268	590	715
	5	Electronics & Telecom Research Institute	72	89	103	86	112	171	205	254	304	457
Taiwan	1	Hon Hai Precision Ind. Co.	309	191	180	216	136	231	183	278	416	572
	2	Industrial Technology Research Institute	219	215	205	196	159	237	224	271	376	464
	3	Taiwan Semiconductor Manufacturing Co.	528	445	428	455	430	459	454	355	292	405
	4	Au Optronics Corp.	0	12	39	76	104	157	176	174	234	358
	5	Mediatek Inc.	3	1	5	22	29	104	121	151	146	223
Finland	1	Nokia Corporation	6	24	154	256	222	403	470	420	449	554
	2	Metro Paper, Inc.	10	52	55	63	46	45	29	39	26	29
	3	ABB OY.	0	5	5	3	13	19	20	14	11	29
	4	Kone Corp.	11	9	10	3	10	9	14	26	33	25
	5	Outotec OYJ	0	0	0	0	0	0	4	9	13	21
Global	1	IBM	3411	3288	3415	3248	2941	3621	3125	4169	4887	5866
	2	Samsung Electronics Co.	1446	1328	1313	1604	1641	2451	2723	3502	3592	4518
	3	Microsoft Corporation	396	499	499	629	746	1463	1638	2026	2901	3086
	4	Canon	1877	1892	1992	1806	1829	2368	1983	2107	2200	2551
	5	Panasonic Corporation[a]	1440	1544	1774	1934	1688	2229	1910	1724	1806	2456

[a] Matsushita Electric Industrial Co. changed its name to Panasonic Corporation in 2008. The numbers in this row are sums of numbers for Matsushita Electric Industrial Co. and Panasonic Corporation, both of which appeared in the USPTO database.

Table 3
Number of organizations with more than 5 U.S. patent grants between 2006 and 2010.
Source: authors' calculation based on USPTO statistics data.

Number of Patents	Singapore	S. Korea	Taiwan	Finland
From 5 to 10	36	97	294	48
From 11 to 100	24	94	233	37
From 101 to 1000	6	12	39	2
From 1001 to 10,000	0	6	4	1
Above 10,000	0	1	0	0
Total	66	210	570	88

has seen a group of globally competitive design-centric companies in the computer and electronics sector, such as Acer, HTC, ASUS, and the world's leading contract manufacturers, including Foxconn (Hon Hai's subsidiary), TSMC and UMD. In particular, ITRI of Taiwan has spun off over 150 leading IT companies, including Acer and UMD.

However, indigenous firms that are strong in product and service design, intellectual property and brands have not emerged in Singapore. Perhaps the closest Singapore comes to this achievement are OSIM, the healthy lifestyle and massage chair retailer, and Creative Technology, the consumer electronics and multimedia company. Neither of these Singaporean companies are yet global household names. Singapore's shortfall in this area is often attributed to its small size as a city state and thus not a place where firms can generate significant revenue and user base at a world class. This is an uncertain argument because Samsung, LG and Hyundai, Nokia, Acer, ASUS and HTC, all originated in countries with relatively small domestic markets. As a matter of fact, a common attribute of these firms is that they have produced and then designed for the global markets since their beginning. World-class design-centric firms, which originate from small countries, must design their products and services for customers in global markets.

4.5. Indications from a design perspective

The metrics have demonstrated usefulness (with limitations) in revealing similarities and disparities in design capability across nations in an economic context. Similarly all four countries have achieved growing patterns in all quantitative indicators. Meanwhile, disparity exists across indicators and sheds light on different design capabilities being built. For instance, Taiwan's strength in patenting and mediocrity in publishing papers is distinctly different from these measures for Singapore. This contrast indicates Taiwan has built stronger design capability (i.e., turning demonstrated knowledge into inventions) than Singapore so far, at least in some technological domains. Furthermore, the results have also demonstrated these countries' different trajectories of design capability building. For instance, according to the distribution of patents across organizations, national design capability might have been primarily built by a few large firms supported by the government in Korea, a single large firm in Finland, wide-spread large and small firms in Taiwan, whereas the patent results indicate little design capability being built in Singapore.

Overall, this macro-level assessment may indicate that each of these countries is on a significantly differing path for its evolution of design capability, so one cannot simply compare them on a single capability dimension. Each of these small countries can also be viewed as a success model in that they have been economically advancing rapidly for three decades. However, none of them is without concerns about their future progress to a sustainable knowledge economy. Based on a design-focused perspective, the foregoing quantitative comparison implies a few potential risks:

1) Taiwan's relatively low R&D spending may indicate a weakness in having sufficient design people to pursue new fields as old ones begin to be over-competitive;
2) South Korea's low publication rate may indicate a weakness in having sufficient depth to educate leading technical design experts of the future;
3) Finland has the weakness of depending upon a single firm to develop the design capacity of the nation, thus any accidental business challenge in the sector or the firm may lead to dissipation of any cumulative capability.
4) Singapore is the weakest in R&D expenditure, patenting rate, and formation of technology-based companies in the group, possibly indicating little design capability being built. There are several interpretations for this result discussed below.

One possible interpretation of Singapore's pattern is that its strong economic performance indicates super efficiency in the model it has relied on to develop the economy in the past decades. It is also possible to interpret the results as casting doubt on the sustainability of Singapore's long-run economic growth. As a matter of fact, in an early study of Singapore's competitiveness, Michael Porter (2002) has attributed Singapore's outstanding economic achievement to taking the *investment-driven strategy* (Porter, 1990) of economic development to an extraordinary level. He also speculated that the limits of the investment-driven strategy will become apparent as wages increase, labor force reaches upper limits, and countries (like China) in the same region increasingly compete using the same strategy. Porter further suggested Singapore should develop an innovation-driven economy, in order to sustain its economic growth in the long run. However, without making use of the lens of design process and design capability, his advice was largely narrative at the level of innovation and did not lead to a focused action plan.

Interesting enough, recently Singapore has explicitly emphasized "design" as the key component in the government's national strategy for next-stage economic growth, and, to our best knowledge, is the only country which has done so. This may result from the government's awareness of the important link between design and innovation-driven economic development, and its weak design capability as indicated by the metrics just reviewed. All these make Singapore an interesting case worthy of further investigation. So now we turn to qualitatively assess Singapore's national strategy at a more detailed micro level.

5. Qualitative assessment of Singapore's design strategy

5.1. Data collection

Our analysis of Singapore's design strategy is based on government documents and fieldwork (on-site interviews). We first surveyed and reviewed various recent and historical official government reports, in order to build an understanding of the evolution and current landscape of design-related strategies, initiatives, actors and activities in Singapore. Table 4 lists the most useful reports we reviewed. The Economic Strategies Committee reports are an important source to understand the historical and recent economic strategies of the government, and how design has emerged as an emphasis in such strategies.

As a second step, we conducted on-site interviews at a number of organizations that participate in design-related initiatives, to learn about their design-related activities and incentives in spring 2011. The selected organizations are listed in Table 5 according to different organization types, including government agencies (GAs), small-medium enterprises (SMEs) and multi-national corporations (MNCs). The job positions of interviewees at these organizations range from design director to chief technology officer to regional sales manager.

Two sets of formalized interview questions were developed for different types of organizations. For government agencies, we asked about key performance indicators; programs and incentives administered; the history of the agency's responsibility; and what about Singapore makes it effective for companies to do design work there. For companies, we asked about the design activities performed in Singapore; any interactions and incentives from government agencies; for multi-national corporations (MNCs), how the Singapore operations fit into the company's global operations. In all cases, the interviews were conducted in a semi-structured manner, and thus responses were not limited to a strict interpretation of the questions, and elaboration and interviewee-instigated discussion was encouraged.

5.2. Design in national strategy

Faced with increased workforce wage and living standards and growing competition from neighboring countries for contract manufacturing that were discussed in Section 4.5, the Singaporean government has been shifting the emphasis in national strategy from a manufacturing-based economy towards a knowledge-based one since the 1980s. Since then, there have been more engineering and value-added jobs created in Singapore. In particular, design has gradually emerged as an emphasis in Singapore's recent national strategy to sustain future economic growth, as evidenced in a number of government documents. This strategic shift towards design and innovation first appears in the late-1970s, when the Product Development Assistance Scheme (PDAS) was introduced by EDB in "*Thirty Years of Economic Development* (1991):

> *PDAS awards cash grants to local companies developing new products or improving existing products or processes. It was set up to encourage local product development capability and to build up indigenous technology.*

In the 1986 Economic Strategies Committee report, the following is recommended:

> *As an industrial centre, we must move beyond being a production base, to being an international total business centre. We cannot depend only on companies coming to Singapore solely to make or assemble products designed elsewhere. We need to attract companies to Singapore to establish operational headquarters, which are responsible for subsidiaries throughout the region. In Singapore such headquarters should do product development work, manage their treasury activities, and provide administrative, technical and management services to their subsidiaries.*

In the 2010 Economic Strategies Committee report, design has been stated in its vision for Singapore's future (pp. 15) which first elevates technology-based design to an important position,

> *We will have a vibrant climate of innovation, with both new and established businesses seeking commercial success through design, new products and services, and tapping on knowledge from a broader base of public and private sector R&D.*

On the other hand, broader conceptualization of design is indicated in a section about emphasizing design-driven innovation (pp.29),

Table 4
Reviewed Governmental Reports.

Title	Author	Year	Summary
The Singapore economy: new directions (Executive Summary)	Economic Committee	1986	The first report of its kind, the 1986 Economic Committee report was written in response to Singapore's 1985–1986 recession, which occurred after a number of decades of strong economic growth. The report presents the following new strategies for promoting growth: (1) Resource allocation (2) Maintain a high savings rate (3) Create a conducive business environment (4) Depend on the private sector (5) Promote offshore activities (6) Nurture both MNCs and lLocal companies
Thirty years of economic development	Economic Development Board	1991	This report summarizes and celebrates the strategies and accomplishments of the Economic Development Board on its 30 year anniversary. Founded in 1961, the initial focus of the Economic Development Board (EDB) was job creation, given the 14% unemployment rate in 1961. At least partially through efforts of the EDB, unemployment was no longer a problem by the late 1970s. Singapore evolved its economic strategy from low-cost labor to higher-skilled labor, to higher value-added industries and services, including research and development, starting in the 1970s. The 1980s are seen by the EDB as Singapore's "Second Industrial Revolution" when Singapore moved into a modern industrial economy based on science, technology, skills and knowledge. In 1986, the small business bureau was set up as part of the EDB.
The Strategic economic plan: towards a developed nation (executive summary)	Ministry of Trade and Industry	1991	In order to maintain and extend Singapore's international competitiveness, and propel Singapore's economic and social progress to that of a developed country, the following strategies are recommended: (1) Promoting national teamwork (2) Becoming internationally oriented (3) Creating a conducive climate for innovation (4) Developing manufacturing and service clusters (5) Spearheading economic eedevelopment (6) Maintaining international competitiveness (7) Reducing vulnerability
Strategic pragmatism: the culture of Singapore's Economic Development Board	Edgar H. Schein	1996	Schein's book reflects on the culture of the Economic Development Board, and its role in Singapore's rapid development. The author conducted a series of interviews in the early 1990s with current and former employees of the EDB, as well as with individuals from industry who had interacted with the agency, and moved operations to Singapore. The author highlights a number of specific cases of companies investing in Singapore, from both the company and EDB's point of view. The author is able to identify a number of cultural elements that link to the success of the EDB in its economic goals, but also brings to light less discussed areas of improvement and criticisms of the EDB.
Report on Singapore's competitiveness (executive summary)	Committee on Singapore's Competitiveness (source)	1998	In response to the regional economic crisis at that time, and to achieve sustained growth, the report recommends the following: (1) Reduce business costs, to help viable companies tide over the crisis and minimize unemployment. (2) Ensure that the framework for economic activity continues to function effectively. (3) Maintain investor confidence. (4) Step up capability-building and economic restructuring (5) Further expand trade with growth markets in the developed countries and seek out new markets beyond the region. (6) Leverage on market opportunities in regional economies to form strategic partnerships.
New challenges, fresh goals—towards a dynamic global city (report of the Economic Review Committee)	Economic Review Committee	2003	There are three recommendations from the 2003 ERC report: Singapore should aim to be: (1) A globalised economy where Singapore is the key node in the global network, linked to all the major economies; (2) A creative and entrepreneurial nation willing to take risks to create fresh businesses and blaze new paths to success; and (3) A diversified economy powered by the twin engines of manufacturing and services, where vibrant Singapore companies complement MNCs, and new startups coexist with traditional businesses exploiting new and innovative ideas.
Report of the Committee on the Expansion of the University Sector	Higher Education Division, Ministry of Education	2008	A detailed plan for the expansion of the university sector from accommodating 25% of Singapore's cohort to 30% is set-out. The key strategy in this plan is the establishment of a new university, addressing the need for a new type of graduate as Singapore moves into knowledge-based, high value-added activities such as research and development.
Dgs II: strategic blueprint of the Design Singapore Initiative	Design Singapore Council	2008	A thorough assessment of the creative design industry in Singapore. The Design Singapore Council created this report in 2008. The report presents measures on the execution of DSG I (2004–2009), the inaugural phase of the

Table 4 (*continued*)

Title	Author	Year	Summary
			Design Singapore program. It also states the goals and performance indicators of DSG II (2009–2015). Finally it presents Design Singapore's vision for Singapore 2020.
High-Skilled People, Innovative Economy, Distinctive Global City (Economic Strategies Committee Key Recommendations)	Economic Strategies Committee	2010	Most recently an Economic Strategies Committee convened in 2009. The 2010 report recommended the following seven key strategies: (1) Growing through skills and innovation (2) Anchor Singapore as a global-Asia hub (3) Build a vibrant and diverse corporate ecosystem (4) Make innovation pervasive, and strengthen commercialization of R&D (5) Become a smart energy economy (6) Enhance land productivity to secure future growth (7) Build a distinctive global city and an endearing home Strategies 1, 3, and 4 are particularly relevant to a discussion of design; however there are threads of the strategy throughout the entire report.

Table 5
Interviewed organizations and agencies and interview questions.

Organization Types	**Organizations**	**Main Questions**
Government Agency (GA)	1. Economic Development Board 2. SPRING 3. Design Singapore 4. Ministry of Education/DTES 5. SMART	– Key performance indicators; – Programs and incentives administered; – The history of the agency's responsibility; – - What about Singapore makes it effective for companies to do design work here.
Multi-National Corporation (MNC)	6. EADS 7. Dell 8. Philips Design 9. Hewlett-Packard 10. Electrolux	– Design activities performed in Singapore; – Any interactions and incentives from Singapore agencies; – How the Singapore operations fit into the company's global operations.
Small-Medium Enterprise (SME)	11. OSIM 12. Fong's Engineering 13. Lawton & Yeo 14. SYSTMZ 15. Design Exchange 16. XentiQ	– Design activities performed in Singapore; – Any interactions and incentives from Singapore agencies.

Instill design thinking in our workforce by accelerating the introduction of design thinking programmes and modules at local educational institutions and leading foreign design institutions. This can also be supported by incentives to help local enterprises grow their capabilities in areas such as product and industrial design.

5.3. Government programs and initiatives

The Singaporean government has implemented a wide range of programs, grants, tax incentives and financing opportunities for the promotion of design activities, through various agencies and almost all channels of the government. Table 6 categorizes some of them collected from our interviews and literature surveys. Most of these support design capability broadly but increasing R&D intensity as well as translation of R&D to the economy is now also receiving attention from the National Research Foundation (NRF) and other Singaporean entities (see Section 5.5).

The government has paid particular attention to the indigenous SMEs in order to incentivize them to adopt design in their business strategy. SME-oriented incentives are generally spearheaded by SPRING (Standards, Productivity & Innovation Singapore), with collaboration of International Enterprises Singapore and the Design Singapore Council. SPRING was founded in 1996 (as a merger of the National Productivity Board and the Singapore Institute of Standards and Industrial Research), to focus on developing and supporting Singapore's SMEs. It is also the national standards and accreditation body. SPRING's Chairman, Philip Yeo, is a noteworthy appointment when one considers his previous positions as head of the EDB (1986 to 2001) and A*STAR (1999 to 2007). International Enterprises (IE) Singapore is known formerly as the Singapore Trade Development Board. IE Singapore is an agency under the Ministry of Trade and Industry, spearheading Singapore's efforts to develop its external economic wing. Design Singapore Council was established in 2004 under the Ministry of Information, Communications and the Arts in response to the 2003 Economic Review Committee identification of Creative Industries as new economic growth sector. Design Singapore's official mission is "to develop Singapore as a global city for design creativity".

A few examples of the incentives and programs tailored for SMEs are given in the next three sub-sections.

– Innovation Voucher Scheme
The Innovation Voucher Scheme is a tax incentive that SPRING offers. SMEs with innovative ideas can receive the vouchers and redeem them at the participating Knowledge Institutions (KIs), such as Nanyang Technology University, Ngee Ann Polytechnic, Singapore Polytechnic and the Singapore Institute of Manufacturing Technology. The aim is to encourage collaboration between SMEs and KIs in making innovative ideas work in practice.
– Design for Enterprises
The Design for Enterprises program, launched in 2008, is charged with encouraging SMEs to adopt "design" and help them develop the relevant capabilities. The program recruits and assigns experienced design facilitators, such as Philips Design, to provide help and supervision for indigenous SMEs that participate in the program. 50–70% of the fees for a design facilitator are subsidized by the government through the program.

Table 6
Singapore government's design incentives (as of Spring 2011).

Creative	Grants and programs	Design Capability Development Programme
		Industry Association Development Scheme
		Design for Business Innovation
		Overseas Promotion Partnership Programme
		BrandPact
		Design for Internationalisation Programme
	Tax incentives	Productivity and Innovation Credit for Investments in Design
Research & Development	Grants and programs	Innovation Voucher Scheme
		Innovation Development Scheme
		Research Incentive Scheme for Companies
		Technology Innovation Programme—Experts
		Technology Innovation Programme—Projects
		Intellectual Property Management
		Environment Technology Research Programme
		Technology for Enterprise Capability Upgrading Initiative
		Technology Innovation Programme—Centres of Innovation
		Technology Pioneer Scheme
		Initiatives in New Technology
		Operation & Technology Roadmapping
		Design for Efficiency Scheme
		Innovation for Environmental Sustainability Fund
		Singapore Israel Industrial Research and Development Foundation
		IP for Internationalisation Programme
	Tax incentives	International Headquarters Award
		Regional Headquarters Award
		Development & Expansion Incentive
		Investment Allowance
		Liberalised Research and Development Tax Deductions
		Productivity and Innovation Credit
		R&D Tax Allowance Scheme
Entrepreneurship	Grants/programs/financing	Incubator Development Program
		Technology Enterprise Commercialisation Scheme
		iStart
		Business Angel Funds
		Early-Stage Venture Funding Scheme
		SPRING Startup Enterprise Development Scheme
		Infocomm Business & Engineering Start-up Program
		Innovation Grant
		Explorer Grant
	Tax incentives	R&D Incentive for Start-up Enterprises Scheme
		Tax Exemption for Start-ups
		Angel Investors Tax Deduction Scheme

The program offers three levels of service, including Design Touch, Design Engage, and Design Excel, tailored for SMEs with different levels of established design capability and varied needs. The program will provide funding for up to 50% of certain costs incurred in the participation.

– National Design Centre
A key initiative of the Design Singapore Council is the establishment of a National Design Centre. The centre will house a Design Thinking and Innovation Academy where design thinking programs will be run for Singapore's small-business community.

5.4. Industry adoption of design

– Multi-National Corporations (MNC)
MNCs' Singapore-based design activities were quite consistent across the firms we interviewed. First of all, it is observed that a number of world-class MNCs have been conducting "look-and-feel" design activities for consumer products in Singapore. Second, some MNCs have relocated engineering and product development teams to Singapore. For example, Dell develops peripherals but not computers or servers in Singapore. Philips has its consumer lifestyle products team in Singapore. Third, some firms have located advanced engineering development work to Singapore: for example, EADS has a small wearable computing development team in Singapore. Hewlett–Packard has a small HP Labs group located in Singapore, focusing on cloud computing. In general, Singapore's policies and institutional environment have successfully attracted MNCs to increase their design activities in Singapore. Such activities of MNCs may directly contribute to Singapore's design capability and also potentially generate indirect spillover effects through formal and informal linkages to indigenous firms (Guimon, 2011).

– Indigenous Small-Medium Enterprises (SME)
Traditionally, most of the local SMEs provide contract manufacturing or engineering services to MNCs. However, throughout our interviews with SMEs, we heard a common sentiment of "moving up the value-chain"—for instance, a contract manufacturer becomes a contract designer and eventually designs products under its own brand. Despite these ambitions, there is no clear evidence that such an industry shift is underway. Although SMEs are commonly interested in the financial incentives that the government offers, and have in fact actively pursued a collection of generous incentives, such as subsidies and grants for design-related activities, our interviews indicate that, the government incentives they received have at best only marginally spurred design activities, and the building of a design culture and design capability. An impediment we learned from the interviewees at the firms we visited is the lack of design expertise, despite strong motivation in place.

– Indigenous Large State-Owned Enterprises (SOE)
Singapore has nurtured a few world-class state-owned companies in the service and logistics sectors. As a matter of fact,

such large SOEs as Singapore Airline and Port of Singapore have been able to proficiently design large-scale service systems, making use of the most advanced technologies. Apparently, they have accumulated a lot of expertise and are also capital-rich. Thus the service and logistics sectors in Singapore may be on the way to an evolving globally-competitive design cluster within Singapore. However, patent data may miss this because of low propensity to patent in such fields, and we performed no interviews in these sectors.

– Other Players
 Singapore also has a few local design consulting firms, such as Lawton & Yeo and Design Exchange. These firms are normally small. For instance, Lawton & Yeo has about 30 employees and Design Exchange has only 12, in 2011. And, their businesses are primarily look-and-feel rather than technology-based design. In addition, a number of non-profit grassroots design organizations, including Design and Technology Educators Society (DTES), the Little Thoughts Group, FARM, and The Design Society have emerged in Singapore in recent years. There gather designers from industry pursuing passion projects that are not directly related to their professional work. This community may potentially have an impact on the forming of designer social networks and thus design clusters, but only if the concentration of expertise domains are taken seriously.

5.5. *Research and education for design*

The analysis in 4.1 has indicated that Singapore needs to improve its ability to turn research results into practically inventive output, on its already-strong education and research system. As a matter of fact, the government has started to make major investments in design-related education and research. The National Research Foundation (NRF), which was set up by the Prime Minister's Office in 2006 to coordinate different research organizations, manages and allocates a fund of S$5 billion to support research and innovation programs.

– Universities
 In May 2009, NRF granted S$22 million to three local universities—Nanyang Technological University (NTU) S$6.5 million; National University of Singapore (NUS) S$9 million; and Singapore Management University (SMU) S$6.5 million—to develop programs to make innovation and entrepreneurship pervasive in the country. NUS has established a design-centric engineering curriculum in academic year 2009–2010, offering to cross disciplines, foster creativity and develop strong design skills. Although these initiatives may not focus on technology-based design one large Singapore program does. A new national university, Singapore University of Technology and Design (SUTD), is being established with a focused mission to systematically combine research intensity and design pedagogy. SUTD aims to educate students with not only basic knowledge, but also hands-on design experience and skills. The International Design Center has already been established as the close collaboration of SUTD with MIT to focus on research and education on technologically-intensive designs of new products, systems, and services. The center will also support and conduct research on design process, with a focus on methods and conditions to promote creative technical work.

– Public R&D organizations
 In addition to the university-based initiatives, NRF and A*STAR have substantial design projects funded. In Singapore, A*STAR is the second largest patenting organization, with 44 US patents granted in 2010 from zero in 2002. Both the NRF Research Centers for Excellence and A*STAR research units have newly established mechanisms for the transition of their research to commercial implementation. A*STAR uses its commercial arm – Exploit Technologies Pte Ltd (ETPL) – to market the intellectual properties created in A*STAR-funded research projects. For instance, A*STAR licensed patents for a magnetic tagging technology to combat counterfeiting in products to a small firm called Singular ID. Singular ID was in fact founded by two former scientists at the Institute of Material Research and Engineering of A*STAR. Singular ID was bought by an Indian firm for S$19.58 million in 2007. Despite small successes like Singular, in fact Singapore has thus far seen only a small number of new companies spun off from research labs and universities, and no research spin-off has grown into world-class and global household names, such as Hewlett & Packard and Google from Stanford University, Acer and UMD from ITRI—the A*STAR counterpart for Taiwan, or even the new but fast-growing A123 from MIT. Such initiatives as SMART Innovation Center and the POC (proof of concepts) grants by NRF could change this situation in the longer term but these are too new to assess.

– Incubators
 The SMART Innovation Center was established in 2009, with the inspiration from MIT's Deshpande Centre for Technological Innovation. SMART aims to identify emerging technologies and nurture technology-based startups. It operates under the Singapore-MIT Alliance for Research and Technology (SMART) and is funded by the National Research Foundation (NRF). Its programs and grants are available to all of Singapore's research Institutions, both universities and polytechnics.

5.6. *A summary of the qualitative assessment of Singapore's design strategy*

Singapore has a large and varied program to pursue design capability. Indeed, a first conclusion is that it has the broadest ranging and highly interlocking top-down strategy of any of the four countries we have studied and to our knowledge than anyone else globally. From the lens of technology-based design, some elements seem to be working well. These include:

1) Educational system—strong science and technological focus;
2) A new university (i.e., SUTD) focused on technology-based design and innovation;
3) Advanced research and technological development—strong publications of papers of importance and sophistication;
4) MNCs increasing technology-based design activities in Singapore;
5) New push for technology-based startup companies.

However, some other current activities in Singapore seem inappropriate based upon our analytical lens—technology-based design, including,

1) An apparent emphasis on "look and feel" design and industrial design rather than technology-based design;
2) Lack of emphasis on developing technologically-based expertise at SMEs.

Despite the lack of basic design expertise of indigenous SMEs, SOEs in the service and logistics sector have accumulated a lot of expertise in designing large-scale service systems and MNCs are also increasing their design activities at their subsidiaries in Singapore. Singapore's overall design capability building may accelerate if it can find ways to leverage the existing capabilities in the service and logistics sector to other technological sectors and to foster spillover effects from SOEs and MNCs to indigenous SMEs (for instance, through collaboration, employee mobility and spinoffs).

In general, we believe that the longer-term aspects of Singapore's strategy are well-aligned with the argument of this paper on the economic importance of technology-based design, even though gaps remain in the current activities. The key adjustment suggested by this assessment is to focus investments and efforts more on technology-based design rather than non-technical design, and more on building relevant capabilities incrementally of indigenous firms—possibly by leveraging the relatively stronger design capabilities of the SOEs and MNCs.

6. Concluding remarks

The literature on developing a knowledge-based economy has primarily focused on innovation as the analytical lens, whereas design is a valuable additional focus because it helps identify actions when one thinks about fostering innovation as an outcome of successful design. However, prior design research has offered few insights and guidance for innovation policies and national economic growth strategies. The limitation is largely due to the lack of focus (design is often viewed too broadly to guide specific actions) and the lack of research analyzing design in an economic context.

To fill this gap between design research and economic policy, we analyzed the design research literature in an economic context. This analysis first identified that *the cumulative nature of technology-based design has important strategic value for sustaining long-term economic growth*. Economic growth will be sustained when a country's future success can accumulatively build on its prior achievements and expertise. Only technology-based design, as opposed to the non-technical designs (e.g., aesthetic design, industrial design, etc.), directly bring the advantages of "accumulation". This finding is sufficient to allow us to argue that, countries (such as Singapore, China) striving to sustain knowledge-based economic growth should focus their innovation policies on technology-based design and building national capabilities for such design. Our argument – grounded on design research – is quite significant both in a scholarly and in a policy sense.

Making use of the lens of technology-based design, we assess and compare the design capabilities in four similar countries. Overall, our macro-level quantitative analysis indicates that each of these countries is on a significantly different path for its evolution of design capability and that, none of these countries is without concerns about their progress to a *sustainable* knowledge economy. More detailed examination of Singapore found that, while Singapore has the most comprehensive top-down strategy for pursuing design that we are aware of globally, the current activities (programs and incentives) seem to have over-emphasized non-technical designs (e.g., look-and-feel and industrial designs) relative to technology-based designs. These conclusions agree with the Singaporean government's use of design as a strategic lever to pursue knowledge-driven economic growth, but also reveal shortfalls which indicates possible directions for strategic adjustment–some of which may well be underway as discussed in Section 5.5.

From an academic viewpoint, improvement of the assessment of design capability would be a viable way to proceed further. The metrics used in the present assessment do not differentiate themselves much from those used to examine national innovation capacity, although the technologically-significant publication rate and decomposition of patent sources have – to our knowledge – not been utilized previously. This may be partially due to the good availability of data on design outcomes (some of which become invention and innovation), and the lack of data on the macro characteristics of the processes of design. Thus, continued development of useful data sources in general is also seen as important even at this stage. Not to mention the data on the characteristics of design process, the examination of R&D spending can also be improved if data is available for further breakdowns by industries or some other characteristic with technical specificity. However, the data sources as of now do not support such decompositions.

The difference in patenting and publication patterns may be due to difference in types of design capability or in technological domains. For example, large-scale technical systems design may not involve patenting as much as material or product design. Publications may also be of more importance in some technologically-based design, such as materials and software, than in others like electro-mechanical design. Thus, a valuable further examination might be to compare publications by disciplines, and patents by technological domains.

Another valuable arena for further research would be to explore the mechanisms potentially important for the emergence and growth of national design capability. For instance, potential hypotheses can be related to the nurturing of design clusters and design ecosystem. Better understanding in this regard would guide the strategic endeavors of governments and firms in building design capabilities.

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