Technological Forecasting & Social Change 104 (2016) 38–56

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Architecting complex international science, technology and innovation partnerships (CISTIPs): A study of four global MIT collaborations

Sebastian M. Pfotenhauer [a,b,*], Danielle Wood [c], Dan Roos [a,d], Dava Newman [a,e]

[a] MIT Technology & Policy Program, Institute for Data, Systems, and Society, Massachusetts Institute of Technology, 77 Massachusetts Avenue, E40-369, Cambridge, MA 02139, United States
[b] Munich Center for Technology in Society (MCTS) and TUM School of Management, Technische Universität München, Arcisstr. 21, 80333 München, Germany
[c] JHU Systems Institute, Johns Hopkins University, 3400 N. Charles St, Baltimore, MD 21218, United States
[d] Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, 1-290, Cambridge, MA 02139, United States
[e] Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, 33-207, Cambridge, MA 02139, United States

ARTICLE INFO

Article history:
Received 26 February 2015
Received in revised form 11 December 2015
Accepted 12 December 2015
Available online 30 December 2015

Keywords:
Innovation policy
Research collaboration
Regional development
University partnerships
System architecture
Policy design
MIT
International partnerships

ABSTRACT

Complex international partnerships have emerged as a policy instrument of choice for many governments to build domestic capacity in science, technology and innovation with the help of foreign partners. At present, these flagship initiatives tend to be primarily practitioner-driven with limited systematic understanding of available design options and trade-offs. Here, we present an analysis of four such partnerships from the university sector between the Massachusetts Institute of Technology (MIT) and governments in the UK, Portugal, Abu Dhabi, and Singapore. Using a system architecture approach in conjunctions with in-depth case studies and elements of interpretive policy analysis, we map how in each country distinct capacity-building goals, activities, and political and institutional contexts translate into different partnership architectures: a bilateral hub-&-spokes architecture (UK), a consortium architecture (Portugal), an institution-building architecture (Abu Dhabi), and a functional expansion architecture (Singapore). Despite these differences in emergent macro-architectures, we show that each partnership draws on an identical, limited set of 'forms' that can by organized around four architectural views (education, research, innovation & entrepreneurship, institution-building) and four levels of interaction between partners (people, programs/projects, objects, organization/process). Based on our analysis, we derive a design matrix that can help guide the development future partnerships through a systematic understanding of available design choices. Our research underscores the utility and flexibility of complex international partnerships as systemic policy instruments. It suggests a greater role for global research universities in capacity-building and international development, and emphasizes the potential of targeted cross-border funding. Our research also demonstrates the analytic power of system architecture for policy analysis and design. We argue that architectural thinking provides a useful stepping stone for STS-type interpretive policy analysis into national innovation initiatives in different political cultures, as well as more custom-tailored approaches to program evaluation.

1. Introduction: Complex International Science, Technology, and Innovation Partnerships

Over the past two decades, a growing number of countries have launched large-scale international partnerships between domestic universities and prominent international partner institutions. For example, since 2006, the country of Portugal has launched five major collaborative initiatives with the Massachusetts Institute of Technology (MIT), Carnegie Mellon University, University of Texas at Austin, Harvard Medical School, and the German Fraunhofer Society to "strengthen the country's knowledge base and international competitiveness through a strategic investment in people, knowledge and ideas" (MIT, 2005; Pfotenhauer et al., 2013). Likewise, in 2006, the government of Singapore inaugurated its Campus for Research Excellence and Technological Enterprise (CREATE) as an "international collaboratory of research centers set up by top global universities and research institutes in Singapore [.] that fosters deep collaborations with each other and with Singapore universities [and] establish[es] a reputation as a leading research hub" (NRF, 2006), inviting as many as 10 international partners to CREATE, including University of California Berkeley, University of Cambridge, ETH Zurich, MIT, Technion, and TU Munich. Another example, the new Skolkovo Institute of Technology (SkolTech) – an innovation-geared research university established just outside Moscow – is being built

---

* Corresponding author at: Munich Center for Technology in Society (MCTS) and TUM School of Management, Technische Universität München, Arcisstr. 21, 80333 München, Germany.

E-mail address: sebastian.pfotenhauer@tum.de (S.M. Pfotenhauer).

http://dx.doi.org/10.1016/j.techfore.2015.12.006

around a suite of collaborative Centers for Research, Education, and Innovation, where local, national, and international partners (including MIT and the universities of Groningen and Delft) come together to jointly work on research projects.

Cross-border activities among universities are not new. However, this new generation of partnerships differs from traditional forms of engagement in several important ways. First, they typically represent *capacity-building agreements*; that is, they are limited-time contractual engagements to build domestic capacity in a specific scientific or technological domain *with the help of an international partner*, after which the partnership may be terminated. Unlike branch campuses or twinning programs, they are not seen as permanent offshore presences, and tend to be driven primarily by the government of hosting country — not by an expanding university per se. Second, they typically *combine explicitly collaborative activities with a set of (paid) services* provided by one partner to the other. Third, they allocate local taxpayer money to fund research (and a host of other activities) *with and at a foreign partner* university, which stands in sharp contrast to the still mostly national patterns in research funding and institution-building. Fourth, the partnerships are typically *complex*, meaning that they simultaneously address goals in education, research, innovation, institution-building, and policy reform, among others. This differs from more traditional forms of cross-border university engagement, which usually only focus on one of these aspects, e.g. in the form of student exchanges, dual degree programs, or individual researcher collaboration. Fifth, they tend to be *large-scale* initiatives that may last up to 20 years, involve hundreds of people, cost tens to hundreds of millions of dollars (not including potential infrastructure development), and often tie in a plethora of institutions in a consortium-like structure.

These large-scale university partnerships are part of an emergent policy instrument for national capacity-building that we call "Complex International Science, Technology, and Innovation Partnerships" – CISTIPs for short – and that share the above properties of (1) limited-term capacity-build arrangement, (2) hybrid collaborative-consultative efforts, (3) funding foreign institutions, (4) complexity, and (5) scale. In general, CISTIPs are not limited to partnerships between universities, but exist across an increasing range of other institutional and sectoral settings. For example emerging space nations today typically build their first satellite with the help of foreign partners (e.g. companies, government agencies, universities), which equally involves the build-up of research, education, and institutional capacity. Likewise, emerging nuclear nations typically build their first nuclear power plant with the partners in established nuclear powers. The present paper is part of a larger effort to study CISTIPs across sectors and institutional configurations.

Here, we focus on CISTIPs for the case of universities, using four partnerships between the Massachusetts Institute of Technology (MIT) and the governments of the UK, Portugal, Abu Dhabi, and Singapore as case studies. We explore how these partnerships have been constructed to address very different capacity-building goals while relying on similar basic building blocks, and provide a conceptual framework as well as a design toolkit to guide the development of such partnerships in the future.

Note that our goal here is not to assess the success or efficiency of these collaborations from a program evaluation perspective. Rather, it is to understand and systematize the design choices made in existing collaborations and to develop tools for managing their complexity, thus focusing primarily on *structural* aspects. We believe that our insights provide a crucial step for a more adequate evaluation agenda, rooted in a prior understanding of complex goals and unique architectures that evade one-size-fits-all approaches. We further see our work as highly compatible with interpretive approaches to policy analysis as found, for example, in Science and Technology Studies: An in-depth mapping of the policy choices embodied by complex S&T initiatives such as CISTIPs gives us a robust empirical footing for interpreting these policy choices vis-à-vis persistent sociotechnical imaginaries (Jasanoff and Kim, 2009), social expectations surrounding S&T (Borup et al., 2006), and the co-production of technoscientific and social orders (Jasanoff, 2004).

2. Three trends in innovation policy: university-centrism, international linkages, and complexity

This section aims to locate the emergence of complex international university partnership within the current landscape of science, technology, and innovation policy. Over the past decade, innovation policy has been shaped by three major trends: an increasingly central role of universities, a surge in internationalization and research collaboration, and growing complexity of policy instruments. Universities, first, have moved boldly to the heart of national and regional innovation strategies across the globe (Mansfield, 1991; Mansfield and Lee, 1996; Salter and Martin, 2001; Mowery, 2004; Etzkowitz, 2008; Youtie and Shapira, 2008; Cowan and Zinovyeva, 2013; Thorp and Goldstein, 2010). The role of universities for innovation – and particularly their often-cited ability to simultaneously address human capital formation, the creation of new knowledge, and the translation of this knowledge into technological and economic advancement – has been explored by decades' worth of theory development on endogenous growth (Lucas, 1988; Romer, 1990; Aghion and Howitt, 1998; Scherer, 1999) and a flourishing, multidisciplinary literature on innovation theory and practice (see Fagerberg, 2006; Smits et al., 2012 for an overview). Universities are considered cornerstones of national, regional, or sectoral innovation systems (Lundvall, 1992; Nelson, 1993; Edquist, 2005; Braczyk et al., 2004; Malerba, 2005) and seen as key nodes in the globalizing learning economy, in which rapid knowledge diffusion and updating, access to knowledge networks, institutional diversity, and global interconnectedness are increasingly replacing classical growth factors such as the accumulation of capital and labor (Archibugi and Lundvall, 2001; Conceição and Heitor, 2001; Llerena and Matt, 2005). Meanwhile, universities have also become major economic actors themselves: With the rise of "entrepreneurial university" models, universities are increasingly engaged in creating proprietary knowledge and commercializing research through spin-offs or licensing, and are assessed not only by their intellectual but also their economic impact (Clark, 1998; Etzkowitz, 2003; Shane, 2004; Thorp and Goldstein, 2010; Slaughter and Leslie, 1997). As a result, many (if not most) national and regional "innovation strategies" of the last couple of decades have revolved around universities in one way or another.

Second, innovation policy has been increasingly concerned with international linkages. Drawing upon partial roots in international development, the current discourse of innovation policy has closely linked to questions of international knowledge circulation, technology transfer, and gradual convergence to the innovation frontier (Bozeman, 2000; Lee and Lim, 2001; Wei, 1995; Reddy and Zhao, 1990; Amsden, 2001), whereby less-developed nations are imagined to start as adopters and recipients of foreign direct investments, gain expertise through imitation and import substitution, and eventually begin to innovate themselves (Kim, 1997; Lall, 1992; Grieve, 2004). Recent literature has tended to emphasize technological *learning* over transfer, in which opportunities to benefit from technology acquisition in the long run depend on local skills and absorptive capacity, as well as the ability to adapt technologies in a local context (Fransman et al., 1984; Cohen and Levinthal, 1990; Keller, 1996; Lall, 1992; Kim, 1997; Amsden, 2001; Cusumano and Elenkov, 1994).

Another way in which research and innovation policy has gravitated towards internationalization is the surge in research collaborations across fields and institutions, as evidenced by a growing number of scientometric studies (Bozeman et al., 2013; Wuchty et al., 2007; Wagner, 2005; Melin, 2000; Georghiou, 1998; Katz and Martin, 1997; Vinkler, 1993; Luukkonen et al., 1992). Research collaboration has been shown to have positive effects on scientific as well as broader economic productivity (Subramanyam, 1983; Wuchty et al., 2007; Lee and Bozeman, 2005; Dietz and Bozeman, 2005). While collaboration may take many forms, most studies have focused on individual-level research collaborations such as co-authorship or citation networks due to the ready availability of such data, even though their limitations are widely acknowledged (Bozeman et al., 2013). Much less attention has been paid to institutional or national-level research collaborations. Those papers that do focus on institutions tend to be mainly concerned with university–industry links or government-industry–university interactions (see e.g. Hagedoorn et al., 2000; Etzkowitz, 2002; Carayannis et al., 2000; Eom and Lee, 2010), institutionalization and management of multidisciplinary, mission-oriented research collaborations (Corley et al., 2006; Bammer, 2008), or collaborative settings in cross-border provision of higher education (Knight, 2004; Altbach and Knight, 2007; Verbik and Merkley, 2006). The present work expands this literature by analyzing international research and innovation collaborations that closely link universities from different countries with the aim of affecting broader institutional or ecosystems change for each partner.

What is more, internationalization in innovation has been increasingly tied to questions of international labor mobility, especially with regard to university students and graduates (Freeman, 2014; Freeman, 2005; Bound et al., 2009; Hunt and Gauthier-Loiselle, 2008). It is an open secret that the US has benefitted from the attraction and retention of highly talented students from around the globe (Finn, 2012). Student and faculty cross-border mobility has been acknowledged as important to national capacity building in higher education (Vincent-Lancrin, 2007; OECD, 2004) and the flow of skills and knowledge (Knight, 2007; Clotfelter, 2010; Kehm and Teichler, 2007). The number of internationally mobile students has doubled between 2001 and 2011 to about 4.3 million, and is estimated to rise above 8 million by 2025 (IIE, 2013; Bhandari and Blumenthal, 2011). As a consequence, many net-sending countries are trying to meet this “international imperative” by becoming net-receiving countries, which will allow them to benefit from bright, mobile individuals in their domestic universities and labor markets (Altbach, 2007).

A third major trend, innovation policy has consistently grown in terms of complexity over the years. The sprawling literature of innovation research has gradually complicated our view of how innovation works and how it ought to be orchestrated — from relatively simple pipeline models of the post-WWII era and later differentiation between push, pull, and interactive modes of innovation (Landau and Rosenberg, 1986; Balconi et al., 2010; Rothwell, 1992), to the more recent frameworks of innovation systems that emphasize how different parts of the system serve complementary functions (Lundvall, 1992; Nelson, 1993; Edquist, 2005; Braczyk et al., 2004). Other scholars have emphasized the gradual erosion of institutional boundaries in innovation (Etzkowitz, 2008) and knowledge production (Gibbons et al., 1994). As a result of this more sophisticated theoretical understanding, innovation strategies have grown in complexity as well, addressing innovation with increasingly holistically approaches from multiple policy angles (Kuhlmann et al., 2012; OECD, 2010). This recognition of complexity has recently led to a more conscious exploration of “systemic instruments” for innovation policy (Smits and Kuhlmann, 2004) and “functions” of innovation systems (Hekkert et al., 2007), which, partly owed to the absence of adequate tools to manage this complexity, has yet to bear fruit in common policy practice. We agree with much of this literature and argue that the emergence of complex innovation partnerships as an increasingly common tool for building capacity in various national and transnational contexts underscores its importance. Yet, a gap continues to exist in developing appropriate frameworks, decision support or evaluation tools to grapple with the complexity of CISTIPs. For the most part, the current literature is concerned with theorizing these ongoing changes. Our research aim is both to improve understanding *and* practice by building theoretical knowledge about the dynamics, rationales, and architectures of CISTIPs as well as practical tools to enable their modeling, evaluation and design.

3. Framework, methods, data: system architecture as policy analysis

Our research uses a comparative case-study design (Yin, 1994; Jasanoff, 2005; Eisenhardt, 2007) together with a system architecture approach (Maier and Rechtin, 2000; Crawley et al., 2015) to study complex university partnerships. Generally, *system architecture* is a framework to analyze, interpret, design, and manage complex systems across their micro- and emergent macro-properties. Here, the term “architecture” is understood as “an abstract description of the entities of a system and the relationship between those entities. […] The premise [of system architecting] is that our systems are more likely to be successful if we are careful about identifying and making the decisions that establish the architecture of a system” (Crawley et al., 2015).

Central to system architecture (and architectural thinking in general) is the idea of form–function relationships. Echoing the civil architectural mantra of “form follows function,” we can look at partnerships as complex systems in which certain partnership components, or *forms*, relate to partnership activities, or *functions*, and analyze how they relate to broader stakeholder objectives. Acknowledging the inherent complexity of many systems, we can then ask how certain form–function combinations are compatible or incompatible with one another, or how alternative partnership architectures align or conflict with stakeholder objectives and contextual constraints.

System architecture analysis is based on the premise that one function can potentially be served by several forms, and that system designers can choose which available form they will employ for a given function. For example, all four case studies in this paper focused, in one way or another, on human resource development for innovation (a function). Yet, they did so in very different ways, employing different system forms.[1] The choice of a particular form over another is determined by various factors — expressed stakeholder preferences, availability of information on design options, institutional context, political constraints, or mere historical chance. System architecture analysis recognizes this contingency but emphasizes that different architectural options do exist at every step of the design process and should – in an ideal world – be made explicit and consciously weighed by the ‘system architect’ (e.g. policy-makers). Conversely, in any architecture, one form may simultaneously serve several functions. For example, introducing a new course in technology management (a form) may serve several functions, such as training human resources, providing a pathway to overcome disciplinary and departmental boundaries by bringing together students with different backgrounds, fostering commercialization of university research, or triggering broader institutional and cultural change at a university. Different forms thus open up or close down certain avenues for addressing stakeholder goals through specific functionalities. Functions may be more or less integrated within certain forms, with considerable impact on system complexity and performance.

To analyze our case studies, we further introduce the concept of *architectural views*. Architectural views are relatively broad conceptual categories in which stakeholders express the objectives of partnerships — independent of which forms might actually be employed to address them, or which specific functions one particular form might serve. For example, a *research view* would highlight all architectural aspects related to initiating, performing, evaluating, or utilizing research, thus bringing to the fore the interrelation of partnership components as diverse as researcher mobility, research projects and grants, researcher recruitment, focus area selection, infrastructure development, industry-sponsored research etc., while moving other questions (e.g., concerning education) temporarily to the background. *Architectural views* do not follow self-evidently from the design of the partnership; rather, they resemble the broader discursive categories or policy priorities that stakeholders associate with the partnership initiative and the institutions involved. In our case studies, we find

---

[1] As discussed below, Cambridge-MIT addressed human resource formation primarily through Master's programs and a variety of add-on activities, MIT-Portugal through PhD Programs and a focus on entrepreneurship, Masdar through building the first graduate university of the country, and Singapore *first* through education in critical engineering fields, *then* through the attraction of MIT faculty, *then* through undergraduate education in creativity and design.

that objectives fall most commonly under four views: (*1*) *education*, (*2*) *research*, (*3*) *innovation* & *entrepreneurship*, and (*4*) *institution-building/institutional change*. Albeit incomplete, we will use these four in the following to structure observed activities within the architecture of the partnership.

We chose the system architecture framework because it is a powerful, albeit under-appreciated, tool for policy analysis of complex phenomena like CISTIPs, and it is highly compatible with interpretive policy analysis frameworks (Dryzek, 1990; Majone, 1992; Fischer and Forester, 1993; Schön and Rein, 1995; Stone, 2001; Hajer and Wagenaar, 2003; Fischer, 2003). While system architecture seeks to analyze a phenomenon with a view towards abstract forms and functions and idealized archetypes, it does not that the resulting architectures are politically "neutral" – on the contrary, it acknowledges that architectures will always embody normative preferences. This enables deeper qualitative inquiry into why only certain policy architectures emerge under certain social, political, and historical circumstance, while others are inhibited. We argue that an answer to this question must include both an appreciation of the political, cultural, and individual components as well as an in-depth understanding of the actual architectures at play.

3.1. Data

Empirically, our research builds on data from more than 100 semi-structured interviews between 2010 and 2014 with actors involved in four partnerships between MIT and governments and universities in four countries: the Cambridge–MIT Institute (with the University of Cambridge, UK), the MIT Portugal Program, the Masdar Institute of Science and Technology (Abu Dhabi), and a suite of three collaborations with Singapore. During the interview period, all partnerships except the Cambridge–MIT Institute were still ongoing and largely in steady-state operation, with the further exception of the latest addition to the MIT–Singapore collaboration in 2010 (cf. below). Interviews were carried out both at MIT and in the partner countries, with the majority of interviews performed by the principal author. Interviewees in MIT's partner countries included institutional leadership; policy-makers from various ministries concerned with science, technology, innovation, or higher education; program managers employed by the partnership; faculty (both participating and non-participating); students; and occasionally representatives of third-party institutions (such as industry partners and funding or accreditation agencies). On the MIT side, interviewees included participating faculty, institutional leadership, and a limited number of participating students. Many of the key actors on the MIT side have been involved in more than one partnership (for example, current faculty participants and leadership in Portugal and Singapore were previously engaged with Cambridge–MIT), thus increasing the empiric reach of individual interviews. In addition, two online surveys have been conducted for MIT–Portugal (Pfotenhauer et al., 2013).

Moreover, we analyzed a wide range of publicly accessible and confidential documents, including annual reports, policy reports, internal strategy documents, and contracts, among others. We note that all of the authors of this study have been affiliated with MIT at some point, and some of them (SP, DR, DN) have been involved with some of the partnerships studied. This involvement afforded additional insights from a participant observation perspective. It is also part of the reason why, in light of potential conflicts of interest, we abstain from evaluative discussion of partnership success in this paper. All findings have been cross-validated through iterative interviews and triangulation of information from various sources.

4. Case studies

4.1. The Cambridge–MIT Institute (CMI)

CMI was launched in 2000 primarily as a response to prevailing government concerns about a decline in British competitiveness and global economic leadership in the wake of de-industrialization, and its alleged lagging transition into an innovation-based economy. It fits into a wider policy discourse at that time that lamented the "historically weak commercial awareness" of British universities, which stood in contrast to the otherwise "high quality of academic science" in the U.K. (DTI, 2001). At the macro-level, CMI followed a *bilateral model* with strong focus on symmetry. From the beginning, CMI was conceived, implemented, and presented as a "joint venture" between two institutions of equal standing, "bringing together two of the world's great universities to build on the complementary strengths of each" (CMI, 2005). A different configuration where a 'superior' American university would have appeared to 'help' an inferior British one was deemed politically unfeasible, which also outweighed practical considerations whether partnering with an more engineering-oriented university, such as Imperial College, would be a better fit.

Institutionally, CMI had a somewhat difficulty standing at Cambridge. CMI was predicated on the government vision that the collaboration with MIT would help transform Cambridge into an entrepreneurial, innovation-oriented university that could spearhead a broader transformation of the U.K. system. In the words of the final assessment, "CMI was a creditable idea, which sought to learn about and import to the UK the critical aspects of the MIT approach to driving innovation out of research, and with the evident and strongly positive spillover benefits to the Boston and New England economies" (Technopolis, 2012). In terms of partnership design, it was envisioned that the innovative effects of the collaboration would radiate outwards from the bilateral core into the British higher education system in a hub-and-spokes fashion through an affiliated National Competitiveness Network, whereby CMI "worked with over 100 universities and more than 1000 companies and public research enterprises" (CMI, 2008). Yet, at the institutional-political level, the very idea that the esteemed University of Cambridge was insufficient in some regards – that it might even learn from a 'young' American engineering university like MIT – was generally greeted with skepticism and at times ran into considerable institutional resistance. According to a Cambridge faculty member, the institutional implementation "was really tough. Taking off the shelf a number of things [.] and adding a few new things – that's the MIT model – is *that* much harder to do in Cambridge [with] the incrustation of 800 years [.]. So we spent a lot of time fighting with senior people in departments [.] trying to persuade them to change the way that they do things so that we could do what we were supposed to do for CMI." Due to these and other institutional constraints, CMI had to act somewhat minimally invasively and find activities that would come as an add-on that came on top of, but would not substantially interfere with, already existing activities at a "world leader in academic research" (CMI, 2008).

This ambivalent role was evident for example in education. CMI successfully introduced six Master's programs at Cambridge (see Table 1), which continued beyond the program termination in 2007. These programs were partly modeled after MIT program: for example, the Technology Policy Program at Cambridge is an explicit sister program of the Technology Policy Program at MIT. Yet, in their hybrid nature and crossing cross the disciplinary boundaries between science, engineering, management and policy and modeled after existing MIT programs, they did not have an obvious institutional home at Cambridge. They ended up being partly hosted and run through the Judge Business School, which in turn created "difficult politics of going to other departments," according to one Cambridge faculty member, particularly with regard to engineering and science. Moreover, while professional Master's programs were welcome, Cambridge considered it inappropriate to touch its PhD programs to promote innovation: Industrially oriented PhDs, as employed at MIT and suggested for the partnership, were not picked up. A Cambridge faculty member summarized the prevailing attitude in Cambridge as: "you either did science and engineering technology, [which] tended to be much more academically oriented, or you did an MBA or one of the business master's programs." In addition to new programs, CMI also implemented an undergraduate

Table 1
Overview of the MIT collaborations.

	Cambridge MIT Institute (CMI)	MIT Portugal Program (MPP)	Masdar Institute of Science and Technology (MIST)	Singapore (SMA/SMART/SUTD)
Years	2000–2007	2006–2012 (Phase 1) 2013–2017 (Phase 2)	2006–2011 (Phase 1) 2011–2016 (Phase 2)	1999–2004 (SMA), 2005–2013 (SMA2), 2007–curr. (SMART), 2010–curr. (SUTD)
Scope	175 faculty (80 UC), 350 students	340 faculty (270 Portuguese), 327 PhD students and 159 Master's students in Portugal, 300 students at MIT	91 newly hired faculty members, 490 students	SMA: 53 Sg faculty, 44 MIT faculty, 900 Alumni SMA2: 56 Sg faculty, 53 MIT faculty SMART: 122 Sg faculty, 62 MIT faculty SUTD: 120 SUTD faculty recruited, 20 MIT faculty
Funding	£68 million	€79 million	approx. $85 million	Several hundred million over multiple partnerships
Goals	· Provide a model for boosting economic impact of UK universities · Minimally invasive initiative at Cambridge, based on add-on activities	· Create distributed critical-mass research clusters in priority areas · Trigger educational and institutional change from within · Add innovation and entrepreneurship activities · Contribute to internationalization	· Provide knowledge and human capital base for transition from resource to knowledge-based economy · Solve fundamental development challenges · Seed ecosystem	· Forge strong integration into global knowledge and economic networks · Utilize foreign talent on local research problems · Transition from "efficiency" to "innovation economy" · History of "best-practice transfer"
Partnership architecture	Bilateral + hub and spokes: University of Cambridge + MIT, involve other UK universities trough Cambridge	Network: MIT + 6 Portuguese universities +20 research centers; 4 sister programs (UT Austin, Carnegie Mellon, Harvard Medical School, Fraunhofer Gesellschaft)	Institution-building: Help building first graduate research university (opened 2009)	Strategic sequencing of multiple partnerships: SMA: distance graduate education SMART: research & innovation center SUTD: new university with focus on design and undergraduate education
Education	6 Master's degrees, 2 B.Sc. degrees	4 PhD degrees, 3 Executive Master's degrees	7 Master's Programs +1 option	SMA: 5 Master's degrees with PhD option SMART: Research fellowships SUTD: 5 undergraduate programs, 4 Master's; 1 PhD
Research focus areas	· Healthcare and Biotechnology · Energy and the Environment · Tomorrow's Technology · Communication and Networks	· Sustainable Energy Systems · Transportation Systems · Bio-Engineering Systems · Engineering Design and Advanced Manufacturing	· Future Energy Systems · Water, Environment, and Health · Microsystems and Advanced Materials	· SMA: Advanced Materials for Micro- and Nano-Systems, Computation and Systems Biology, Computational Engineering, Manufacturing Systems and Technology, Chemical and Pharmaceutical Engineering · SMART: BioSystems and Micromechanics, Envir. Sensing and Modeling, Infectious Diseases, Future Urban Mobility, Low Energy Electronic Systems · SUTD: Transdisciplinary with design focus; targeted design initiatives such as Lee Kuan Yew Center for Innovative Cities, International Design Centre

exchange program, allowing Cambridge students to spend a year at MIT and vice versa.

Much in line with the reasoning of "equal standing," CMI's principal focus was thus on research – more precisely, activities that built on and highlighted existing scientific excellence at both institutions. In an attempt to obtain broad institutional support and buy-in, the program initially funded a suite of smaller research projects across a variety of domains, identified through calls for proposals, which later were consolidated into fewer but more resource-intense flagship projects. Faculty and student researchers on both sides interacted primarily through videoconferences (often on a weekly basis) as well as occasional in person-meetings, and many senior researchers spent extended research periods (including full sabbaticals) at the partner institution. Among the most successful and visible research projects was the "Silent Aircraft Initiative (SAI)," which brought together engineers from MIT, Cambridge, Rolls Royce, and Boeing as well as practitioners and regulators to explore an integrated aircraft and engine design that could reduce noise emission and fuel consumption per passenger. The Silent Aircraft Initiative was considered a prime example of CMI's vision to "create an environment where business and [Higher Education Institutions] are able to forge links with each other" (DTI, 2001). It also illustrates what has come to be known as the "Knowledge Integration Communities" approach, introduced by CMI as a systematic way to embed a research project within broader stakeholder communities from early on (Acworth, 2008). Other examples of such knowledge integration community-based multi-stakeholder projects included the low energy mixing ventilation system, drawing together energy, fluid dynamics, architecture, and engineering specialists from both universities to improve energy efficiency in buildings; and the Smart Infrastructure Network, in which MIT and Cambridge researchers developed new sensors and monitoring systems for transportation infrastructure in collaboration with large British and international firms.

Innovation was further supported through the "consideration of use" principle, in which all research projects had to stand the test of potential application and commercialization before being approved, as well as the CMI-affiliated National Competitiveness Network that brought together universities, businesses, and government organizations from around the country in a variety of conferences, forums, and workshops.[2] CMI further introduced various educational offerings, including a Management of Technology & Innovation core curriculum in the newly introduced Master's programs.

4.2. The MIT–Portugal Program (MPP)

The MIT Portugal Program (MPP) was launched in 2006 (and renewed in 2012) "to strengthen the country's knowledge base and international competitiveness through a strategic investment in people, knowledge and ideas" (MIT, 2005). In contrast to CMI, MPP was set up as a *consortium model* that linked MIT to an entire segment of the Portuguese higher education and research system (including the country's 7 leading universities, 15 national research laboratories, and industry), for several historical reasons. While Portugal matches the UK in its long university tradition (the University of Coimbra dates back to 1290), Portugal does not feature single eminent research university of the caliber of Cambridge. The country's modern higher education landscape bears the birthmarks of an authoritarian regime between 1926 and 1974, from which it inherited brought broad structural deficiencies, a strong aversion against elitism, and relatively low trust in governmental leadership. This "late awakening" (Heitor and Horta, 2011) and the inclusive social equity approach in many public initiatives in the post-dictatorship era (including a focus on equal access to higher education access and equitable distributions of research funding) long prevented the emergence of strong national research universities and national discourses about excellence formation, and made a broad institutional base was preferable for the partnership.

Given this context, the partnership priorities differ markedly from CMI. At the research level, the principal objective was the achievement of critical mass. While Portuguese universities have always had pockets of individual research excellence, institutions and fields have tended to remain below the critical threshold for global impact and visibility. Consequently, the government was looking for a mechanism to have multiple Portuguese universities join forces in collaborative research efforts, for which MIT was envisioned as catalyst. Such intra-Portuguese networking was arguably even more important links between Portuguese institutions and MIT, and it spans research (e.g., all funded projects involved multiple Portuguese universities), education (e.g., with joint degrees and student rotation between several Portuguese universities), and innovation (e.g., joint venture competitions and other national innovation events).

For the selection of research domains, MPP pursued a two-fold goal. On the one hand, it sought to support existing strong research enterprises at Portuguese universities (e.g., transportation systems or energy systems). On the other hand, the Portuguese leveraged MPP to jump start entire new areas with little or no predecessor in the country. For example, the MPP Bioengineering Systems focus area entailed a push to establish stem cell research as a new field of research in Portugal, drawing heavily upon MIT stem cell expertise to shape research and institutional directions, influence regulatory frameworks, and break ground for nationwide research networks such as "stemcellnet" that involved hospitals and industry alongside universities. All research and education areas were centered on an Engineering Systems-core (cf. Table 1), combining engineering questions with economic, management, policy, and social aspects of technology — an integrative approach pioneered at MIT's Engineering Systems Division (MIT, 2005, 2006). Moreover, most projects were designed to address specific Portuguese needs and develop research agendas around unique Portuguese research opportunities. For example, MPP's Green Islands Project in the Azores is developing an integrated test-bed in sustainable energy and transportation systems to implement and test technologies at scale in a well-bounded island ecosystem.

A second major difference to CMI was MPP's high priority on educational change, facilitated by a general sense that such an overhaul was needed in the country to close diagnosed gaps with peer countries (Pfotenhauer et al., 2013; Heitor and Bravo, 2010). MPP created 7 U.S.-style graduate programs (cf. Table 1), all of which award joint degrees from a consortium of Portuguese universities — a novelty in the Portuguese system. Some education programs were designed entirely as a sequence of two-week modules, with students rotating throughout the country for different parts of the curriculum and spending immersion periods in different labs, granting student access to the country's leading labs and fostering inter-institutional ties. This meant, among other things, breaking with traditional academic calendars. All MPP courses are offered in English and many are co-taught by Portuguese and MIT faculty, who also co-supervise all PhD students. Many courses were modeled after MIT courses, with a strong emphasis on innovation, entrepreneurship, and industry needs. MPP also included a faculty immersion ("teach the teachers") program that encourages Portuguese junior faculty to visit MIT and audit classes that could be transplanted to Portugal. More than a dozen Portuguese faculty audited and adapted MIT's popular "innovation teams" course, in which students develop business plans for emerging biotech research in cooperation with industry partners.

Generally, education was seen as a central vehicle to emphasize innovation. All MPP education tracks include mandatory components in innovation, entrepreneurship, management, and economics, and students frequently cite this as a key factor distinguishing MPP from traditional Portuguese programs. In addition, all MPP-funded research projects require industry participation. Yet, according to MIT faculty involved in both MPP and CMI, large-scale industry collaboration has

---

[2] The Network addressed, among other things, questions such as standardizing IP policy across universities and fostering entrepreneurial education.

proven more difficult in Portugal than in the UK because of a lack of technology-intensive industries. Instead, MPP has focused more strongly on university-based entrepreneurship. For example the Innovation and Entrepreneurship Initiative (IEI), founded in 2010 in co-operation between MPP and the *Higher Institute of Business and Labor Sciences*, launched Portugal's first venture competition, *Building Global Innovators*, which is which provides a variety of education and mentoring offers and also links Portugal to the Boston ecosystem.[3]

In terms of institutional change, MPP inhibits a middle ground. On the one hand, it is certainly more institutionally invasive than CMI; on the other hand, it does not engage in full-fledge institution-building, as discussed below.[4] Rather, MPP seeks to trigger cultural change from *within* existing institutional structures, as exemplified by the introduction of distinctly different educational programs, a focus on inter-institutional collaboration and critical mass formation, and the injection of innovation activities. These interventions have created some noticeable spillovers into the broader university landscape (Pfotenhauer et al., 2013). MPP also fits well into a broader national trajectory of reform, which since the late 90s has emphasized international benchmarking and peer review, competition, and participation in international networks (Heitor and Horta, 2011). It furthermore resonates with broader policy mandates to be proactive in "strategic higher education planning," build excellence, and better integrate universities into the country's "economic, social and regional life" (OECD, 2007), and is part of the national response to Europe-wide reform pressures around innovation and graduate education (EC, 2000; EU, 1999; Keeling, 2006). Notably, MPP was also seen as an explicit vehicle to attract international students to Portugal[5] – a problem that Cambridge and the UK did not have – designed to help Portugal undertake a shift from being traditionally a "sending" country of graduate students who pursue studies abroad, to a "receiving country" that can attract high-skilled students from around the world (Pfotenhauer et al., 2013).

4.3. The Masdar Institute of Science and Technology (MI)

To understand MIT's role in the creation of the Masdar Institute (MI) – the first graduate-level research university in the United Arab Emirates (UAE) – one must begin by looking at the much larger national development project of which it is part: Masdar, also known as the Abu Dhabi Future Energy Company. One of several high-profile science and innovation initiatives currently underway on the Arab Peninsula (KPMG, 2012), Masdar was launched in 2006 as the spearhead of Abu Dhabi's transition strategy from a prosperous oil and gas-based economy into a diversified, knowledge-based economy (Reiche, 2010). Abu Dhabi's oil-fueled breakneck pace of development since the 1960s has created an enormous per capita wealth; yet, it has also created considerable economic, social, and environmental sustainability challenges. The country is highly vulnerable to the boom-and-bust cycles of the oil and gas market, produces one of the highest carbon footprints per capita in the world, has an agricultural sector where most food is imported – and water desalinated – on a daily basis, and its labor market is utterly dependent on foreigners and foreign companies. In response to these challenges, Masdar – Arabic for "source" – embodies Abu Dhabi's vision for a future with smaller dependence on hydrocarbon exports, an educated populace capable sustaining a modern economy, and greater environmental responsibility, all of which the country hopes to achieve through an "evolution as a leader in global energy — from a provider of fossil fuels to a developer of alternative energy and clean technologies" (MIST, 2011).

Masdar Institute sits at the heart of this vision. It is at once envisaged to produce and accumulate cutting-edge scientific knowledge around advanced energy and sustainability technologies, train local talent in engineering, and spawn a local innovation economy. Masdar Institute is surrounded by *Masdar City*, an urban development project intended to serve as a test-bed for innovative technologies emanating from MI, where they can be embedded in urban design and tested under the real-world conditions of a desert city as a living laboratory. The city is imagined as a place fully reliant on renewable energy sources, with a low carbon and waste footprint, car-free, home to some 50,000 high-skilled scientists, engineers, and entrepreneurs as well as hundreds of firms specialized on energy and sustainability energy technology, manufacturing, and investment (Hopwood, 2010; Nader, 2009). Masdar Institute and City are complemented by *Masdar Clean Energy*, a major developer of large-scale sustainable energy projects in the region and an intended major customer of energy technology emanating from MI (Masdar, 2012), and *Masdar Capital*, a globally active (through regionally committed) venture fund focused on technology commercialization primarily in clean technologies.

What existed in 2006, then, was an extremely ambitious vision for Masdar as the key to the UAE's social, economic, and environmental future. What did not exist, however, were any R&D infrastructure, scientific or technological expertise, or human resource base to produce the envisioned technologies, jumps-start a high-tech economy, and enable the leap towards sustainable society. As an MIT faculty laconically noted: "Masdar Institute was meant to solve that" (Pfotenhauer, forthcoming).

The main objective of the MIT–Masdar partnership could thus be best characterized as an *institution-building model*. Unlike CMI and MPP, MIT did not have an existing institution to interact with in Abu Dhabi, but was brought in to develop the first research university of the country in the first place. This implied solving a number of start-up challenges for the Masdar initiative: For example, how can world-class faculty and students be recruited to a place lacking a physical presence and reputation? How can research activities be defined before faculty are hired? How can a novel institution without research operations be linked to cutting-edge science around advanced energy and sustainability? And what types of labs and equipment will this research need?

The MIT partnership was seen as instrumental in addressing these challenges (ibid.). To begin with, MIT played a key role in developing the original research and education portfolio. A group of senior MIT faculty under the leadership of the Technology & Development Program outlined, and later concretely defined, MI's research agenda around three broad themes: Water, Environment and Health; Future Energy Systems; and Microsystems and Advanced Materials. The process involved specifically MIT faculty with expertise in energy and sustainability research, many of which were gathered at the MIT Energy Initiative, and incentivized them to work on Masdar-related issues by funding collaborative projects — faculty first through faculty-to-faculty collaborations with newly hired MI faculty, and later on through group-to-group flagship projects. Right from the start, Masdar thus had a strong and credible research partner that helped jumpstart activities and tie MI into existing knowledge networks.

Second, at the individual level, the MIT partnership was the key to attracting faculty, students, and administrative leadership. All initial faculty and administrative positions were advertised and filled under the auspice of MIT, with MIT faculty reaching out to known potential candidates from their own networks and screening applications. New hires were offered the opportunity to spend their first year at MIT while their laboratories were being set up at Masdar Institute. During this visit, faculty could take advantage of a research grant to launch collaborative projects with MIT mentors that could later be continued for a second year at Masdar, thus stimulating strong research ties from the start. Time at MIT also afforded a chance for junior faculty to audit

---

[3] Currently in its fourth edition, the first three edition of the competition attracted of 287 participants from 22 countries, raising a total of $17 M and leading to 19 companies and 150+ new jobs.

[4] In fact, attempts to institutionalize MPP in the form of a permanent national graduate school have failed repeatedly in the past.

[5] The ratio of international students in MPP has been consistently higher than one third, which is about a factor of four higher than in comparable programs across the country (Pfotenhauer et al., 2013).

classes develop teaching curricula, similar to MPP's “teach-the-teachers” model. These opportunities were key factors, as MI faculty attest, in their decision to join the young body of faculty, along with attractive starting packages, generous salaries and benefits. Today, MI has 91 faculty in about two dozen labs and research groups. MIT was also key in recruiting students to the new institute: Aided by the MIT brand and generous packages that included full tuition, a monthly stipend, housing, computers, and airfares, MI's first cohort in 2009 included 89 of 1200 applicants with an extremely competitive average quantitative GRE score of 765. Today, 491 students from 66 countries are studying at Masdar, including close to 50% females. Finally, MIT supported the recruitment of administrative leadership. Initially, several key administrative positions were temporarily filled with senior MIT faculty or other senior managers with previous ties to MIT, including the Presidency, the Office of Institute Initiatives, or the Office of Sponsored Programs.

Third, MI's educational programs were developed by MIT faculty, modeled closely after MIT's own course offerings in energy and sustainability-related subjects. MI offers 9 Master's degree programs and, as of 2013, also an interdisciplinary doctoral program, all designed in collaboration with MIT. While all education tracks are “classical” engineering degrees (e.g. Chemical Engineering, Computer and Information Science, Mechanical Engineering, Water Environmental Engineering), all of them are customized around the theme of energy and sustainability theme. For example, the learning goals of the Chemical Engineering program include “an ability to identify and address current and future chemical engineering problems related to energy sources, generation, conversion and green chemical production within a broader framework of sustainable development,” and “an ability to apply a multi-disciplinary approach to conceive, plan, design, and implement solutions to chemical engineering problems in the field of energy and sustainability.”

In terms of innovation, the partnership served the dual function of building the “front-end” of an envisioned Masdar innovation pipeline on the one hand, and attracting industry and R&D partners to Abu Dhabi on the other. Again, the MIT brand was critical: By the time this article goes to press, sponsored research partnerships and local research operations now exist with Boeing, Honeywell UOP, Etihad, the Abu Dhabi Company for Onshore Oil Operations (ADCO), and Siemens, among others.

Institutionally, MIT helped guide and set up the physical and digital infrastructure at MI, the Institute's governance structure (from by-laws to administration to IP policy), and its operational routines. For example, MI broke new ground in Abu Dhabi with certain infrastructural developments, including the first clean room in the country, and was also the first to address research related operational challenges from supply chain and customs issues for equipment and lab supplies, to high-tech construction in the middle of the desert, to downstream regulatory challenges such as hazardous waste treatment. In short, MI was Abu Dhabi's first attempt at learning how to run a full-fledged university-based research enterprise in the Emirate. This helped reveal broader systems challenges, such as the absence of certain types of regulatory frameworks or a national NSF-type funding body that would allow researchers and institutions to compete for grants (as opposed to governmental block-grant funding or industry-sponsored research).

4.4. Singapore–MIT

The history between MIT and Singapore spans an entire suite of partnerships, with three major engagements since the late 1990s. These partnerships tackle a range of different objectives, representative of broader policy developments in the city-state, which we shall outline in the following alongside the partnership mechanics.

The Singapore–MIT Alliance (SMA), first, was launched in 1999 mainly as an educational collaboration with the National University of Singapore and Nanyang Technological University, and was renewed and expanded in 2005. SMA offered graduate degrees in five areas (cf. Table 1) through distance education methods centered on video lectures, co-advising of students by faculty from both sides, student mobility periods to MIT, and a dual-degree option. SMA also supported some research in focus areas aligned with these education programs. Particularly with the second 5-year phase of the program (SMA-2), the program began building up a stronger research component around certain flagship projects. The second phase also increased the emphasis on collaborative teaching and research, adding stronger residency requirements for MIT faculty in Singapore. In terms of focus areas, SMA was originally largely centered on “classical” engineering domains, including Advanced Materials for Micro- and Nano-Systems, Computational Engineering, Manufacturing Systems and Technology, Chemical and Pharmaceutical Engineering, and Computation and Systems Biology, with SMA-2 moving more heavily into the biosciences. SMA thus reflects the country's long-standing tradition in education at a time when the country was still mostly focused on classical engineering and “efficiency infrastructure” (Tan and Phang, 2005).

The second initiative – the Singapore–MIT Alliance for Research and Technology (SMART), launched in 2007 – put research front and center. The first of an array of 10 internationally operated research centers in the new Singapore Campus for Research Excellence and Technological Enterprise (CREATE), SMART is focused primarily on hosting MIT faculty and their research for extended periods of time, encouraging them to work with local collaborators on research questions relevant to the city-state. MIT faculty participating in SMART spend at least 1 year out of a 5-year engagement (and 6 consecutive months) in Singapore in exchange for considerable resources (funding, laboratories, and students). Where SMA research was originally focused on manufacturing and computer science, three of SMART's five research thrusts are in the life sciences — coinciding with a broader shift in research and development priorities in Singapore (Chuan Poh, 2010) and marking Singapore's changing self-image from “intelligent island to biopolis” (Clancey, 2012). SMART does not include education programs, but it offers post-doctoral fellowships. It also draws heavily upon graduate students and former research clusters from SMA.[6] In addition, SMART established its own Innovation Center, modeled after MIT's Deshpande Center, which can be seen as a response to the self-diagnosis of weak national performance in technology licensing, technology transfer, and technological entrepreneurship (Wong, 1999). The aggressive import of the world's leading researchers also follows the government's insight that not all talent and research can be home-grown in a state of the size of Singapore.

A third partnership was launched in 2010, when Singapore and MIT agreed to jointly establish the new Singapore University of Technology and Design (SUTD). SUTD posed similar institution-building and start-up challenges as Masdar, although arguably less crass given Singapore's high level of technoscientific and infrastructural development. Compared to the previous two programs, SUTD added a dedicated undergraduate education component to the portfolio with a strong emphasis on creativity and design thinking. SUTD reflects the growing belief among Singapore's leadership that a key factor hampering the transition “from efficiency-driven growth to innovation-driven growth” might be a lack of creativity (Remaking Singapore Committee, 2003; Tan and Phang, 2005). SUTD is also unusual in that it operates outside the existing, strong university system and, in effect, provides an explicit counter-model to Singapore's large public universities with their prevalent technical education.

Over the course of the three partnerships, MIT–Singapore followed what could be called a *functional expansion model*. Fundamentally, the interactions cover the same four main activities as the three other collaborations — education, research, innovation, and institution-building. Yet, the striking difference is their addressing through

---

[6] As an example, the SMA Computation and Systems Biology track merged into SMART BioSyM research group.

successive, separate partnerships with limited functional overlap and interaction between them: Master's level and doctoral education through SMA; semi-institutionalized research and innovation through SMART; and a full-fledged research university centered on undergraduate education and design thinking in SUTD. In contrast, the other partnerships addressed the various objectives through comprehensive collaborative arrangements. This gradual roll-out and functional expansion is consistent with the technocratic and systemically integrated policy style known from Singapore's long-term governing party, and with previous examples of “favorable sequencing” (Huff, 1995).

The suite of MIT partnerships further resonates with two persistent policy themes in Singapore: outward orientation and the import of global “best practices.” From its 1965 independence, the nation aimed to maintain its position as a critical gateway for trade in Southeast Asia and to build an economic model around global commerce. Singapore's rapid industrialization, spurred by foreign direct investment, ran into a glass ceiling in the mid-1970s due to the limits imposed by a lack of an indigenous science and technology base and low levels of education. As a result, the government decided “to phase out its labor-intensive industry and focus on skills-intensive, high–value-added, technology-intensive industries such as electronics manufacturing, data storage, and petrochemicals” (Chuan Poh, 2010). This next phase of Singapore's progress – economic, technological, and in labor skills – was again largely driven by multinational companies, not indigenous firms as elsewhere in the region (Wong, 1995). Along the way, Singapore began importing institutional models from around the globe. Former president Lee Kuan Yew openly admitted the aggressive and eclectic borrowing of success recipes from Hong Kong, Switzerland, Israel, the US, among others (Yew, 1990), and Singapore's “technology corridor” was inspired by Massachusetts' Route 128 (Ebner, 2004). Singapore began attracting foreign academic institutions to open local operations, including MIT, NYU, Yale, Duke, among others. Politically, this positioning as a “global city” was seen as a matter of necessity for a country with considerable space constraints, few natural resources, and a self-image of a nation under permanent security threat (Choon, 2004).

4.5. A word on MIT's goals

The above case studies illustrate the socio-political context in which the four partnerships were conceived and implemented, and the policy goals governments pursued through them. Before continuing with our architectural analysis, we shall briefly contrast with MIT's rationales for engaging in these partnerships. In a nutshell, our interviews show that MIT is primarily interested in these partnerships for four reasons. First, by way of international collaboration, MIT researchers may obtain privileged access to research sites and questions that may otherwise not be easily available to them. For example, research on solar cell deployment or test-bed environments for integrated energy-transportation systems are better suited to the sites in Abu Dhabi or the Portuguese Azores Islands, respectively, than Massachusetts. Second, participating in a high-profile collaboration supported by national or regional government grants MIT preferential access to some of the best students and researchers of a country. Third, these large-scale collaborations frequently have a quasi-experimental character. MIT faculty, in collaborations with their partners, is frequently encouraged to try out new and hybrid organizational forms or educational approaches that would be hard to implement at MIT. For example, the SUTD undergraduate curriculum was based on an MIT-internal review of its own curriculum, but was never implemented at home. In fact, some of the MIT faculty engaged in SUTD precisely because it offered an opportunity to implement new ways of teaching engineering differently in a new institution. Fourth, the partnerships allow MIT to raise additional research funds of substantial magnitude, ranging from tens to hundreds of millions over several years. All four partnerships met these criteria from the perspective of MIT participants and leadership. The authors found similar reasoning about expected benefits for eminent research university engaging in comparable partnerships, for example at Singapore's SMART center or Portugal's other international engagements, to which we had access through formal interviews or informal conversations. For reasons of space constraints, we must abstain from a more in-depth discussion of MIT's international strategy here.

5. Systems architecture analysis (the macro-view): models, goals, priorities

The initiatives discussed above represent four distinct cases of CISTIPs where complex international university partnerships have been utilized by different countries to address distinct capacity-building goals. The UK sought a mechanism to enhance the “rear end” of the innovation pipeline at its leading university – Cambridge – through add-on activities to spearhead a broader systemic transformation and strengthen economic competitiveness. Portugal sought to combine the strength of its six leading universities in critical focus areas and incentivize educational change around innovation and entrepreneurship from within exiting institutions. Abu Dhabi sought to realize a national developmental vision by establishing the first graduate research university of the country and hence the research and human resource “front end” of a knowledge-based, low-carbon economy. Singapore used different partnerships as targeted interventions to support evolving policy priorities, first emphasizing technical graduate education, then the imported research expertise and innovation models, then creativity and design.

Comparative analysis further reveals that the different partnership goals were realized through distinct macro-architectures that mobilized distinct activities. CMI embodied a *bilateral* “institute” model between two universities of equal standing. As a result of a politically mandated symmetry, the partnership focused primarily on collaborative faculty research based on existing strengths at both institutions, and added

Table 2
Different partnership priorities with respect to four architectural views (education, research, innovation & entrepreneurship, and institution-building/institutional change).
Dark red = high priority, medium red = medium priority, light red = low priority.

	Education	Research	Innovation & entrepreneurship	Institution–building/ Institutional Change
Cambridge MIT Institute (CMI)	▒	▓	▓	░
MIT Portugal Program (MPP)	▓	▓	▓	▒
Masdar Institute of S&T (MIST)	▓	▒	▒	▓
Singapore–SMA	▓	▒	▒	░
Singapore–SMART	░	▓	▓	▒
Singapore–SUTD	▓	░	▓	▓

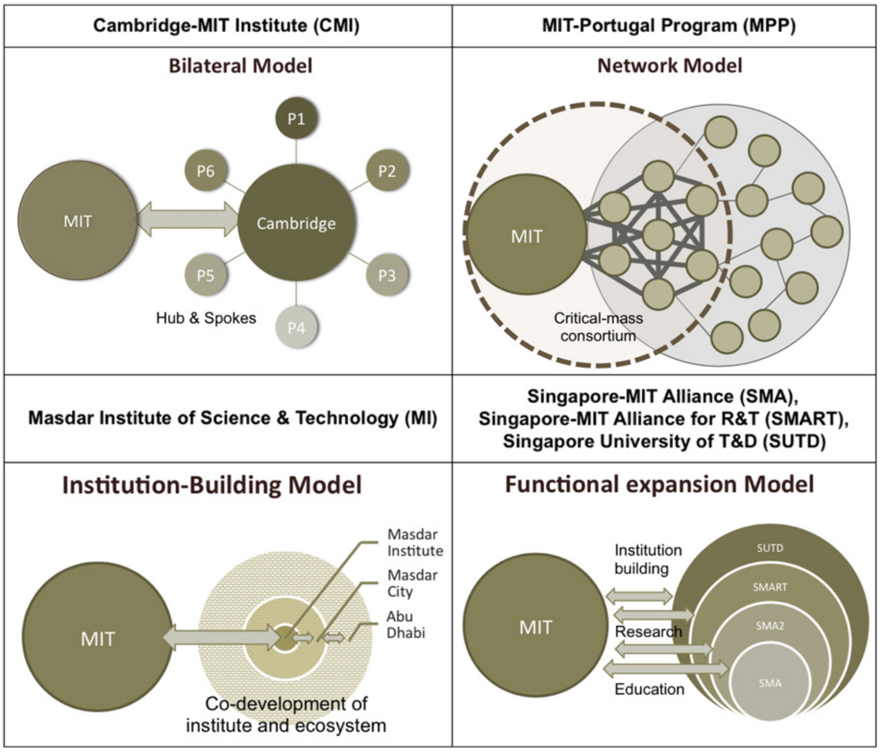


Fig. 1. Different collaboration models identified by systems architecture analysis.

innovation activities like “knowledge integration communities” on top of existing structures. CMI was institutionally only minimally invasive and achieved limited educational change. Other universities in the UK were expected to benefit through interactions with Cambridge, not interactions with MIT directly. MPP, second, was based on a *network* model that tied together multiple Portuguese institutions to form nation-wide, critical-mass research and education consortia, targeting both existing and new scientific domains. Its education programs broke radically with existing Portuguese traditions and sought to stimulate institutional change from within. Due to the structure of the Portuguese economy, MPP emphasized entrepreneurship over large-scale industry partnerships. Third, Masdar Institute was primarily an *institution-building* partnership intended to develop the country's human resource base and solve start-up challenges for a socioeconomic transition. The partnership jump-started national research through collaboration with MIT, and focused on recruitment of talent to the country. MIT faculty developed blueprints for educational programs and institutional routines, and shaped the Institute's research agenda, and helped set the stage for a fledgling innovation ecosystem. MIT–Singapore spans an entire suite of partnerships, which were rolled out in a *functional expansion* model. SMA focused primarily on education with associated research activities, while employing mostly virtual infrastructures. SMART emphasized research by creating local labs for MIT faculty and an Innovation Centre, encouraging local research collaboration from within that flexible institutional base. SMART did not include an education component. SUTD fills an important perceived gap in the Singapore higher education system, focusing undergraduate education and research on creativity and design thinking and breaking largely with Singapore's education tradition. All three Singapore partnerships built off one another, if only to a limited extend. We summarize the different priorities for partnership activities in Table 2. The different macro-architectures are depicted in Fig. 1.

We observe that this accommodation of utterly different capacity-building goals as well as socio-political and economic contexts speaks

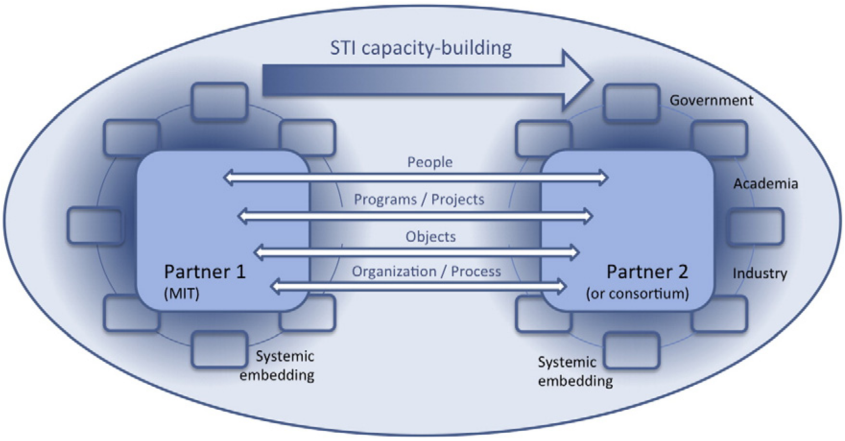


Fig. 2. Levels of interaction (mobility) for capacity-building through international partnerships.

to the flexibility of CISTIPs as a policy instrument. This flexibility is underscored by the fact that all four partnerships have been realized with the help of one and the same partner – MIT – yet through utterly different architectures. We further note that the heterogeneity of our case studies contradicts simplistic notions of "best practice transfer" or an "MIT model," which would assume that one pre-defined original model exists and that the partner is a mere recipient rather than an active agent in the construction of the initiative.

5.1. Developing a typology of partnership activities: views and classes

Our analysis reveals that despite the stark differences in goals, macro-architectures, and context, all partnership activities can be subsumed under four 'architectural views' that cut across all cases: (*1*) *education*, (*2*) *research*, (*3*) *innovation*, (*4*) *institution building*/*institutional change* (cf. section 2 for an elaboration on views). We consider this an important finding that that such a small set of views can gainfully employed to capture the broad range of CISTIPs activities in universities and beyond. Regarding the education view, first, we find that all four CISTIPs had substantial activities in terms of people mobility (i.e. students, faculty and administrators traveling between the partners) as well as educational recruitment (for faculty, students, administrators, or all of the above), in which MIT played a crucial role. Education activities in most cases further included the creation of degree programs with the help of MIT, as well as immersion programs at MIT. Frequently, course syllabi were transferred and educational infrastructure being set up. The partnership furthermore had an influence on organizational practices regarding education, including course instruction, academic calendars, and networks. In terms of research, second, all partnerships equally focused on mobility and recruitment. The partnerships further helped define – or were formed around – scientific priority areas of the partner country; they funded research projects through various means; and in some case facilitated the acquisition of equipment or the construction of lab facilities. They also usually connected program research activities to local or national partners in a variety of configurations, for example in the CMI National Competitiveness Network or SMART's local collaboration requirements. Third, innovation activities in all partnerships included a mobility component whereby faculty or program managers from MIT spent time at the partner institution in a mentoring function and, in most cases, faculty and administrators from the partner spent time at MIT with the goal of an immersive experience. Innovation was further facilitated through dedicated education and support programs, as well as auxiliary activities such as networks, workshops, or business-plan competitions. All partnerships further grappled with questions of intellectual property in one way or another, and in some cases adopted MIT's IP and tech-transfer models to local institutions. Across the board, MIT practice and organization around innovation and industry linkages were at the center of attention for all partnerships, at times to the extent that partners sought to copy complete institutional models (e.g. the Deshpande Center in SMART). Finally, for institution-building, all MIT partnerships were used to develop institutional strategies or reinforce existing ones in the partner country. MIT faculty was frequently approached for governance roles or participation in advisory bodies, and typically actively participated in leadership recruitment. In some of the partnerships, the partnership furthermore helped bring underway new national policies, such as the stemcell frameworks in Portugal or human subject research procedures in Abu Dhabi.

In addition to the transversal cut provided by 'architectural views,' we find that CISTIP activities can be productively grouped according to their *level* of interaction. Again, we find four levels particularly useful to capture all major actives: components related to *people* (e.g., mobility, recruitment,), to *programs*/*projects* (e.g., educational programs, research projects), to *objects* (e.g., course curricula, IP policies), and to *organizations*/*processes* (e.g., institutional models, hiring practices, evaluation systems). These four levels, or 'classes of forms,' provide a different cut through the case study material than the architectural views to systematize partnership activities and achieve comparison between different partnerships (cf. Fig. 2). The classes of forms help organize the form–function analysis into a manageable framework and provide a typology to compare the diverse components of each partnership. We can think about them as *levels of interaction* at which one partner collaborates with, or provides a service for, the other partner. Our classification of activities is consistent with Knight's (2007) analysis of different "levels of mobility" in cross-border higher education, which provides a typology of what crosses borders.

We conclude that despite their considerable differences in goals, activities, context, and emerging macro-architectures, a few basic architectural organizing principles can be found to guide the analysis and design of CISTIPs. These include four *architectural views* (education, research, innovation & entrepreneurship, institution-building) and *levels of interaction between the partners* (people, programs/projects, objects, organization/process). We will return to this typology in the subsequent design section.

6. System architecture and design (the micro-view): designing complex university partnerships

This final section is geared towards a *design perspective* on complex international university partnerships (and CISTIPs more generally). It is motivated by the empirical observation that, as of yet, CISTIPs remain largely practitioner-driven: that is, they are initiated, designed, and managed by governments and institutional leaders, often with few conceptual frameworks and methodological tools at hand. Our research finds that CISTIPs design tends to follow political reasoning, opportunities, and constraints, and is informed primarily by individual experience or knowledge about similar activities. It is typically *not* based a systematic overview of design options and an attempt to relate these options to certain functions or objectives.[7] For example, CMI from the start embraced a model of "institutions of equal standing," resulting in a bilateral architecture with limited opportunity for institutional change, the foreclosure of certain educational or institutional options, the assembly of participants into this pre-determined framework, a hence a pre-selection of research activities that could be accommodated in Cambridge. It also included an undergraduate student exchange that, although successful and highly visible, did not relate to the research priorities or industrial linkages in any direct way. A (hypothetical) alternative scenario could have been to start with pre-existing faculty ties between MIT and the UK and tailor an institutional framework around it; to customize student mobility around research priorities; and to focus more overtly on mechanisms that support the very institutional change that the government was hoping for. Similar arguments could be made for the other partnerships. We thus argue that it is possible for CISTIPs to bring more value to stakeholders when based on a conscious analysis and design process to select forms (i.e. people, programs/projects, objects, and processes/organizations) and functions that fit their objectives and contextual constraints.

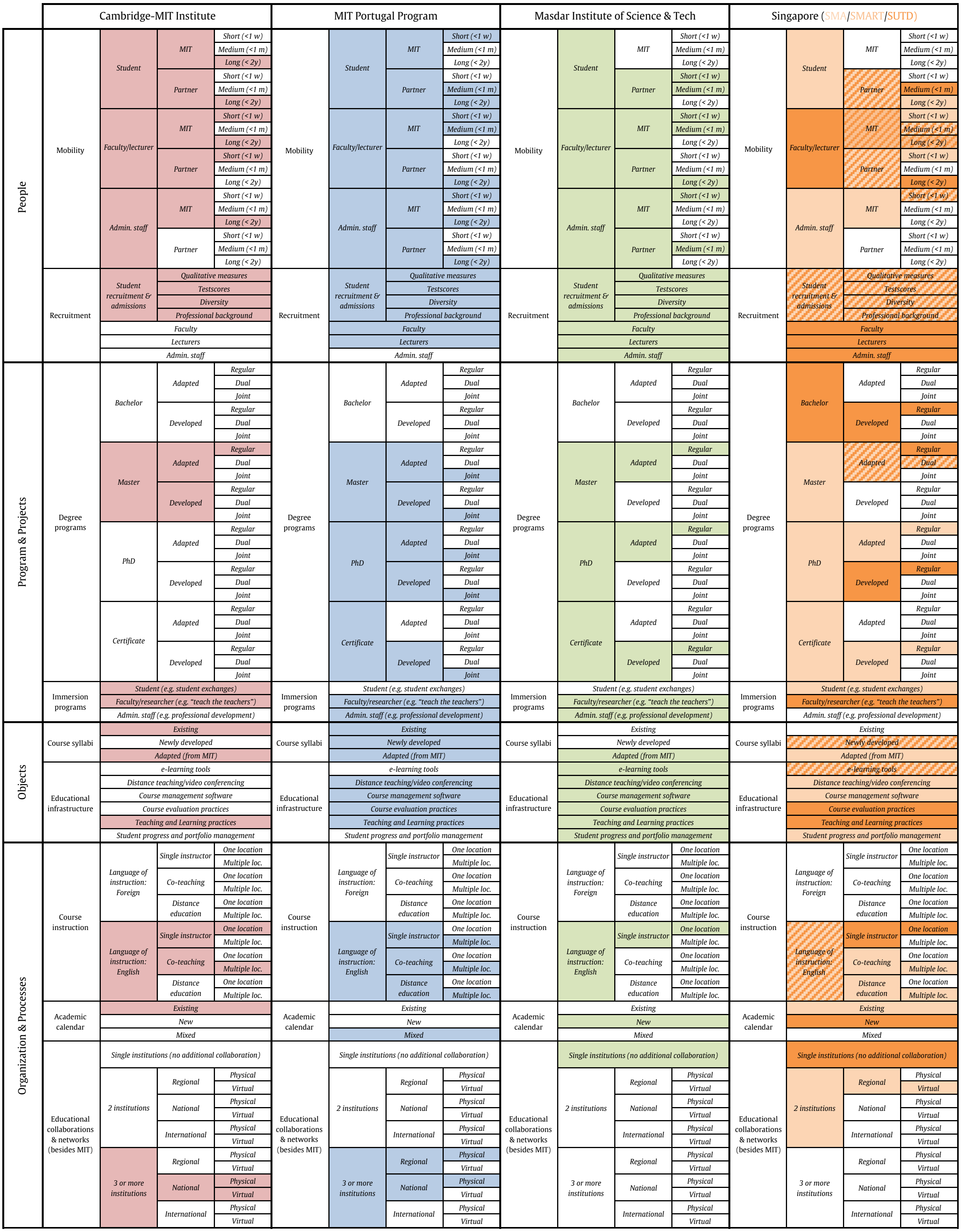
Second and related, without exception, all partnerships underwent at least one major restructuring or adjustment, which usually involved abandonment of certain mechanisms and the introduction of new ones, and frequently leadership change. For example, in CMI, the broad funding of smaller research projects across various domains early in the partnership was later replaced by calls for larger, more comprehensive flagship projects. Similarly, MPP moved from a closed (internal) call process to an open (Portugal-wide) call for proposals in year three, and increased the length of stay for visiting students at MIT. From a policy perspective, it thus is desirable to obtain a holistic

---

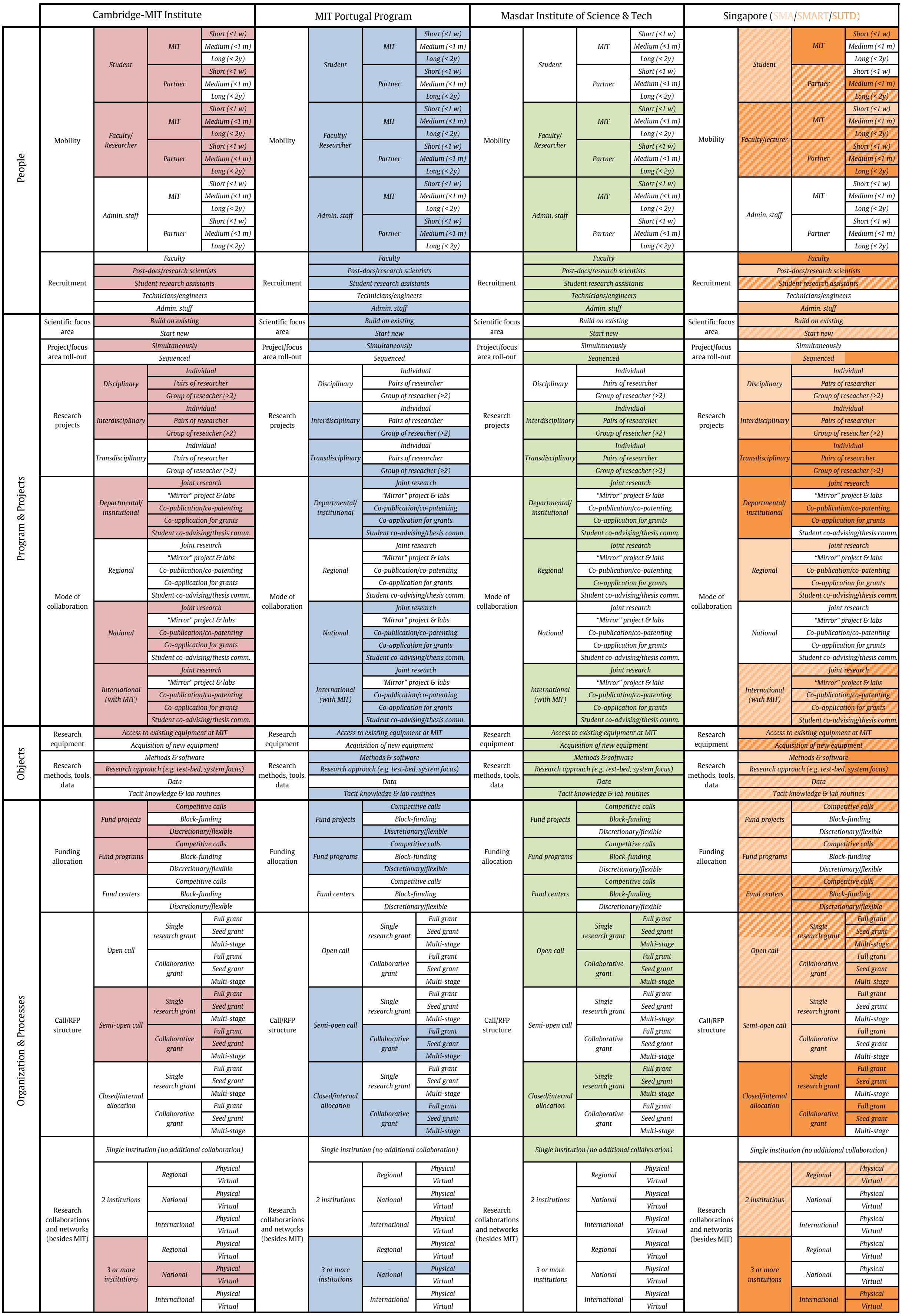
[7] This observation extends beyond our four case studies and has been confirmed through conversations with stakeholders in other countries or at other institutions, and even in other sectors (Wood and Weigel, 2014).

Table 3

a–d. Partnership micro-architectures in comparison, disaggregated by architectural view (education, research, innovation & entrepreneurship, institution-building) and level of interaction (people, programs/projects, objects, organization/process).



					Cambridge-MIT Institute	MIT Portugal Program	Masdar Institute of Science & Tech	Singapore (SMA/SMART/SUTD)
People	Mobility	Student	MIT	Short (<1 w)		■		
				Medium (<1 m)				
				Long (< 2y)	■			
			Partner	Short (<1 w)			■	
				Medium (<1 m)		■	■	▓
				Long (< 2y)	■	■		░
		Faculty/lecturer	MIT	Short (<1 w)	■	■	■	░
				Medium (<1 m)		■	■	▨
				Long (< 2y)	■			▨
			Partner	Short (<1 w)	■			░
				Medium (<1 m)				
				Long (< 2y)		■	■	▓
		Admin. staff	MIT	Short (<1 w)		■	■	▨
				Medium (<1 m)				
				Long (< 2y)	■	■		
			Partner	Short (<1 w)				
				Medium (<1 m)			■	
				Long (< 2y)		■		
	Recruitment	Student recruitment & admissions	Qualitative measures		■	■	■	▨
			Testscores		■	■	■	▨
			Diversity		■	■	■	▨
			Professional background		■	■	■	▨
		Faculty				■	■	▓
		Lecturers				■	■	▓
		Admin. staff					■	▓
Program & Projects	Degree programs	Bachelor	Adapted	Regular				
				Dual				
				Joint				
			Developed	Regular				▓
				Dual				
				Joint				
		Master	Adapted	Regular	■		■	▓
				Dual				▨
				Joint		■		
			Developed	Regular				
				Dual				
				Joint		■		
		PhD	Adapted	Regular			■	░
				Dual				
				Joint		■		
			Developed	Regular				▓
				Dual				
				Joint		■		
		Certificate	Adapted	Regular				
				Dual				
				Joint				
			Developed	Regular			■	░
				Dual				
				Joint		■		
	Immersion programs	Student (e.g. student exchanges)			■			░
		Faculty/researcher (e.g. "teach the teachers")			■	■	■	▓
		Admin. staff (e.g. professional development)				■	■	
Objects	Course syllabi	Existing			■	■		
		Newly developed				■		▨
		Adapted (from MIT)			■	■	■	░
	Educational infrastructure	e-learning tools					■	▨
		Distance teaching/video conferencing				■	■	░
		Course management software				■	■	░
		Course evaluation practices				■	■	▓
		Teaching and Learning practices			■	■	■	▓
		Student progress and portfolio management					■	░
Organization & Processes	Course instruction	Language of instruction: Foreign	Single instructor	One location				
				Multiple loc.				
			Co-teaching	One location				
				Multiple loc.				
			Distance education	One location				
				Multiple loc.				
		Language of instruction: English	Single instructor	One location	■		■	▓
				Multiple loc.		■		
			Co-teaching	One location				
				Multiple loc.	■	■		░
			Distance education	One location				
				Multiple loc.		■		░
	Academic calendar	Existing			■			░
		New					■	▓
		Mixed				■		
	Educational collaborations & networks (besides MIT)	Single institutions (no additional collaboration)					■	▓
		2 institutions	Regional	Physical				
				Virtual				░
			National	Physical				
				Virtual				
			International	Physical				
				Virtual				
		3 or more institutions	Regional	Physical		■		
				Virtual				
			National	Physical	■	■		
				Virtual	■			
			International	Physical				
				Virtual				



Cambridge-MIT Institute | MIT Portugal Program | Masdar Institute of Science & Tech | Singapore (SMA/SMART/SUTD)

People	Mobility	Student	MIT	Short (<1 w)
				Medium (<1 m)
				Long (< 2y)
			Partner	Short (<1 w)
				Medium (<1 m)
				Long (< 2y)
		Faculty/ Researcher	MIT	Short (<1 w)
				Medium (<1 m)
				Long (< 2y)
			Partner	Short (<1 w)
				Medium (<1 m)
				Long (< 2y)
		Admin. staff	MIT	Short (<1 w)
				Medium (<1 m)
				Long (< 2y)
			Partner	Short (<1 w)
				Medium (<1 m)
				Long (< 2y)
	Recruitment	Faculty		
		Post-docs/research scientists		
		Student research assistants		
		Technicians/engineers		
		Admin. staff		
Program & Projects	Scientific focus area	Build on existing		
		Start new		
	Project/focus area roll-out	Simultaneously		
		Sequenced		
	Research projects	Disciplinary	Individual	
			Pairs of researcher	
			Group of researcher (>2)	
		Interdisciplinary	Individual	
			Pairs of researcher	
			Group of researcher (>2)	
		Transdisciplinary	Individual	
			Pairs of researcher	
			Group of researcher (>2)	
	Mode of collaboration	Departmental/ institutional	Joint research	
			"Mirror" project & labs	
			Co-publication/co-patenting	
			Co-application for grants	
			Student co-advising/thesis comm.	
		Regional	Joint research	
			"Mirror" project & labs	
			Co-publication/co-patenting	
			Co-application for grants	
			Student co-advising/thesis comm.	
		National	Joint research	
			"Mirror" project & labs	
			Co-publication/co-patenting	
			Co-application for grants	
			Student co-advising/thesis comm.	
		International (with MIT)	Joint research	
			"Mirror" project & labs	
			Co-publication/co-patenting	
			Co-application for grants	
			Student co-advising/thesis comm.	
Objects	Research equipment	Access to existing equipment at MIT		
		Acquisition of new equipment		
	Research methods, tools, data	Methods & software		
		Research approach (e.g. test-bed, system focus)		
		Data		
		Tacit knowledge & lab routines		
Organization & Processes	Funding allocation	Fund projects	Competitive calls	
			Block-funding	
			Discretionary/flexible	
		Fund programs	Competitive calls	
			Block-funding	
			Discretionary/flexible	
		Fund centers	Competitive calls	
			Block-funding	
			Discretionary/flexible	
	Call/RFP structure	Open call	Single research grant	Full grant
				Seed grant
				Multi-stage
			Collaborative grant	Full grant
				Seed grant
				Multi-stage
		Semi-open call	Single research grant	Full grant
				Seed grant
				Multi-stage
			Collaborative grant	Full grant
				Seed grant
				Multi-stage
		Closed/internal allocation	Single research grant	Full grant
				Seed grant
				Multi-stage
			Collaborative grant	Full grant
				Seed grant
				Multi-stage
	Research collaborations and networks (besides MIT)	Single institution (no additional collaboration)		
		2 institutions	Regional	Physical
				Virtual
			National	Physical
				Virtual
			International	Physical
				Virtual
		3 or more institutions	Regional	Physical
				Virtual
			National	Physical
				Virtual
			International	Physical
				Virtual

					Cambridge-MIT Institute	MIT Portugal Program	Masdar Institute of Science & Tech	Singapore (SMA/SMART/SUTD)
People	Mobility	Student	MIT	Short (<1 w)				
				Medium (<1 m)				
				Long (< 2y)				
			Partner	Short (<1 w)		🟦		
				Medium (<1 m)				
				Long (< 2y)				
		Faculty/ Lecturer/ Researcher Scientist	MIT	Short (<1 w)	🟥	🟦	🟩	🟠
				Medium (<1 m)	🟥			🟠
				Long (< 2y)				🟠
			Partner	Short (<1 w)		🟦		
				Medium (<1 m)			🟩	
				Long (< 2y)			🟩	🟧
		Admin. staff	MIT	Short (<1 w)	🟥	🟦	🟩	▨
				Medium (<1 m)	🟥			▨
				Long (< 2y)				🟠
			Partner	Short (<1 w)		🟦	🟩	🟧
				Medium (<1 m)		🟦		🟧
				Long (< 2y)		🟦		
	I & E personnel recruitment			Admin. staff			🟩	▨
				Innovation researchers		🟦	🟩	▨
				External mentors		🟦		
Program & Projects	I & E education			Academic	🟥	🟦	🟩	🟧
				Immersive (e.g. internships)	🟥	🟦	🟩	🟧
				Extracurricular		🟦		▨
	I & E support & training			Student	🟥	🟦	🟩	▨
				Faculty/Researcher	🟥	🟦	🟩	▨
				Admin. staff	🟥	🟦	🟩	🟠
	Entrepreneurial mentoring	At MIT		By entrepreneurs		🟦		
				By I & E professional				
				By faculty		🟦		
				By alumni				
		At foreign partner		By entrepreneurs		🟦		🟠
				By I & E professional		🟦		▨
				By faculty		🟦	🟩	▨
				By alumni				
	I & E auxiliary activities			I & E research		🟦		🟠
				Workshops	🟥	🟦	🟩	🟠
				Industry affiliates/liaison program (possibly tiered)	🟥	🟦	🟩	🟠
Objects	Intellectual property rules			Institutional		🟦	🟩	▨
				Regional/inter-institutional		🟦		
				National			🟩	
				International			🟩	
Organization & Processes	I & E personnel recruitment & remuneration			Faculty		🟦	🟩	
				Post-docs/research scientists/lecturers		🟦	🟩	▨
				Students		🟦	🟩	
				Admin. staff			🟩	▨
	Institutionalized I&E/tech-transfer practices			Idea creation		🟦	🟩	▨
				Patenting & licensing		🟦	🟩	▨
				Seed grants	🟥	🟦	🟩	▨
				Translational/development grants	🟥	🟦		🟠
				Spin-off/company formation	🟥	🟦		🟠
				Incubation & acceleration		🟦		🟠
				Mentoring		🟦		🟠
				Venture formation		🟦		🟠
				Industry liaison	🟥	🟦	🟩	🟠
				Networking	🟥	🟦	🟩	▨
	Industry involvement			Research sponsorship	🟥	🟦	🟩	🟠
				Research collaboration	🟥	🟦	🟩	🟠
				Industry workshops	🟥	🟦	🟩	
				Consulting	🟥	🟦	🟩	
				Student internships	🟥	🟦	🟩	🟧
				Student placements/recruiting	🟥	🟦	🟩	
				Curriculum design		🟦		
				Teching by industry faculty	🟥	🟦		

overview of architectural options and their properties *early on* in the design process, and anticipate possible course corrections.

Third, we observe that the partnership design process tends to be form-driven, as opposed to function-driven, likely owed to the fact that policy-makers architect "with examples in mind" (along the lines of an availability heuristic (Tversky and Kahneman, 1973). For example, key stakeholders might suggest to include a student exchange (a most common cross-border mechanism in higher education) without necessarily specifying what the intended outcome of that exchange is in relation to capacity-building, or assessing whether that outcome could be achieved through a different, structurally more apposite mechanism. Excessive focus on form, however, may lead to early lock-ins on certain architectures (Crawley et al., 2015) and to outcomes that do not meet stakeholders' implicit objectives.

To provide policy-makers and institutional leaders with a more complete picture of available design options, we now reverse the direction of the systems architecture analysis. Instead of asking which forms *have* been used (in the MIT partnerships), we use the findings of our analysis to inductively ask which forms *can be used* to architect these partnerships. To begin with, we coded the activities of all partnerships, using the 4 × 4 typology of architectural views and classes or levels of form as a guiding framework (Table 3a–d). The tables summarize, in comparative perspective, the various design choices that the four MIT partnerships have made at different levels of interaction, with separate charts for the four architectural views (education, research, innovation & entrepreneurship, and institution-building). The table needs to be read from the left to the right, almost like a decision tree. For example, starting in the top left corner, three different types of "people" mobility were used across the partnerships for "education" purposes: student, faculty, and administrator mobility. For each of them, one may further distinguish whether people from one partner spent time at the partner institution or vice versa. Moreover, mobility periods can be short, medium, or long-term. Sticking to the top left corner of Table 3a for the time being, we see that CMI employed, for example, long-term student mobility periods for both MIT and Cambridge students — the aforementioned undergraduate exchange.

Table 3a-d reveal that the characteristic architectural differences between the partnerships become easily discernable when looking at the color-coded matrix from a distance. For example, Masdar Institute fills almost the entire institution-building column, underscoring the

				Cambridge-MIT Institute	MIT Portugal Program	Masdar Institute of Science & Tech	Singapore (SMA/SMART/SUTD)
People	Leadership recruitment	Recruit senior administration	President	□	□	■	■
			VP	□	□	■	■
			Provost	□	□	■	■
		Recruit senior academics	Deans	□	□	■	■
			Center Directors	□	□	■	▨
	Help staff governance & advisory bodies	Institutional	Board of trustees/governers	□	□	■	▨
			Scientific advisory board	■	□	■	▨
			External review/visiting committee	■	■	■	■
		Institutional – Councils	Education	□	□	■	■
			Research	□	■	■	■
			I & E	■	■	■	■
			Industry	■	□	■	■
		National	Advisory boards	□	□	■	▨
		National – Councils	Education	□	□	■	▨
			Research	□	□	■	░
			I & E	□	□	■	░
			Industry	□	□	■	░
			Foundations/other bodies	□	□	□	▨
Program & Projects	Strategy development for institution		Definition of institutional mission	□	□	■	■
			Definition of institutional vision	□	□	■	■
			Definition of institutional objectives	□	□	■	▨
			Definition of institutional business plan	□	□	■	▨
		Definition of priority areas	Institutional	□	■	■	▨
			Regional	□	■	□	▨
			National	□	■	■	□
		Network formation	Institutional	■	■	■	□
			Regional	■	■	□	▨
			National	■	■	■	□
			International	□	■	■	▨
			Outreach/PR	□	□	□	□
Objects	Broader policies		Performance indicators	□	□	■	■
			Student extracurricular activities	□	■	■	■
		Education	International (e.g. admissions processes)	□	■	■	■
			Regional (e.g. mutual recognition)	□	■	■	■
			National (e.g. visa rules)	□	□	■	□
			International (e.g. compliance)	□	□	■	□
		Research	Institutional (e.g. IRB/human subject research)	□	□	■	■
			Regional (e.g. state funding)	□	□	■	■
			National (e.g. stem cell policy, research funding)	□	■	■	■
			International (e.g. research agreements)	□	□	□	■
		I&E	Institutional (e.g. IP rules)	■	■	■	■
			Regional (e.g. clusters formation)	■	■	■	░
			National (e.g. tax incentives)	□	■	□	□
			International (e.g. venture attraction)	□	■	□	□
Organization & Processes	Organizational structure	Programs	Organizational structure	■	■	■	▨
			Governance processes/rules	■	■	■	▨
			Infrastructure	□	□	■	▨
			Systemic embedding	□	□	■	▨
		Departments	Organizational structure	□	□	■	■
			Governance processes/rules	□	□	■	■
			Infrastructure	□	□	■	■
			Systemic embedding	□	□	■	■
		Schools/ Faculties	Organizational structure	□	□	□	■
			Governance processes/rules	□	□	□	■
			Infrastructure	□	□	□	■
			Systemic embedding	□	□	□	■
		Centers/ Institutes	Organizational structure	□	■	■	▨
			Governance processes/rules	□	■	■	▨
			Infrastructure	□	□	■	▨
			Systemic embedding	□	□	■	▨
		Ecosystem	Organizational structure	□	■	■	□
			Governance processes/rules	□	■	■	□
			Infrastructure	□	□	■	□
			Systemic embedding (e.g. triple helix links)	■	■	■	□
			Integration of education, research, I&E (e.g. problem-based learning, i-teams)	□	■	■	■
	Legal matters	Internal/ institutional	Institutional charter	□	□	■	▨
			Statutes & by-laws	□	□	■	▨
			Governing bodies	□	□	■	▨
			Rules & regulation	□	□	■	▨
		External	Legal status (e.g. public university)	□	□	■	■
			Accreditation	□	□	■	■
			Employee services (e.g. health care)	□	□	■	■
			Public service	□	□	■	■
			"Outside the system" activities (e.g. hiring of non-civil servant-faculty, long-term funding)	■	■	■	▨

institution-building character of this partnership. Likewise, the Singapore columns highlight how different successive partnerships fulfilled different – and often complementary – roles.

Based on this pool of architectural choices, we now aggregate Table 3a-d into a basic *design matrix* (Table 4) that summarizes what we consider the most relevant design decisions for constructing a partnership of the CISTIP type. Again, the table needs to be read from the left to the right. For example, a government or institution could use the design matrix to consider whether they would like to use student mobility as a mechanism, and if so, whether primarily for research or education purposes (or both). Likewise, two cells below, educational programs can be set up through the partnership at four different levels: Bachelor, Masters, PhD, and certificate programs. Similarly, the design matrix allows us to consider holistically whether a certain education program should be linked to, say, industrial immersion experience or a certain research cluster. In this condensed form, Table 4 represents a minimal set of design options that we found pertinent to understanding and constructing CISTIPs, and that we believe policy-makers should consider when contemplating future partnerships. Note that the design matrix once more overlays the four architectural views (education, research, innovation & entrepreneurship, institution-building) with the four different levels of activity we identified (people, programs/projects, objects, organization/processes).

A few additional remarks are worth making. First, we wish to stress the inductive character of our findings. While we have wielded 'architectural views' and 'levels of interaction' as a-priori analytic categories in this paper, they have in reality been derived *inductively* from an empirically grounded, bottom-up analysis of observed partnership activities. We chose the more deductive style of presentation in this paper for reasons of analytic clarity. A major finding of the broad research effort on CISTIPs in the university sector, the satellite sector and other sectors is that architectural views and levels of interaction are consistently emerging as unifying frameworks from the analysis of CISTIPs that are otherwise quite different in their implementation.

Second, Tables 3a–d and 4 present primarily a form-driven architectural analysis. They do *not* explicitly map which function stakeholders (or program architects) associate with specific components for each MIT partnerships. Such a mapping would certainly be possible, an expected explosion of complexity in presentation notwithstanding – bearing in mind, however, that different stakeholder might disagree on the purpose of certain components. Here, we limited ourselves to outlining and systematizing form-based design options that policy-

Table 4
Design matrix for complex international university partnerships.

	Education		Research		Innovation & Entrepreneurship		Institution-building/ Institutional change	
People	Mobility	*Student*	Mobility	*Student*	Mobility	*Student*	Leadership recruitment	*Senior administration*
		Faculty/ Lecturer		*Faculty/ Lecturer*		*Faculty/ Lecturer*		*Senior academics*
		Admin. Staff		*Admin. Staff*		*Admin. Staff*	Governance & advisory bodies	*Institutional*
	Recruitment	*Student*	Recruitment	*Student*	Recruitment	*Admin. Staff*		
		Faculty/ Lecturer		*Faculty/ Lecturer*		*Innovation researchers*		*National*
		Admin. Staff		*Admin. Staff*		*External mentors*		
Programs & Projects	Create/support degree programs	*Bachelor*	Scientific focus area	*Build on existing*	I&E education	*Academic*	Strategy development for institution	*Mission*
		Master		*Start new*		*Immersive (e.g. internships)*		
		PhD	Project/focus area roll-out	*Simultaneously*		*Extracurricular*		*Vision*
		Certificate		*Sequenced*	I&E support & training	*Student*		
	Immersion programs	*Student (e.g. student exchanges)*	Research projects	*Disciplinary*		*Faculty/ Researcher*		*Objectives*
				Interdisciplinary		*Admin. Staff*		
		Faculty/researcher (e.g. "teach the teachers" program)		*Transdisciplinary*	Entrepreneurial mentoring	*AT MIT*		*Business plan*
			Research collaboration	*Departmental/institutional*		*At foreign partner*		
				Regional	I&E auxiliary activities	*I&E research*		*Definition of priority areas*
		Administrative staff (e.g. professional development)		*National*		*Workshops*		*Network formation*
				International (besides MIT)		*Industry liaison*		*Outreach/PR*
Objects	Course syllabi	*Existing*	Research equipment	*Access to existing equipment at MIT*	Intellectual property rules	*Institutional*	Performance indicators	
		Newly developed						
		Adapted (from MIT)		*Acquisition of new equipment*		*Regional/inter-institutional*	Student extracurricular activities	
	Educational infrastructure	*e-learning tools*	Research methods, tools, data	*Methods & software*				
		Distance teaching/video conf.		*Research approach (e.g. test-bed, system focus)*		*National*	Broader policies	*Education*
		Course management software						
		Course evaluation practices		*Data*		*International*		*Research*
		Teaching and Learning practices		*Tacit knowledge & lab routines*				*I&E*
		Student progress/management						
Organization & Processes	Course instruction	*Language of instruction: Foreign*	Funding allocation	*Fund projects*	Institutionalized I&E/tech-transfer practices	*Idea creation*	Organizational structure	*Programs*
						Patenting & licensing		
				Fund programs		*Seed grants*		*Departments*
		Language of instruction: English				*Translational/developm. grants*		
				Fund centers		*Spin-off/company formation*		*Schools/ Faculties*
						Incubation & acceleration		
	Academic calendar	*Existing*	Call/RFP structure	*Open call*		*Mentoring*		*Centers/ Institutes*
						Venture formation		
		New		*Semi-open call*		*Industry liaison*		*Ecosystem*
						Networking		
		Mixed		*Closed/internal allocation*	Industry involvement	*Research sponsorship*	Integration of education, research, I&E (e.g. problem-based learning, i-teams)	
						Research collaboration		
	Educational collaborations & networks (besides MIT)	*single institution (no additional collaboration)*	Research collaborations & networks (besides MIT)	*single institution (no additional collaboration)*		*Industry workshops*		
						Consulting		
		2 institutions		*2 institutions*		*Student internships*	Legal matters	*Internal/ institutional*
						Student placements/recruiting		
		3 or more institutions		*3 or more institutions*		*Curriculum design*		*External*
						Teching by industry faculty		

makers and institutional leaders can draw upon to implement desired functionalities and pursue program objectives. In other work, our research team finds it helpful to perform a function-driven analysis that identifies the decisions stakeholders make to assign functions to forms.

Third, all four partnerships address multiple scientific focus areas at the same time. While the selection of "scientific focus areas" has been included in Tables 3a-d and 4 under the "research" view at the level of "programs/projects," the choice of focus areas has actually much greater implications that affect all other partnership components. Scientific focus areas may differ considerably in terms of educational approaches, research infrastructure needs, ramp-up time, or lab-to-market time for research findings. Consider, for example, the vastly different needs of IT research vs. wet-lab biology vs. nuclear engineering. Focus areas may also vary greatly in terms of pre-existing capacity in the partner country. For example, MPP was leveraged both to both *build on* existing strengths (e.g., in transportation research) and *jumpstart* new fields (e.g., stem cell research). For partnership architects, it might be more appropriate to consider each scientific focus area individually through a separate design matrix, thus treating "focus areas" as a de facto third, orthogonal dimension to "views" and "levels of interaction."

Finally, our architecture analysis provides a first step towards thinking about CISTIPs in terms of *archetypes* — that is, basic architectural patterns into which more complex architectures can be broken down. In the systems architecture literature, archetypes are frequently derived from a large number of cases using sorting algorithms. While the number of cases assessed in the paper is small (i.e. four), we may still hypothesize that certain archetypical patterns will be found across a wider range of partnerships. We expect that our macro-architectures provide clues for where archetypes might emerge, e.g., along such dividing lines as bilateral vs. multilateral components; institution-building activities vs. activities geared at institutional change; or functionally integrated vs. functionally separated components. More research is needed to develop a systematic account of CISTIP archetypes in the university sector and other sectors.

7. Conclusion

This paper discussed complex international capacity-building partnerships as a novel policy instrument that sits in the intersection of three broad trends in innovation policy — growing attention to universities, growing emphasis on international links and collaboration, and growing complexity of policy strategies. Based on four case studies of national "flagship" partnerships, we demonstrated how the United Kingdom, Portugal, Abu Dhabi, and Singapore each used this policy instrument in fundamentally different ways and for very different capacity-building goals when partnering with MIT. Yet, we demonstrated that these partnerships are based on a common core of organizing principles that cut across goals and architectures, which can be productively captured by *architectural views* (education, research, innovation & entrepreneurship, institution-building) and *levels of interaction* between the partners (people, programs/projects, objects, organization/process). Based on architectural analysis, we developed a design matrix supplemented by a pool of concrete design options derived from our cases that can help guide the development of complex partnerships in the future. We believe that this design matrix in particular will be useful for governments and institutional leaders around the world seeking to deploy this policy instrument in a targeted, effective manner.

Our analysis speaks to a number of broader issues in science and innovation policy. First, our cases illustrate the countries as diverse as the UK, Portugal, Abu Dhabi, and Singapore all saw value in sponsoring a foreign institution as part of a national capacity-building effort in science and innovation. This stands in marked contrast to the vast majority of public research funding patterns found around the globe, which remains a primarily national endeavor. This suggests that a potentially greater role for eminent global research universities in international development beyond mere branch campuses and participation in "brain circulation." The four partnerships in our study embody a *new hybrid model of cross-boarder interaction*, combining elements of a classical two-way partnership (e.g. exchanges or research collaboration) with consultancy-type services (e.g. advise on organizational models, recruitment assistance, access to existing research networks, or the transfer of objects). In this sense, an explicit *fourth institutional mission* besides education, research, and regional innovation is conceivable for research universities: to act as catalysts for regional or national development *elsewhere* by offering services to governments and university systems abroad.

Second, our architecture framework fits well within the recent push for systemic instruments in innovation policy (Smits and Kuhlmann, 2004). It resonates with the "functional" approach to innovation systems analysis taken by some scholars in recent years (Hekkert et al., 2007), even though our focus here has been on capacity-building at the institutional level. We demonstrated that complex international university partnerships can simultaneously address multiple policy domains – including education, research, innovation, and institution-building – and act on different levels – people, programs/projects, objects, and organization/processes –which underscores the potential for systemic intervention of CISTIPs. Moreover, our use of systems architecture for design leads the way to a wider and more targeted application of systemic policy instruments in the future.

Future research should principally focus on four directions. First, from the perspective of interpretive policy analysis, it is important to explore in greater depth the influence of the unique social, political, and economic history of each country on the genesis and implementation of each partnerships, and with it the impact of different underlying political cultures. Here, approaches from Science and Technology Studies will likely be of great value. For example, in their work on sociotechnical imaginaries, Jasanoff and Kim (2009) investigate the "collectively imagined forms of social life and social order centering on the development and fulfillment of national scientific and/or technological projects." Sociotechnical imaginaries have been successfully employed to the study of large-scale national science and technology initiatives as key sites of contemporary state-making and societal reconfigurations, illustrating how the social practices surrounding seemingly identical technologies (such as nuclear power) differ vastly in their social practice across countries. The same argument could be made for the implementation of innovation initiatives according to "MIT practice." Imaginaries may thus help us explain why some architectures are feasible only in certain socio-political contexts, while other architectures are inhibited, and how idiosyncratic features of national identity and societal experiences enter into what on the surface looks like the same policy instrument.

Second, as mentioned above, the university partnerships discussed here share some structural characteristics with other forms of collaborative technological capacity-building, notably around space and nuclear technology (Wood and Weigel, 2010, 2011). Future research should attempt a rigorous comparison between an established sector of large-scale capacity-building partnerships and a new one, and identify pertinent similarities and differences between them.

Third, to better support policy-makers, the present analysis should be complemented by an in-depth discussion of governance questions surrounding the conception, design, negotiation, implementation, and operation of these partnerships — all of which come with their own set of challenges. We suggest that given the multi-year, cyclical character of these large-scale initiatives, a life-cycle approach might be well-suited to discuss these various governance stages and their respective needs. Such an approach models the decisions made at each stage of a CISTIP and allows comparisons across CISTIP according to the features of each life-cycle stage.

Fourth, as mentioned at the outset, the purpose of this paper was *not* to provide an evaluation of the "success" of these four partnerships. Most part these partnerships are still ongoing and their full impact will not be visible for at least another few years. Nonetheless, evaluation is of course important, particularly for national "flagship" initiatives like the ones discussed here. Our analysis has highlighted the considerable differences between the four CISTIPs in terms of policy rationales, objectives, strategy, socioeconomic and institutional context, and resulting architectures. Hence, it would be unreasonable to expect that a single measure of "success" can be meaningfully applied across the cases. Our system architecture analysis provides a potential way forward for assessing CISTIPs 'on their own terms:' the observed differences in architecture are precisely the result of differences in stakeholder goals and thus speak directly to questions of evaluation. Future research should aim to explore such custom-tailored evaluation regimes cognizant of differences in system architecture, and if necessary contrast them with existing evaluation procedures implemented by program sponsors and governments.

Acknowledgements

This work was sponsored by the NSF Science of Science and Innovation Policy (SciSIP) Program under Collaborative Grant "Technology, Collaboration, Learning: Modeling Complex International Innovation Partnerships" (#1262263). SP gratefully acknowledges partial funding by the MIT Leading Technology Policy Initiative and the MIT–Portugal Program. The authors would further like to thank Mackenzie Hird, Francisco Del Canto Viterale, Josh Jacobs, Katherine Chu, Lorie Breslow, the members of the MIT International Advisory Committee, and all interview participants for their generous support and invaluable feedback.

References

Acworth, E.B., 2008. University–industry engagement: the formation of the knowledge integration community (KIC) model at the Cambridge–MIT Institute. Res. Policy 37, 241–254.
Aghion, P., Howitt, P., 1998. Endogenous Growth Theory. MIT Press.
Altbach, P., 2007. Tradition and Transition: The International Imperative in Higher Education. CIHE Publishing, Chestnut Hill, MA.
Altbach, P.G., Knight, J., 2007. The internationalization of higher education: motivations and realities. J. Stud. Int. Educ. 11, 290–305. http://dx.doi.org/10.1177/1028315307303542.

Amsden, A., 2001. Rise of "The Rest:" Challenges to the West from Late-Industrializing Economies. Oxford University Press, New York.

Archibugi, D., Lundvall, B.-Å. (Eds.), 2001. The Globalizing Learning Economy. Oxford University Press, New York.

Balconi, M., Brusoni, S., Orsenigo, L., 2010. In defence of the linear model: an essay. Res. Policy 39, 1–13. http://dx.doi.org/10.1016/j.respol.2009.09.013.

Bammer, G., 2008. Enhancing research collaborations: three key management challenges. Res. Policy 37, 875–887. http://dx.doi.org/10.1016/j.respol.2008.03.004.

Bhandari, R., Blumenthal, P. (Eds.), 2011. International Students and Global Mobility in Higher Education. Palgrave Macmillan, New York.

Borup, M., Brown, N., Konrad, K., Van Lente, H., 2006. The sociology of expectations in science and technology. Tech. Anal. Strat. Manag. 18, 285–298.

Bound, J., Turner, S., Walsh, P., 2009. Internationalization of U.S. doctorate education. Science and Engineering Careers in the United States. NBER, pp. 59–97.

Bozeman, B., 2000. Technology transfer and public policy: a review of research and theory. Res. Policy 29, 627–655. http://dx.doi.org/10.1016/S0048-7333(99)00093-1.

Bozeman, B., Fay, D., Slade, C.P., 2013. Research collaboration in universities and academic entrepreneurship: the-state-of-the-art. J. Technol. Transf. 38, 1–67. http://dx.doi.org/10.1007/s10961-012-9281-8.

Braczyk, H.-J., Cooke, P., Heidenreich, M., 2004. Regional Innovation Systems: The Role of Governances in a Globalized World. second ed. Routledge.

Carayannis, E.G., Alexander, J., Ioannidis, A., 2000. Leveraging knowledge, learning, and innovation in forming strategic government–university–industry (GUI) R&D partnerships in the US, Germany, and France. Technovation 20 (9), 477–488.

Choon, B.K., 2004. Narrating imagination. In: Choon, B.K., Pakir, A., Kiong, T.C. (Eds.), Imagining Singapore. Eastern Universities Press, Singapore.

Chuan Poh, L., 2010. Singapore betting on biomedical sciences. Issues in Science and Technology.

Clancey, G., 2012. Intelligent island to biopolis: smart minds, sick bodies and millennial turns in Singapore. Sci. Technol. Soc. 17, 13–35. http://dx.doi.org/10.1177/097172181101700102.

Clark, B.R., 1998. Creating Entrepreneurial Universities: Organizational Pathways of Transformation. Pergamon Press, New York.

Clotfelter, C. (Ed.), 2010. American Universities in a Global Market. University of Chicago Press, Chicago, IL.

CMI, 2005. Cambridge MIT Institute Annual Report (2005).

CMI, 2008. Accelerating Innovation by Crossing Boundaries. The Cambridge MIT Institute, pp. 2000–2006.

Cohen, W., Levinthal, D., 1990. Absorptive capacity: a new perspective on learning and innovation. Adm. Sci. Q. 35.

Conceição, P., Heitor, M., 2001. Universities in the learning economy: balancing institutional integrity with organizational diversity. In: Archibugi, D., Lundvall, B.-Å. (Eds.), The Globalizing Learning Economy. Oxford University Press, New York, pp. 83–96.

Corley, E.A., Boardman, P.C., Bozeman, B., 2006. Design and the management of multi-institutional research collaborations: theoretical implications from two case studies. Res. Policy 35, 975–993. http://dx.doi.org/10.1016/j.respol.2006.05.003.

Cowan, R., Zinovyeva, N., 2013. University effects on regional innovation. Res. Policy 42, 788–800. http://dx.doi.org/10.1016/j.respol.2012.10.001.

Crawley, E., Cameron, B., Selva, D., 2015. System Architecture: Strategy and Product Development for Complex Systems. 1 ed. Prentice Hall, Boston.

Cusumano, M.A., Elenkov, D., 1994. Linking international technology transfer with strategy and management: a literature commentary. Res. Policy 23, 195–215. http://dx.doi.org/10.1016/0048-7333(94)90053-1.

Dietz, J.S., Bozeman, B., 2005. Academic careers, patents, and productivity: industry experience as scientific and technical human capital. Res. Policy 34, 349–367. http://dx.doi.org/10.1016/j.respol.2005.01.008.

Dryzek, J.S., 1990. Discursive Democracy: Politics, Policy, and Political Science. Cambridge University Press, Cambridge; New York.

DTI, 2001. UK Innovation Performance: Strengths, Weaknesses, Opportunities, Threats and Main Problems. UK Department of Trade and Industry.

Ebner, A., 2004. Development strategies and innovation policies in globalisation: the case of Singapore. In: Mani, S., Romijn, H. (Eds.), Innovation, Learning, and Technological Dynamism of Developing Countries. United Nations, pp. 47–76.

EC, 2000. Lisbon European Council, Presidency Conclusions (Lisbon Strategy). Lisbon European Council.

Edquist, C., 2005. Systems of innovation: perspectives and challenges. In: Fagerberg, J., Mowery, D.C., Nelson, R. (Eds.), The Oxford Handbook of Innovation. Oxford University Press, Oxford.

Eisenhardt, K.M., 2007. Theory building from cases: opportunities and challenges. Acad. Manag. J. 25–32.

Eom, B.-Y., Lee, K., 2010. Determinants of industry–academy linkages and, their impact on firm performance: The case of Korea as a latecomer in knowledge industrialization. Res. Policy 39, 625–639. http://dx.doi.org/10.1016/j.respol.2010.01.015 (Special Section on Government as Entrepreneur).

Etzkowitz, H., 2002. Incubation of incubators: innovation as a triple helix of university–industry–government networks. Sci. Public Policy 29 (2), 115–128.

Etzkowitz, H., 2003. Research groups as "quasi-firms": the invention of the entrepreneurial university. Res. Policy 32, 109–121.

Etzkowitz, H., 2008. The Triple Helix: Industry, University, and Government in Innovation. Routledge, New York.

EU, 1999. The Bologna Declaration: Towards the European Higher European Area. http://www.euractiv.com/en/priorities/sweden-admits-lisbon-agenda-failure/article-182797.

Fagerberg, J., 2006. Innovation: a guide to the literature. In: Fagerberg, J., Mowery, D.C., Nelson, R.R. (Eds.), The Oxford Handbook of Innovation. Oxford University Press, Oxford, England, pp. 1–27.

Finn, M.G., 2012. Stay Rates of Foreign Doctorate Recipients From U.S. Universities, 2009. National Science Foundation, Division of Science Resource Statistics.

Fischer, F., 2003. Reframing Public Policy: Discursive Politics and Deliberative Practices. 1 ed. Oxford University Press.

Fischer, F., Forester, J., 1993. The Argumentative Turn in Policy Analysis and Planning. Duke University Press, Durham, N.C.

Fransman, M., King, K., Bell, M., 1984. "Learning" and the accumulation of industrial technological capacity in developing countries. Technological Capability in the Third World. Macmillan, pp. 187–209.

Freeman, R.B., 2005. Does globalization of the scientific/engineering workforce threaten U.S. economic leadership? Working Paper No. 11457. National Bureau of Economic Research

Freeman, R.B., 2014. Immigration, international collaboration, and innovation: science and technology policy in the global economy (Working Paper No. 20521). National Bureau of Economic Research.

Georghiou, L., 1998. Global cooperation in research. Res. Policy 27, 611–626. http://dx.doi.org/10.1016/S0048-7333(98)00054-7.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzmann, S., Scott, P., Trow, M., 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. Sage Publications.

Grieve, R.H., 2004. Appropriate technology in a globalizing world. Int. J. Technol. Manag. Sustain. Dev. 3, 173–187. http://dx.doi.org/10.1386/ijtm.3.2.173/0.

Hagedoorn, J., Link, A.N., Vonortas, N.S., 2000. Research partnerships. Res. Policy 29, 567–586. http://dx.doi.org/10.1016/S0048-7333(99)00090-6.

Hajer, M.A., Wagenaar, H., 2003. Deliberative Policy Analysis: Understanding Governance in the Network Society. Cambridge University Press, Cambridge, UK; New York, USA.

Heitor, M., Bravo, M., 2010. Portugal at the crossroads of change, facing the shock of the new: people, knowledge and ideas fostering the social fabric to facilitate the concentration of knowledge integrated communities. Technol. Forecast. Soc. Chang. 77, 218–247.

Heitor, M., Horta, H., 2011. Science and technology in Portugal: from late awakening to the challenge of knowledge-integrated communities. In: Neave, G., Amaral, A. (Eds.), Higher Education in Portugal 1974–2009. Springer, Netherlands, Dordrecht, pp. 179–226.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: a new approach for analysing technological change. Technol. Forecast. Soc. Chang. 74, 413–432. http://dx.doi.org/10.1016/j.techfore.2006.03.002.

Hopwood, D., 2010. Abu Dhabi's Masdar plan takes shape. Renew. Energy Focus 11, 18–23. http://dx.doi.org/10.1016/S1755-0084(10)70025-9.

Huff, W.G., 1995. The developmental state, government, and Singapore's economic development since 1960. World Dev. 23, 1421–1438. http://dx.doi.org/10.1016/0305-750X(95)00043-C.

Hunt, J., Gauthier-Loiselle, M., 2008. How much does immigration boost innovation? Working Paper No. 14312. National Bureau of Economic Research

IIE, 2013. Project Atlas: Trends and Global Data 2013. Institute of International Education, Center for Academic Mobility Research.

Jasanoff, S., 2004. States of Knowledge: The Co-production of Science and the Social Order. 1 New. ed. Routledge.

Jasanoff, S., 2005. Why compare? Designs on Nature: Science and Democracy in Europe and the United States. Princeton University Press, pp. 13–41

Jasanoff, S., Kim, S.-H., 2009. Containing the atom: sociotechnical imaginaries and nuclear power in the United States and South Korea. Minerva 47(2), 119–146. doi:DOI: http://dx.doi.org/10.1007/s11024-009-9124-4

Katz, J.S., Martin, B.R., 1997. What is research collaboration? Res. Policy 26, 1–18. http://dx.doi.org/10.1016/S0048-7333(96)00917-1.

Keeling, R., 2006. The Bologna process and the Lisbon research agenda: the European Commission's expanding role in higher education discourse. Eur. J. Educ. 41 (2), 203–223.

Kehm, B., Teichler, U., 2007. Research on internationalisation in higher education. J. Stud. Int. Educ. 11, 260–277.

Keller, W., 1996. Absorptive capacity: on the creation and acquisition of technology in development. J. Dev. Econ. 49, 199–227. http://dx.doi.org/10.1016/0304-3878(95)00060-7.

Kim, L., 1997. Imitation to Innovation: The Dynamics of Korea's Technological Learning. Harvard Business School Press, Boston, MA.

Knight, J., 2004. Internationalization remodeled: definition, approaches, and rationales. J. Stud. Int. Educ. 8 (Spring), 5–31.

Knight, J., 2007. Cross-border tertiary education: an introduction. Cross-Border Tertiary Education: A Way Towards Capacity Development. OECD, Paris, pp. 21–46.

KPMG, 2012. Infrastructure100: World Cities Edition. KPMG International, Amsterdam.

Kuhlmann, S., Shapira, P., Smits, R., 2012. Introduction. A systemic perspective: the innovation policy dance. In: Smits, R., Kuhlmann, S., Shapira, P. (Eds.), The Theory and Practice of Innovation Policy: An International Research Handbook. Edward Elgar Pub, Cheltenham, UK u.a., pp. 1–22.

Lall, S., 1992. Technological capabilities and industrialization. World Dev. 20, 165–186. http://dx.doi.org/10.1016/0305-750X(92)90097-F.

Landau, A., Rosenberg, N., 1986. The Positive Sum Strategy: Harnessing Technology for Economic Growth. The National Academy Press.

Lee, S., Bozeman, B., 2005. The impact of research collaboration on scientific productivity. Soc. Stud. Sci. 35, 673–702. http://dx.doi.org/10.1177/0306312705052359.

Lee, K., Lim, C., 2001. Technological regimes, catching-up and leapfrogging: findings from the Korean industries. Res. Policy 30, 459–483. http://dx.doi.org/10.1016/S0048-7333(00)00088-3.

Llerena, P., Matt, M., 2005. Innovation Policy in a Knowledge-Based Economy: Theory and Practice. Springer.

Lucas, R.E., 1988. On the mechanics of economic development. J. Monet. Econ. 22 (1), 3–42.

Lundvall, B.-Å., 1992. National Innovation Systems: Towards a Theory of Innovation and Interactive Learning. Pinter, London.

Luukkonen, T., Persson, O., Sivertsen, G., 1992. Understanding patterns of international scientific collaboration. Sci. Technol. Hum. Values 17, 101–126. http://dx.doi.org/10.1177/016224399201700106.

Maier, M.W., Rechtin, E., 2000. The Art of Systems Architecting. second ed. CRC Press.

Majone, G., 1992. Evidence, Argument, and Persuasion in the Policy Process. Reissue ed. Yale University Press, New Haven.

Malerba, F., 2005. Sectoral systems of innovation: a framework for linking innovation to the knowledge base, structure and dynamics of sectors. Econ. Innov. N. Technol. 14, 63–82.

Mansfield, E., 1991. Academic research and industrial innovation. Res. Policy 20, 1–12. http://dx.doi.org/10.1016/0048-7333(91)90080-A.

Mansfield, E., Lee, J.-Y., 1996. The modern university: contributor to industrial innovation and recipient of industrial R&D support. Res. Policy 25, 1047–1058. http://dx.doi.org/10.1016/S0048-7333(96)00893-1.

Masdar, 2012. Welcome to Masdar [WWW Document]. URL http://www.masdar.ae/en/home/index.aspx (accessed 6.19.12).

Melin, G., 2000. Pragmatism and self-organization: research collaboration on the individual level. Res. Policy 29, 31–40. http://dx.doi.org/10.1016/S0048-7333(99)00031-1.

MIST, 2011. Learning to Change the World: The Masdar Institute of Science and Technology.

MIT, 2005. Program Overview Brochure, MIT Portugal Program. http://www.mitportugal.org/index.php?option=com_docman&task=doc_download&gid=3&Itemid=383.

MIT, 2006. Assessment of an MIT–Portugal Collaboration — Final Report. MIT.

Mowery, D.C., 2004. Ivory Tower and Industrial Innovation: University–Industry Technology Transfer Before and After the Bayh–Dole Act in the United States. Stanford University Press.

Nader, S., 2009. Paths to a low-carbon economy—the Masdar example. Energy Procedia 1, 3951–3958. http://dx.doi.org/10.1016/j.egypro.2009.02.199.

National innovation systems. In: Nelson, R. (Ed.), A Comparative Analysis. Oxford University Press, New York/Oxford.

NRF, 2006. Campus for Research Excellence And Technological Enterprise (CREATE) — Vision [WWW Document]. URL http://www.create.edu.sg/about-create/vision (accessed 2.23.15).

OECD, 2004. Internationalisation and Trade in Higher Education. OECD, Paris.

OECD, 2007. Tertiary Education in Portugal. OECD, Paris.

OECD, 2010. The OECD Innovation Strategy. OECD, Paris.

Pfotenhauer, S., 2015. Development unlocked: co-producing Emirati science and society at Masdar Institute of Science and Technology. In: Siddiqi, A., Diaz-Anadon, L. (Eds.), Accelerating Science and Technology Development in the Middle East: Unleashing the Potential of Near Ties (forthcoming).

Pfotenhauer, S.M., Jacobs, J.S., Pertuze, J.A., Newman, D.J., Roos, D.T., 2013. Seeding change through international university partnerships: the MIT–Portugal program as a driver of internationalization, networking, and innovation. High Educ. Policy 26, 217–242. http://dx.doi.org/10.1057/hep.2012.28.

Reddy, N.M., Zhao, L., 1990. International technology transfer: a review. Res. Policy 19, 285–307. http://dx.doi.org/10.1016/0048-7333(90)90015-X.

Reiche, D., 2010. Renewable energy policies in the gulf countries: a case study of the carbon-neutral "Masdar city" in Abu Dhabi. Energy Policy 38, 378–382. http://dx.doi.org/10.1016/j.enpol.2009.09.028.

Remaking Singapore Committee, 2003. Changing Mindsets, Deepening Relationships: The Report of the Remaking Singapore Committee (Chaired by Vivian Balakrishnan). The Committee.

Romer, P., 1990. Endogenous technological change. J. Polit. Econ. 98 (5), 71–102.

Rothwell, R., 1992. Successful industrial innovation: critical factors for the 1990s. R&D Manag. 22, 221–240. http://dx.doi.org/10.1111/j.1467-9310.1992.tb00812.x.

Salter, A.J., Martin, B.R., 2001. The economic benefits of publicly funded basic research: a critical review. Res. Policy 30, 509–532. http://dx.doi.org/10.1016/S0048-7333(00)00091-3.

Scherer, F.M., 1999. New Perspectives on Economic Growth and Technological Innovation. Brookings/BNAC.

Schön, D.A., Rein, M., 1995. Frame Reflection: Toward The Resolution Of Intractrable Policy Controversies. Basic Books, New York.

Shane, S., 2004. Academic Entrepreneurship: University Spinoffs and Wealth Creation. E. Elgar, Cheltenham, UK; Northampton, MA.

Slaughter, S., Leslie, L.L., 1997. Academic Capitalism: Politics. Policies and the Entrepreneurial University, John Hopkins University Press.

Smits, R., Kuhlmann, S., 2004. The rise of systemic instruments in innovation policy. Int. J. Foresight Innov. Policy 1, 4–32.

Smits, R., Kuhlmann, S., Shapira, P., 2012. The Theory and Practice of Innovation Policy: An International Research Handbook. Edward Elgar Pub, Cheltenham, UK u.a.

Stone, D., 2001. Policy Paradox: The Art of Political Decision Making. third ed. W. W. Norton & Company, New York.

Subramanyam, K., 1983. Bibliometric studies of research collaboration: a review. J. Inf. Sci. 6, 33–38. http://dx.doi.org/10.1177/016555158300600105.

Tan, K.-S., Phang, S.-Y., 2005. From Efficiency-Driven to Innovation-Driven Economic Growth : Perspectives from Singapore. World Bank Publications.

Technopolis, 2012. The Evolution of the Knowledge Triangle. The Technopolitan, p. 9.

Thorp, H.H., Goldstein, B., 2010. Engines of Innovation: The Entrepreneurial University in the Twenty-first Century. Univ of North Carolina Press.

Tversky, A., Kahneman, D., 1973. Availability: a heuristic for judging frequency and probability. Cogn. Psychol. 5, 207–232.

Verbik, L., Merkley, C., 2006. The international branch campus — models and trends. Obs. Borderless Higher Educ. 1, 1–31.

Vincent-Lancrin, S., 2007. Developing capacity through cross-border tertiary education. Cross-Border Tertiary Education: a Way Towards Capacity Development. OECD, Paris, pp. 47–108.

Vinkler, P., 1993. Research contribution, authorship and team cooperativeness. Scientometrics 26, 213–230. http://dx.doi.org/10.1007/BF02016801.

Wagner, C.S., 2005. Six case studies of international collaboration in science. Scientometrics 62, 3–26. http://dx.doi.org/10.1007/s11192-005-0001-0.

Wei, L., 1995. International technology transfer and development of technological capabilities: a theoretical framework. Technol. Soc. 17, 103–120. http://dx.doi.org/10.1016/0160-791X(94)00028-C.

Wong, P.-K., 1995. Singapore's technology strategy. In: Simon, D.F. (Ed.), The Emerging Technological Trajectory of the Pacific Rim. M.E. Sharpe, New York, pp. 103–131.

Wong, P.-K., 1999. University–industry technological collaboration in Singapore: emerging patterns and industry concerns. Int. J. Technol. Manag. 18, 270–284.

Wood, D., Weigel, A., 2010. Capability building, partnership and development: analysis of the space activities of equatorial countries. International Academy of Astronautics/NASRDA Symposium on the Equatorial Plane. Abuja, Nigeria.

Wood, D., Weigel, A., 2011. Building technological capability within satellite programs in developing countries. Acta Astronautica 69, 1110–1122. http://dx.doi.org/10.1016/j.actaastro.2011.06.008.

Wood, D., Weigel, A., 2014. Architectures of small satellite programs in developing countries. Acta Astronautica 97, 109–121. http://dx.doi.org/10.1016/j.actaastro.2013.12.015.

Wuchty, S., Jones, B.F., Uzzi, B., 2007. The increasing dominance of teams in production of knowledge. Science 316 (5827), 1036–1039.

Yew, L.K., 1990. The Geoffrey Stern interview with Lee Kuan Yew (cited in Huff, W.G. "the developmental state, government, and Singapore's economic development since 1960." World development 23(8), pp. 1421–1438, 1995). LSE Mag. 2, 21–25.

Yin, R.K., 1994. Case Study Research: Design and Methods. second ed. Sage Publications, Inc.

Youtie, J., Shapira, P., 2008. Building an innovation hub: a case study of the transformation of university roles in regional technological and economic development. Res. Policy 37, 1188–1204. http://dx.doi.org/10.1016/j.respol.2008.04.012 (Special Section on University–Industry Linkages: The Significance of Tacit Knowledge and the Role of Intermediaries).

Dr. Sebastian Pfotenhauer is a lecturer and research scientist with the MIT Technology & Policy Program and a Fellow at the Harvard Program on Science, Technology and Society, Harvard Kennedy School. His research focuses on national and regional innovation strategies and especially the role of international partnerships within these strategies, with a particular view towards questions of capacity-building. His interests furthermore include innovation theory, the circulation of innovation models, and sociotechnical imaginaries of innovation. Dr. Pfotenhauer has served as consultant for innovation and higher education policy to the OECD and various governments and has been co-leading research efforts on the NSF-sponsored project "Technology, Collaboration, and Learning: Modeling Complex International Innovation Partnerships." Dr. Pfotenhauer has recently accepted a professorship at the Munich Center for Technology in Society and the TUM School of Management at TU Munich, which he will take up in Fall 2015.

Dr. Danielle Wood works as a systems engineer and technology policy researcher within the Systems Institute at Johns Hopkins University. Dr. Wood's research applies engineering and policy to study the complex, socio-technical systems implemented by the public sector to meet critical societal needs around the world. Dr. Wood is currently co-leading a JHU research team executing the collaborative project entitled "Technology, Collaboration, and Learning: Modeling Complex International Innovation Partnerships," funded by NSF. Dr. Wood is a graduate of the Engineering Systems Division at the Massachusetts Institute of Technology where she studied aerospace engineering, technology policy and international development.

Dr. Daniel Roos is the Japan Steel Industry Professor Emeritus of Engineering Systems and Civil and Environmental Engineering at MIT. Dr. Roos was the Founding Director of MIT's Engineering Systems Division (ESD) from 1998 to 2004 and serves as Chair of the Engineering Systems University Council, an organization of universities with Engineering Systems programs. Previous MIT responsibilities for Dr. Roos include serving as Director of the MIT Center for Transportation Studies, and Director of the MIT Center for Technology, Policy and Industrial Development. At MIT, Dr. Roos was Founding Director of the International Motor Vehicle Program (IMVP) and currently serves as Chair of the IMVP Advisory Board. He is co-author of The Machine that Changed the World, which has been published in 11 languages and has sold over 600,000 copies. Dr. Roos also served as Special Assistant to the MIT Chancellor and Provost, helping to form large-scale industrial and global partnerships. He had a leadership role in partnerships with Ford, Merrill Lynch, Portugal, and Cambridge University in the U.K.

Dr. Dava Newman is a professor of Engineering Systems and Aeronautics & Astronautics at MIT and recently appointed Deputy Administrator at NASA. Before joining NASA, she was director of MIT's Technology & Policy Program, as well as director of the MIT–Portugal Program. Dr. Newman received her Ph.D. in Aerospace Biomedical Engineering from MIT. Her expertise is in system design and engineering with a particular view towards technology policy questions, as well as multidisciplinary research that combines aerospace biomedical engineering, human-in-the-loop modeling, biomechanics, human interface technology, life sciences, systems analysis, design and policy. Current research efforts include: advanced space suit design, dynamics and control of astronaut motion, mission analysis, and engineering systems design and policy analysis. Dava Newman was the lead Principal Investigator of the ongoing NSF-sponsored research project "Technology, Collaboration, and Learning: Modeling Complex International Science Technology and Innovation Partnerships" at MIT.