Global Production Networks
The Case of China

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Introduction

The emergence of global corporate networks that integrate dispersed production, engineering, product development and research activities across geographic borders poses new challenges and opportunities for national industrial and innovation policies. This book is a collection of essays on questions that are of great importance for policy debates and management strategies in emerging economies:

- What are the driving forces and characteristics of these global networks?
- What do we know about the increasing diversity and complexity of these networks?
- What are possible impacts on the geographic distribution of knowledge?
- Where does China's ambitious strategy to upgrade its economy through innovation fit into this new geography of innovation?
- And what lessons, if any, could be drawn for policies in emerging economies that seek to capture the gains from global network integration?

The book has greatly benefited from extremely stimulating discussions during my participation at the Cátedra Extraordinaria México-China in 2015 and during a series of lectures I gave in March 2015. I owe new insights to faculty and students at UNAM about China's role in Latin America, especially in Mexico. A seminar at the Consultative Forum on Science and Technology (an independent relevant group of scientists related to the government) and meetings with information technology industry representatives generated profound brainstorming discussions about Mexico's industrial manufacturing and innovation challenges. I am grateful for having been selected for this program. Most importantly, I owe a great debt of gratitude to Professor Enrique Dussel Peters, a great scholar, gracious host, and personal friend.

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Global Production Networks, Knowledge Diffusion, and Local Capability Formation. A Conceptual Framework

Dieter Ernst and Linsu Kim

Introduction

Global production networks (GPN) transform the production and use of knowledge, with far-reaching implications for an evolutionary theory of economic change. There is a fundamental trend towards increasing mobility of knowledge, yet little do we know about drivers and implications. Twenty years after the pioneering book of Nelson and Winter[1], it is time to develop a research agenda that addresses these transformations, based on a combination of appreciative theory, case studies, econometric work and formal modeling.

A major constraint is a lack of communication between research on GPN, research on international knowledge diffusion, and research on local capability formation. While all three are highly relevant strands of research, their lack of interaction obstructs our understanding of how global networks affect knowledge diffusion and the formation of local capabilities. There is a need to bridge this gap through "appreciative theories", as defined in Richard Nelson´s thought-provoking review of economic growth theory[2].

This paper develops a conceptual framework that links together the above three areas of research, as a first step towards an appreciative theory. We argue that globalization has culminated in an important organizational innovation: the spread of GPN. These networks combine concentrated dispersion of the value chain across firm and national boundaries, with a parallel process of integration of hierarchical layers of

1. Nelson, R. and S. G. Winter, 1982, *An Evolutionary Theory of Economic Change,* Bellknap Press, Cambridge, Massachussetts.
2. See: Nelson, Richard, 1995, "The Agenda for Growth Theory: A Different Point of View", *IASA Working Paper.* In contrast to formal growth theories, appreciative theories do not attempt to compress stylized facts into rigorous formulations. Rather, an attempt is made to include more of the observed empirical richness of IT and transformations in business organization than formal theories. This of course comes at the cost of being unable to model these relationships mathematically. Hence the need for formal theories. But for the latter to be fruitful, they need to be based on appreciative theories, and on the findings of case studies and econometric analysis.

network participants. This has created new opportunities for international knowledge diffusion that lowertier network suppliers should strive to exploit. To substantiate this argument, we proceed as follows. Section 1 sketches our research agenda, while section 2 analyzes the three dynamic forces that drive the rapid development of GPN. Section 3 highlights the economic structure and peculiar characteristics of the flagship model of GPN. Section 4 explores the categories of knowledge, and the mechanisms of knowledge transfer from flagship companies to local network suppliers. And in section 5, we discuss under what conditions GPN can act as mediators of local capability formation. We conclude with policy and management implications for global flagships and local suppliers, and spell out priorities for future research.

1. Research Agenda

Multinational corporations (MNCs) have been around for a long time[3]. Until recently, their international production has focused on the penetration of protected markets through tariff-hopping investments, and on the use of assets developed at home to exploit international factor cost differentials, primarily for labor[4]. This has given rise to a peculiar pattern of international production: offshore production sites in low-cost locations are linked through triangular trade with the major markets in North America and Europe[5].

A progressive liberalization and deregulation of international trade and investment, and the rapid development and diffusion of information and communication technology (IT) have fundamentally changed the global competitive dynamics, in which MNCs operate. While both market access and cost reductions remain important, it became clear that they have to be reconciled with a number of equally important requirements that encompass: the exploitation of uncertainty through improved operational flexibility[6]; a compression of speed-to-market through reduced product development and product life cycles[7]; learning and the acquisition of specialized external capabilities[8]; and a shift of market penetration strategies from established to new and unknown markets[9].

3. Wilkins, M., 1970, *The Emergence of Multinational Enterprise,* Harvard University Press, Cambridge MA.
4. See for example: Dunning, John, 1981, *International Production and the Multinational Enterprise,* George Allen & Unwin, London.
5. Dicken, Peter, 1992, *Global Shift: The Internationalization of Economic Activity,* London: Paul Chapman, 2nd edition.
6. Kogut, Bruce, 1985, "Designing Global Strategies: Profiting from Operational Flexibility," Sloan *Management Review,* fall; and Kogut, Bruce and N. Kulatilaka, 1994, "Operating Flexibility, Global Manufacturing, and the Option Value of a Multinational Network," *Management Science,* 40, 1, January.
7. Flaherty, Theresa, 1986, "Coordinating International Manufacturing and Technology," in Michael Porter (ed.), *Competition in Global Industries,* Boston, Harvard Business School Press.
8. Antonelli, C. (ed.), 1992, *The Economics of Information Networks,* Elsevier North Holland, Amsterdam; Kogut, Bruce and U. Zander, 1993, "Knowledge of the Firm and the Evolutionary Theory of the Multinational Corporation," *Journal of International Business Studies,* fourth quarter; Zander U. and Bruce Kogut, 1995, "Knowledge and the Speed of the Transfer and Imitation of Organizational Capabilities: An Empirical Test," *Organizational Science* 6; Zanfei, A., 2000, "Transnational firms and the changing organisation of innovative activities", *Cambridge Journal of Economics* 24: 515-542; Dunning, John (ed.), 2000, *Regions, Globalization and the Knowledge-Based Economy,* Oxford University Press.
9. Christensen, C. M., 1997, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail,* Boston, Harvard Business School Press.

In response to the increasingly demanding requirements of global competition, three interrelated transformations have occurred in the organization of international economic transactions. First, global production networks (GPN) have proliferated as a major organizational innovation in global operations[10]. Second, these networks have acted as a catalyst for international knowledge diffusion, providing new opportunities for local capability formation in lower-cost locations outside the industrial heartlands of North America, Western Europe and Japan. Third, a long-term process of "digital convergence"[11], enabling the same infrastructure to accommodate manipulation and transmission of voice, video, and data, has created new opportunities for organizational learning and knowledge exchange across organizational and national boundaries, hence magnifying the first two transformations.

The combination of these three transformations has changed dramatically the international geography of production and innovation. We focus on the first two of these transformations[12]. The first transformation signals a new divide in industrial organization: a transition is under way from "multinational corporations", with their focus on standalone overseas investment projects, to "global network flagships" that integrate their dispersed supply, knowledge and customer bases into global (& regional) production networks[13]. There is a growing acceptance in the literature that, to capture the impact of globalization on industrial organization and knowledge diffusion, the focus of research needs to move from the industry and the individual firm to the international dimension of business networks[14].

But our understanding of these networks is limited. Research on GPN is at the formative stage and shares three common weaknesses. First, most studies have focused too narrowly on the perspective of the network flagship ("flagship bias")[15].

10. Borrus, M., D. Ernst, and S. Haggard (eds.), 2000, *International Production Networks in Asia. Rivalry or Riches?* Routledge, London etc.
11. Chandler, A.D. and J.W. Cortada, 2000, "The Information Age: Continuities and Differences", chapter 9 in: Chandler, A. D. and J.W. Cortada (eds.), *A Nation Transformed by Information,* Oxford University Press, Oxford and New York.
12 The impact of "digital convergence" is addressed in Ernst, D., 2001, "Digital Information Systems and Global Flagship Networks - A New Divide in Industrial Organization", paper, the International Richard Nelson and Sidney Winter Conference, Aalborg, Denmark, June 12-15, 2001, organized by the Danish Research Unit on Industrial Dynamics (DRUID) and 2001, "Digital Information Systems and Global Production Networks - Developmental Implications", to appear in: Latham, R. and S. Sassen, eds, Conflict and Cooperation in a Connected World, Social Science Research Council (SSRC), New York, forthcoming.
13. Ernst, D., 1997, "From Partial to Systemic Globalization. International Production Networks in the Electronics Industry", report prepared for the Sloan Foundation project on the Globalization in the Data Storage Industry, The Data Storage Industry Globalization Project Report 97-02, Graduate School of International Relations and Pacific Studies, University of California at San Diego (94 pages) and 2001, "The Economics of Electronics Industry: Competitive Dynamics and Industrial Organization", in: *The International Encyclopedia of Business and Management (IEBM),* editors: Malcolm Warner and William Lazonick.
14. Ghoshal, S. and C. A. Bartlett, 1990, "The Multinational Corporation as an Interorganizational Network", *Academy of management Review,* Vol.15, No.4, 603-625; Gereffi, Gary and Miguel Korzeniewicz (eds), 1994, *Commodity Chains and Global Capitalism,* Praeger, Westport, CT; UNCTAD, 1993, *World Investment Report, 1993: Transnational Corporations Integrated International Production,* Geneva; Rugman, A.M. and J. R. D´Cruz, 2000, *Multinationals as Flagship Firms. Re¬gional Business Networks,* Oxford University Press, Oxford and New York; Birkinshaw, J. and P. Hagstrøm (eds.), 2000, *The Flexible Firm. Capability Man¬agement in Network Organizations,* Oxford University Press, Oxford etc.
15. Rugman, A.M. and J. R. D´Cruz, 2000, *Multinationals as Flagship Firms. Regional Business Networks,* Oxford University Press, Oxford and New York.

We need research that explores as well implications for network suppliers, especially lower-tier suppliers from developing countries. Second, research has focused primarily on the geographic dispersion of tangible production, but tells us little about other aspects of global networks ("production bias"). While global networks in financial services are relatively well covered, we need research on the evolving global networks of business and information services[16]. Third, there is also an "R&D bias": research has focused narrowly on the relocation of R&D and strategic alliances primarily among regions in the US, Western Europe and Japan[17]. The impact of GPN on the diffusion of other forms of knowledge, especially knowledgeintensive support services, has been largely neglected, and this is true in particular for their diffusion to lower-cost locations.

We adopt a broader approach, analyzing as well the geographic dispersion of cross-functional, knowledge-intensive support services that are intrinsically linked with production, such as human resource management, global supply chain management, and knowledge management. Even if these activities do not involve formal R&D, they still give rise to considerable international knowledge diffusion and knowledge sharing[18].

Equally important is the second transformation: GPN in their operations reportedly disseminate important knowledge to local suppliers in low-cost locations, which could catalyze local capability formation. Knowledge transfer, however, is not automatic. It requires a significant level of absorptive capacity on the part of local suppliers and a complex process to internalize disseminated knowledge. But our understanding of knowledge transfer and local capability formation is limited. Inte national knowledge transfer has been extensively studied, but research has primarily focused on such formal mechanisms as foreign direct investment (FDI) and foreign licensing (FL)[19]. These formal mechanisms, however, are only the tip of the iceberg. A larger amount of knowledge is transferred through various informal mechanisms[20]. Research on informal knowledge transfer is scarce. The importance of local capa-

16. Such as research presented in Aharoni, Y. and L. Nachum (eds.), 2000, *Globalization of Services. Some Implications for Theory and Practice,* Routledge, London and New York.
17. Birkinshaw, J. and P. Hagstrøm, *The Flexible Firm;* Rugman, A.M. and J. R. D´Cruz, *Multinationals as Flagship Firms.*
18. Ernst, D., 2001, "Global Production Networks and the Changing Geography of Innovation Systems. Implications for Developing Countries", special issue of the Journal of the Economics of Innovation and New Technologies , on "Integrating Policy Perspectives in Research on Technology and Economic Growth", edited by Anthony Bartzokas and Morris Teubal.
19. Reddy, N.M. and Zhao, L., 1990, "International technology transfer: a review".
20. Westphal, Larry, Linsu Kim, and Carl Dahlman, 1985, "Reflections on the Republic of Korea's Acquisition of Technological Capability," in Nathan Rosenberg and Claudio Frischtak (eds.) *International Technology Transfer: Concepts, Measures, and Comparisons,* New York, Praeger, 167-221; Kim, Linsu, 1991, "Pros and Cons of International Technology Transfer: An Developing Country View" in Tamir Agmon and Mary Ann von Glinow (eds.), *Technology Transfer in International Business,* New York, Oxford University Press, 223-239; 1997, *Imitation to Innovation: The Dynamics of Korea's Technological Learning,* Boston, Harvard Business School Press; Ernst, Dieter, T. Ganiatsos and Lynn Mytelka, 1998, *Technological Capabilities and Export Success: Lessons from East Asia,* London, Routledge; Ernst, Dieter, 2000, "Inter-Organizational Knowledge Outsourcing: What Permits Small Taiwanese Firms to Compete in the Computer Industry? *Asia Pacific Journal of Management,* 17, 2, 223-255.

bilities in assimilating, adapting, and improving imported technology has long been recognized, but few studies exist on the complex process of local capability formation in developing countries.

2. Forces Driving Global Production Networks

What has driven the shift in industrial organization from "multinational corporations" to "global network flagships" that integrate their dispersed supply, knowledge and customer bases into global (& regional) production networks? To answer this question, we introduce a stylized model of globalization drivers, focusing on three interrelated explanatory variables: institutional change through liberalization, information technology, and competition.

2.1. Institutional Change: Liberalization

North[21] defines institutions as "the rules of the game of a society that structure human interaction." They are composed of formal rules (statute law, common law, regulations), informal constraints (conventions, norms of behavior, and self-imposed codes of conduct), and the enforcement characteristics of both. Institutions shape the allocation of resources, the rules of competition and firm behavior.

We take liberalization as convenient shorthand for institutional changes that affect globalization. Liberalization dates back to the early 1970s: it thrived in response to the breakdown of fixed exchange rate regimes and the failure of Keynesianism to cope with pervasive stagflation. To a large degree, it has been initiated by government policies. But there are also other actors that have played an important role: financial institutions; rating agencies; supra-national institutions like bi-lateral or multi-lateral investment treaties and regional integration schemes, like the EU or NAFTA. In some countries with decentralized devolution of political power, regional governments can also play an important role.

Liberalization includes four main elements: trade liberalization; liberalization of capital flows; liberalization of FDI policies; and privatization. While each of these has generated separate debates in the literature, they hang together. Earlier success in trade liberalization has sparked an expansion of trade and FDI, increasing the demand for cross-border capital flows. This has increased the pressure for a liberalization of capital markets, forcing more and more countries to open their capital accounts. In turn this has led to a liberalization of FDI policies, and to privatization tournaments.

The overall effect of liberalization has been a considerable reduction in the cost and risks of international transactions and a massive increase in international liquid-

21. North, D. C., 1996, "Institution, Organizations, and Market Competition," keynote address to the Sixth Conference of the International Joseph Schumpeter Society, Stockholm, 2-5 June; 12.

ity. Global corporations (the network flagships) have been the primary beneficiaries: liberalization provides them with a greater range of choices for market entry between-trade, licensing, subcontracting, franchising, etc. *(locational specialization)* than otherwise; it provides better access to external resources and capabilities that a flagship needs to complement its core competencies *(outsourcing)*; and it has reduced the constraints for a geographic dispersion of the value chain *(spatial mobility).*

We also need to emphasize a perplexing result: as liberalization has been adopted as an almost universal policy doctrine, it has lost much of its earlier power to influence locational decisions. As their FDI policies become indistinguishable, host countries are forced to differentiate themselves by other means, and to implement much more aggressive policies. The result has been a rapid proliferation of *complementary* policies geared to *business facilitation* and the development of *created assets.* This explains why a replication of clustering effects at multiple locations is now a realistic option.

2.2. The Dual Impact of Information and Communication Technology

A second important driver of GPN has been the rapid development and diffusion of information and communication technology (IT). These technologies have had a dual impact: they increase the need and create new opportunities for globalization. This argument is based on two propositions. First, the cost and risk of developing IT has been a primary cause for *market* globalization: international markets are required to amortize fully the enormous R&D expenses associated with rapidly evolving process and product information technologies[22]. Of equal importance are the huge expenses for IT-based organizational innovations[23]. As the extent of a company´s R&D effort is determined by the nature of its technology and competition rather than its size, this rapid growth of R&D spending requires a corresponding expansion of sales, if profitability is to be maintained. No national market, not even the US market, is large enough to amortize such huge expenses.

A second proposition explains why international production rather than exports have become the main vehicle for international market share expansion. Of critical importance has been the enabling role played by IT: it has substantially increased the mobility, i.e. dispersion of firm-specific resources and capabilities across national boundaries; it also provides greater scope for cross-border linkages, i.e.the integr tion of dispersed specialized clusters. This has substantially reduced the friction of time and space, both with regard to markets and production: a firm can now serve

22. Kobrin, S.J., 1997, "The Architecture of Globalization: State Sovereignty in a Networked Global Economy", in: J.H. Dunning (ed.), *Governments, Globalization and International Business,* Oxford University Press, London etc., 149.
23. Brynjolfson, E. and L.M. Hitt, 2000, "Beyond Computation: Information Technology, Organizational Transformations and Business Performance", manuscript, Sloan School of Management, MIT, July; Ernst, Dieter and D. O'Connor, 1992, *Technology and Global Competition: The Challenge for Newly Industrializing Economies,* OECD Development Centre Studies, Paris, chapter 1.

distant markets equally well as local producers; it can also now disperse its value chain across national borders in order to select the most cost-effective location.

In addition, IT and related organizational innovations provide effective mechanisms for constructing flexible infrastructures that can link together and coordinate economic transactions at distant locations[24]. This has important implications for organizational choices and locational strategies of firms. In essence, IT fosters the development of leaner, meaner and more agile production systems that cut across firm boundaries and national borders. The underlying vision is that of a network of firms that enable a global network flagship to respond quickly to changing circumstances, even if much of its value chain has been dispersed.

2.3. Competition and Industrial Organization

Together with liberalization, IT has drastically changed the dynamics of competition. Again, we reduce the complexity of these changes and concentrate on two impacts: a broader geographic scope of competition; and a growing complexity of competitive requirements. Competition now cuts across national borders - a firm´s position in one country is no longer independent from its position in other countries[25]. This has two implications. The firm must be present in all major growth markets *(dispersion).* It must also integrate its activities on a worldwide scale, in order to exploit and coordinate linkages between these different locations *(integration)*. Competition also cuts across sector boundaries and market segments: mutual rai ding of established market segment fiefdoms has become the norm, making it more difficult for firms to identify market niches and to grow with them.

This has forced firms to engage in complex strategic games to pre-empt a competitors' move. This is especially the case for knowledge-intensive industries like electronics[26]. Intense price competition needs to be combined with product differentiation, in a situation where continuous price wars erode profit margins. Of critical importance, however, is speed-to-market: getting the right product to the largest volume segment of the market right on time can provide huge profits. Being late can be a disaster, and may even drive a firm out of business. The result has been an increasing uncertainty and volatility, and a destabilization of established market leadership positions[27].

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24. Hagstrøm, P., 2000, "New Wine in Old Bottles: Information Technology Evolution in Firm Strategy and Structure", in: Birkinshaw, J. and P. Hagstrøm (eds.), 2002, *The Flexible Firm. Capability Management in Network Organizations,* Oxford University Press, Oxford etc.; Antonelli, C., 1992, (ed.), *The Economics of Information Networks,* Elsevier North Holland, Amsterdam.
25. Porter, M., 1990, *The Competitive Advantage of Nations,* Macmillan, London.
26. Ernst, D., 2001, "The Economics of Electronics Industry: Competitive Dynamics and Industrial Organization", in: Warner, M. and W. Lazonick, *The International Encyclopedia of Business and Management (IEBM),* Thomson Learning, London.
27. Richardson, G.B., 1996, " Competition, Innovation and Increasing Returns", DRUID Working Paper #96-10, Department of Business Studies, Aalborg University, July; Ernst, D., 1998, "High-Tech Competition Puzzles. How Globalization Affects Firm Behavior and Market Structure in the Electronics Industry", *Revue d`Economie Industrielle,* No.85.

This growing complexity of competition has changed the determinants of firm organization and growth, as well as the determinants of location. No firm, not even a dominant market leader, can generate all the different capabilities internally that are necessary to cope with the requirements of global competition. Competitive success thus critically depends on a capacity to selectively source specialized capabilities outside the firm that can range from simple contract assembly to quite sophisticated design capabilities. This requires a shift from individual to increasingly collective forms of organization, from the multidivisional (M-form) functional hierarchy[28] of "multinational corporations" to the networked global flagship model[29].

Take the electronics industry, which has become the most important breeding ground for this new industrial organization model. Over the last decades, a massive process of vertical specialization has segmented an erstwhile vertically integrated industry into closely interacting horizontal layers[30]. An important catalyst was the availability of standard components, which allowed for a change in computer design away from centralized (IBM mainframe) to decentralized architectures (PC, and PC-related networks). This has given rise to the co-existence of complex, globally organized product- specific value chains (e.g., for microprocessors, memories, board assembly, PCs, operating systems, applications software, and networking equipment).

Each of these value chains consists of a variety of GPN that compete with each other, but that may also cooperate[31]. The number of such networks, and the intensity of competition varies across sectors, reflecting their different stage of development and their idiosyncratic industry structures. Until recently, these fundamental changes in the organization of international production have been largely neglected in the literature, both in research on knowledge spill-over through FDI, and in research on the internationalization of corporate R&D.

3. Global Production Networks: Structure and Characteristics

3.1. The Network Flagship Model

The concept of a GPN covers both intra-firm and inter-firm transactions and forms of coordination (see Figure 1): it links together the flagship´s own subsidiaries, affiliates

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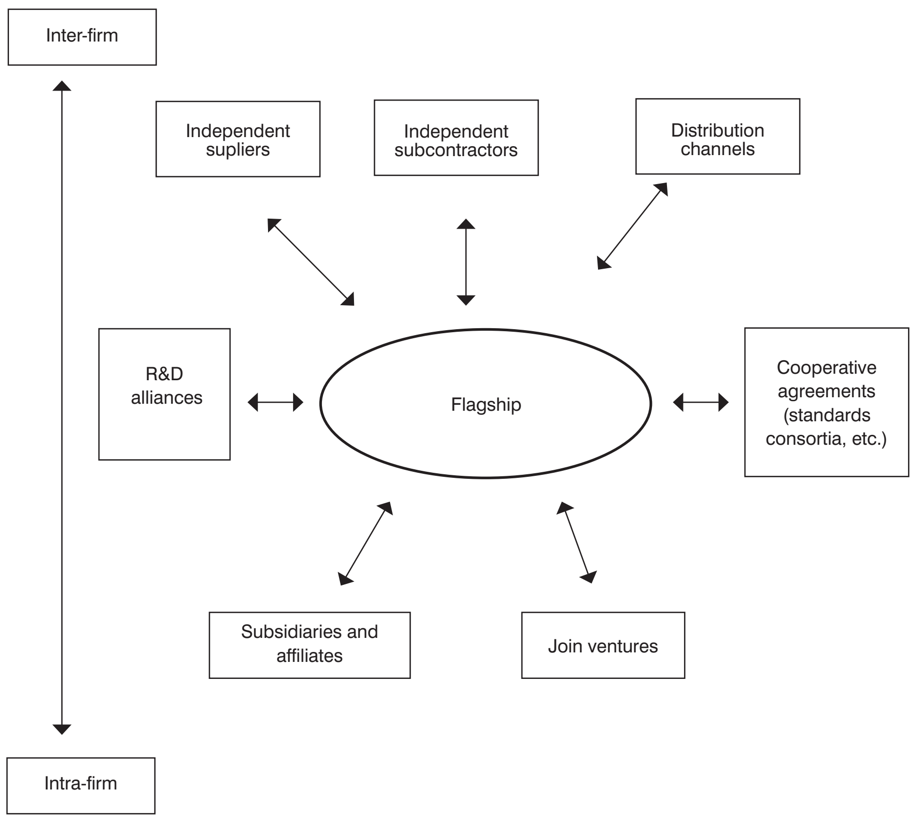
28. Williamson, O.E., 1975, *Markets and Hierarchies: Analysis and Antitrust Implications,* New York, The Free Press; Chandler, A.D., 1977, *The Visible Hand: the managerial Revolution in American Business,* Harvard University Press, Cambridge MA.
29. Ernst, D., 2001, "Digital Information Systems and Global Flagship Networks - A New Divide in Industrial Organization", paper, the International Richard Nelson and Sidney Winter Conference, Aalborg, Denmark, June 12-15, 2001, organized by the Danish Research Unit on Industrial Dynamics (DRUID).
30. Grove, A.S., 1996, *Only the Paranoid Survive. How to Exploit the Crisis Points that Challenge Every Company and Career,* Harper Collins Business, New York and London.
31. Ernst, D., 2001, "Global Production Networks and the Changing Geography of Innovation Systems. Implications for Developing Countries", special issue of the *Journal of the Economics of Innovation and New Technologies* on "Integrating Policy Perspectives in Research on Technology and Economic Growth", edited by Anthony Bartzokas and Morris Teubal.

and joint ventures with its subcontractors, suppliers, service providers, as well as partners in strategic alliances[32]. These arrangements may, or may not involve ownership of equity stakes. A network flagship like IBM or Intel breaks down the value chain into a variety of discrete functions and locates them wherever they can be carried out most effectively, where they improve the firm's access to resources and capabilities and where they are needed to facilitate the penetration of important growth markets.

Figure 1: The nodes of a global production network



32. Ernst, D., 1997, "Partners in the China Circle? The Asian Production Networks of Japanese Electronics Firms", in: Barry Naughton (ed.), The China Circle, The Brookings Institution Press, Washington, D.C.; 1997b, *From Partial to Systemic Globalization. International Production Networks in the Electronics Industry,* report prepared for the Sloan Foundation project on the Globalization in the Data Storage Industry, The Data Storage Industry Globalization Project Report 97-02, Graduate School of International Relations and Pacific Studies, University of California at San Diego; 2001, "Global Production Networks and the Changing Geography of Innovation Systems. Implications for Developing Countries", special issue of the *Journal of the Economics of Innovation and New Technologies* on "Integrating Policy Perspectives in Research on Technology and Economic Growth", edited by Anthony Bartzokas and Morris Teubal.

The main purpose of these networks is to provide the flagship with quick and low-cost access to resources, capabilities and knowledge that are complementary to its core competencies. In other words, transaction cost savings matter. Yet, the real benefits result from the dissemination, exchange and outsourcing of knowledge and complementary capabilities.

A focus on international knowledge diffusion through an extension of firm orga-nization across national boundaries distinguishes our concept of GPN from network theories developed by sociologists, economic geographers and innovation theorists that focus on localized, mostly inter-personal networks[33]. The central problem of these theories is that industries now operate in a global rather than a localized setting[34]. Important complementarities exist, however, with work on global commodity chains (GCC)[35]. A primary concern of the GCC literature has been to explore how different value chain stages in an industry (i.e. textiles) are dispersed across borders and how the position of a particular location in such GCC affects its development potential.

As for the dynamics of network evolution, our approach differs fundamentally from the transaction cost approach to networks and vertical disintegration that centers on the presumed efficiency gains from these organizational choices[36]. This approach skips some of the more provocative chapters in the economic history of the modern corporation. Chandler's vibrant histories (e.g., 1962) show that the quest for profits and market power via increased throughput and speed of coordination were more important in explaining hierarchy than the traditional emphasis on transaction costs. This implies that the analysis of the determinants of institutional form must shift away from the narrow focus on transactions costs to the broader competitive environment in which firms operate. It is time to bring back into the analysis market structure and competitive dynamics, as well as the role played by knowledge and innovation.

Our concept of GPN similarly points to these often-overlooked dimensions of organizational choice. Like hierarchies, GPN not only promise to improve efficiency, but can permit flagships to sustain quasi-monopoly positions, generate market power through specialization, and raise entry barriers[37]; they also enhance the net-

33. Powell, W. and L. Smith-Doerr, 1994, "Networks and Economic Life", in: N. Smelser and R. Swedber (eds.), *The Handbook of Economic Sociology,* Princeton University Press, Princeton, 368-402.
34. Ernst, D., P. Guerrieri, S. Iammarino, and C. Pietrobelli, 2001, "New Challenges for Industrial Districts: Global Production Networks and Knowledge Diffusion", concluding chapter, in: Guerrieri, P., S. Iammarino, and C. Pietrobelli (eds.), *Small Enterprise Clusters in Globalized Industries - Italy and Taiwan,* Edward Elgar, Aldershot.
35. Gereffi, Gary and Miguel Korzeniewicz, *Commodity Chains and Global Capitalism.*
36. Williamson, O.E., 1985, *The Economic Institutions of Capitalism, Firms, Markets and Relational Contracts,* New York, The Free Press; Williamson, O.E., 1998, "Strategy Research: Governance and Competence perspectives", Haas School of Business, University of California, manuscript, June; Milgrom, P. and J. Roberts, 1992, "The Economics of Modern manufacturing: Technology, Strategy, and Organization", *The American Economic Review,* Vol. 80, no.3: 511- 528.
37. Ernst, D., 2001, "The Economics of Electronics Industry: Competitive Dynamics and Industrial Organization".

work flagships´ capacity for innovation[38]. These considerations are of particular concern for developing countries' integration into GPN, and their capacity to strengthen their local capabilities. Two distinctive characteristics of GPN shape the scope for international knowledge diffusion: a rapid yet concentrated dispersion of value chain activities, and, simultaneously, their integration into hierarchical networks.

3.2. Concentrated Dispersion

GPN typically combines a breath-taking speed of geographic dispersion with spatial concentration: much of the recent cross-border extension of manufacturing and services has been concentrated on a growing, but still limited number of specialized lower-cost clusters. Apart from the usual suspects in Asia (Korea, Taiwan, China, Malaysia, Thailand, and now also India), this includes once peripheral locations in Europe (e.g., Ireland, Central and Eastern Europe and Russia), Brazil, Mexico, and Argentina in Latin America, some Carribbean locations (like Costa Rica), and a few spots elsewhere in the so-called RoW (= rest of the world).

The inclusion of these clusters into GPN creates new opportunities for knowledge diffusion to local suppliers, which could catalyze local capability formation. Different clusters face different opportunities and constraints, depending on the product composition of the GPN. The degree of dispersion differs across the value chain: it increases, the closer one gets to the final product, while dispersion remains concentrated especially for critical precision components.

Let us look at some indicators in the electronics industry, a pace setter of GPN[39]. On one end of the spectrum is final PC assembly that is widely dispersed to major growth markets in the US, Europe and Asia. Dispersion is still quite extended for standard, commodity-type components, but less so than for final assembly. For instance, flagships can source keyboards, computer mouse devices and power switch supplies from many different sources, both in Asia, Mexico and the European periphery, with Taiwanese firms playing a major role as intermediate supply chain coordinators. The same is true for lower-end printed circuit boards. Concentration of dispersion increases, the more we move toward more complex, capital-intensive precision components: memory devices and displays are sourced primarily from Japan, Korea, Taiwan and Singapore; and hard disk drives from a Singapore-centered triangle of locations in Southeast Asia. Finally, dispersion becomes most concentrated for high-precision, design-intensive components that pose the most demanding requirements on the mix of capabilities that a firm and its cluster needs to master:

38. Lazonick, W., 2000, *Understanding Innovative Enterprise: Toward the Integration of Economic Theory and Business History,* manuscript, University of Masachusetss Lowell and The European Institute of Business Administration (INSEAD), Fontainebleau, May.
39. Ernst, D., 2001, "Global Production Networks and the Changing Geography of Innovation Systems. Implications for Developing Countries".

microprocessors for instance are sourced from a few globally dispersed affiliates of Intel, two secondary American suppliers, and one recent entrant from Taiwan, Via Technologies.

The hard disk drive (HDD) industry provides another example both for quick dispersion, as well as for spatial concentration. Until the early 1980s, almost all HDD production was concentrated in the U.S., with limited additional production facilities in Japan and Europe. Today, only 1 percent of the final assembly of HDDs has remained in the US, while Southeast Asia dominates with almost 70% of world production, based on units shipped. Slightly less than half of the world´s disk drives come from Singapore, with most of the rest of the region´s production being concentrated in Malaysia, Thailand, and the Philippines.

Seagate, the current industry leader, provides a good example of the flagship model of concentrated dispersion. Today, Seagate operates 22 plants worldwide: 14 of these plants, i.e. 64% of the total, are located in Asia. Asia's share in Seagate's worldwide production capacity, as expressed in sq-ft, has increased from roughly 35% in 1990 to slightly more than 61% in 1995 - an incredible speed of expansion. Concentrated dispersion is also reflected in the regional breakdown of Seagate's employment. Asia's share increased from around 70% in 1990 to more than 85% in 1995.

In short, rapid cross-border dispersion coexists with agglomeration. GPN extend national clusters across national borders. This implies two things: First, some stages of the value chain are internationally dispersed, while others remain concentrated. And second, the internationally dispersed activities typically congregate in a limited number of overseas clusters. This clearly indicates that agglomeration economies continue to matter, hence the path-dependent nature of development trajectories for individual specialized industrial clusters.

3.3. Integration: Hierarchical Layers of Network Participants

A GPN encompasses both intra-firm and inter-firm linkages and integrates a diversity of network participants who differ in their access to and in their position within such networks, and hence face very different opportunities and challenges for GPN. This implies that GPN do not necessarily give rise to less hierarchical forms of firm organization[40]. GPN typically consist of various hierarchical layers that range from network flagships that dominate such networks, down to a variety of usually smaller, local specialized network suppliers. This taxonomy helps to assess the different capacities of these firms to benefit from knowledge diffusion and to upgrade local capability formation.

40. As predicted for instance in Bartlett, C.A. and S. Ghoshal, 1989, *Managing Across Borders: The Transnational Solution,* Harvard Business School Press, Boston, Mass.; Nohria, N. and R.G. Eccles, 1992, *Networks and Organizations: Structure, Form, and Action,* Harvard Business School Press, Boston, Mass.

Network Flagships

We distinguish two types of global flagships: i) "brand leaders" (BL), like Cisco, GE, IBM, Compaq or Dell; and ii) "contract manufacturers" (CM), like for instance Solectron or Flextronics, that establish their own GPN to provide integrated global supply chain services to the "global brand leaders". Cisco is an interesting example of a "brand leader": its GPN connects the flagship to 32 manufacturing plants worldwide. These suppliers are formally independent, but they go through a lengthy process of certification to ensure that they meet Cisco´s demanding requirements. Outsourcing volume manufacturing and related support services enable "brand leaders" to combine cost reduction, product differentiation and time-to-market. Equally important are financial considerations: getting rid of low-margin manufacturing helps the BL to in-crease shareholder returns[41].

"Contract manufacturers" have rapidly increased in importance since the mid-1990s. This represents an acceleration of a long-standing trend towards vertical specialization in the electronics industry[42]. The role model of CM-type network flagships is Solectron that only a few years ago was a typical SME, but has transformed itself into the electronics industry`s largest CM. With an average growth rate of 43% over the past five years, Solectron has increased its worldwide locations from about 10 in 1996 to almost 50 today[43]. The company defines itself now as a global supply chain facilitator: global brand leaders "… can turn to Solectron at any stage of the supply chain, anywhere in the world, and get the highest-quality, mostflexible solutions to optimize their existing supply chains[44]".

The flagship is at the heart of a network: it provides strategic and organizational leadership beyond the resources that, from an accounting perspective, lie directly under its management control[45]. The strategy of the flagship company thusdirectly affects the growth, the strategic direction and network position of lower-end participants, like specialized suppliers and subcontractors. The latter, in turn, " have no reciprocal influence over the flagship strategy"[46]. The flagship derives its strength from

41. Other important drivers of outsourcing include hedging against damage due to volatile markets and periodic excess capacity; and scale economies: surface-mount-technology (SMT) requires large production runs, reflecting its growing capital and knowledge intensity.
42. Mowery, D.C. and J.T. Macher, 2001, "E-Business and the Semiconductor Industry Value Chain: Implications for Vertical Specialization and Integrated Semiconductor Manufacturers".
43. Luethje, Boy, 2001, "Electronics Contract Manufacturing: Transnational Production Networks, the Internet, and Knowledge Diffusion in Low-cost Locations in Asia and Eastern Europe".
44. Solectron, 2000, "What is a Global Supply-Chain Facilitator?" at www.solectron.com, p. 1.
45. Rugman, A. M., 1997, "Canada," Chapter 6 in J. H. Dunning (ed.) *Governments, Globalization and International Business,* London, Oxford University Press, 182.
46. Rugman, A.M. and J. R. D´Cruz, 2000, *Multinationals as Flagship Firms.* Regional Business Networks. With Rugman`s flagship model, we share the emphasis on the hierarchical nature of these networks. However, there are important differences. Rugman and D`Cruz focus on localized networks within a region; they also include "non-business infrastructure" as "network partners". We do not share their assumption that a combination of transaction cost and resource-based theory is sufficient to explain such forms of business organization.

its control over critical resources and capabilities that facilitate innovation[47], and from its capacity to coordinate transactions and knowledge exchange between the different network nodes. Both are the sources of its superior capacity for generating profits.

Increasing vertical specialization is the fundamental driver of this flagship model of industrial organization[48]. Flagships retain in-house activities in which they have a particular strategic advantage; they outsource those in which they do not. It is important to emphasize the diversity of such outsourcing patterns[49]. Some flagships focus on design, product development and marketing, outsourcing volume manufacturing and related support services. Other flagships outsource as well a variety of high-end, knowledge-intensive support services. This includes for instance trial production (prototyping and ramping-up), tooling and equipment, benchmarking of productivity, testing, process adaptation, product customization and supply chain coordination. It may also include design and product development.

The result is that an increasing share of the value-added becomes dispersed across the boundaries of the firm as well as across national borders. Even if these activities do not involve formal R&D, they may still require a substantial diffusion of knowledge. Take the spread of “turnkey production arrangements” in the PC industry[50]: a flagship (e.g., Compaq) out-sources all stages of the value-chain for a particular PC family, except marketing; and a local lead supplier (e.g., in Taiwan) is responsible for the design and development of new products, as well as for manufacturing, transport and after-sales services, delivered through its own mini-GPN.

Local Suppliers

This example brings us to the role of local network suppliers and the factors that determine their network position. “Turnkey production arrangements” illustrate a tendency of flagships to extend outsourcing to comprise an integrated package of higherend support services, to be provided by a local lead supplier. Greatly simplifying, we distinguish two types of local suppliers[51]: higher-tier “lead suppliers” and lower-tier suppliers.

“Higher-tier” suppliers, like for instance Taiwan´s Acer group[52] play an intermediary role between global flagships and local suppliers. They deal directly with global

47. Lazonick, W., 2000, *Understanding Innovative Enterprise: Toward the Integration of Economic Theory and Business History.*
48. Ernst, D., 2001, “The Economics of Electronics Industry: Competitive Dynamics and Industrial Organization”.
49. Mowery, D.C. and J.T. Macher, 2001, “E-Business and the Semiconductor Industry Value Chain: Implications for Vertical Specialization and Integrated Semiconductor Manufacturers”; Ernst, D., 1997, From Partial to Systemic Globalization. International Production Networks in the Electronics Industry.
50. Ernst, Dieter, 2000, “Inter-Organizational Knowledge Outsourcing: What Permits Small Taiwanese Firms to Compete in the Computer Industry? *Asia Pacific Journal of Management,* 17, 2, 223-255.
51. We do not consider arms´ -length suppliers of standard (off-the-shelf) equipment and components. In reality there are of course many more layers of local suppliers that hang together in complex and continuously evolving arrangements.
52. Ernst, D., 2000, “Placing the Networks on the Internet: Challenges and Opportunities for Managing in Developing Asia”.

flagships (both “brand leaders” and “contract manufacturers”); they possess valuable proprietary assets (including technology); and they have developed their own mini-GPN[53]. With the exception of hard-core R&D and strategic marketing that remain under the control of the network flagship, the lead supplier must be able to shoulder all steps in the value chain. As our example shows, it must even take on the coordination functions necessary for global supply chain management. This requires that the lead supplier develops dense linkages between geographically dispersed, yet concentrated and locally specialized clusters, integrating these into its own networks.

“Lower-tier” suppliers are in a much more precarious position. Their main competitive advantages are low cost and speed, and flexibility of delivery. They aretypically used as “price breakers” and “capacity buffers”, and can be dropped at short notice. This second group of local suppliers rarely deals directly with the global flagships; they interact primarily with local higher-tier suppliers. Lower-tier suppliers normally lack proprietary assets; their financial position is weak; and they are highly vulnerable to abrupt changes in markets and technology, and to financial crises.

This distinction helps us to explain why some suppliers are more prone than others to knowledge diffusion and capability development. In most cases, “higher-tier” suppliers can reap substantial benefits through knowledge diffusion, while “lower-tier” suppliers are unlikely to benefit, unless effective support institutions and policies are in place.

4. Global Production Networks and Knowledge Diffusion

Let us recapitulate the fundamental rationale of GPN: they help flagships to sustain their competitiveness, by providing them with access to specialized suppliers at lower-cost locations that excel in quick and flexible response to the flagships’ requirements. The flagships can exert considerable pressure on local suppliers, especially in small developing countries: they can discipline suppliers by threatening to drop them from the networks whenever they fail to provide the required services at low price and world class quality.

At the same time, GPN also act as powerful carriers of knowledge. First, flagships need to transfer technical and managerial knowledge to the local suppliers. This is necessary to upgrade the suppliers’ technical and managerial skills, so that they can meet the technical specifications of the flagships. Second, once a network supplier successfully upgrades its capabilities, this creates an incentive for flagships to transfer more sophisticated knowledge, including engineering, product and process development. This reflects the increasingly demanding competitive requirements that we referred to earlier. In the electronics industry for instance, product-life-cycles have been cut to six months, and sometimes less[54]. Overseas production thus frequently occurs soon after the launching of new products. This is only possible if

53. Chen, Tain-Jy and Chen Shin-Horng, 2002, “Global Production Networks and Local Capabilities: New Opportunities and Challenges for Taiwan,” *East West Center Working Paper: Economic Series #* 15, February.
54. Ernst, D., 2001, “The Economics of Electronics Industry: Competitive Dynamics and Industrial Organization”.

flagships share key design information more freely with overseas affiliates and suppliers. Speed-to-market requires that engineers across the different nodes of a GPN are plugged into the flagship´s designdebates (both on-line and face-to-face) on a regular basis.

Of course, knowledge transfer is not a sufficient condition for effectiveknowledge diffusion. Diffusion is completed only when transferred knowledge isinternalized and translated into the capability of the local suppliers[55]. Much depends on the types of knowledge involvedand the mechanisms that flagships use to disseminate different types of knowledge.Section 4 is devoted to these issues. Equally important for effective knowledge diffusion however are the motivations, resources and capabilities of local suppliers, an issue that we address in section 5.

4.1 The Categories of Knowledge

Knowledge may be classified into various categories depending on the purpose of its use. Polanyi[56] classified knowledge into explicit and tacit knowledge. Explicitknowledge refers to knowledge that is codified in formal, systematic language (*encoded* knowledge). It is knowledge that can be combined, stored, retrieved, and transmitted with relative ease and through various mechanisms. With the falling cost of information processing and communication, due to microprocessors, optical fibers and the Internet, it is expected that this will increase further the mobility of explicit knowledge, making it accessible worldwide in real time at minimal cost[57] reshaping established organizational arrangements, work practices and life styles.

But explicit knowledge is useful only when tacit knowledge enables individuals and organizations to make sense of and utilize it. Tacit knowledge refers to knowledge that is so deeply rooted in the human body and mind that it is hard to codify and communicate. It is knowledge that can only be expressed through action, commitment, and involvement in a specific context and locality. Tacit knowledge is based on experience: people acquire it through observation, imitation, and practice. Its diffusion requires apprentice-type training and face-to-face interaction. It can also be transferred, however, through the movement of human carriers of such knowledge, a fact that much of the literature on industrial districts used to neglect.

It is hard to exaggerate the importance of tacit knowledge. Nonaka (2001)[58] for instance argues that it accounts for three quarters of all knowledge used by firms.

55. Kim, Linsu, 1997, *Imitation to Innovation: The Dynamics of Korea's Technological Learning;* Ernst, Dieter, T. Ganiatsos and Lynn Mytelka. 1998. *Technological Capabilities and Export Success: Lessons from East Asia,* London, Routledge.
56. Polanyi, Michael, 1962, *Personal Knowledge: Towards a Post-Critical Philosophy,* Chicago, University of Chicago Press.
57. David, Paul and D. Foray, 1995, "Accessing and Expanding the Science and Technology Knowledge-base, STI Review, OECD, Paris.
58. Nonaka, Ikujiro, 2001, "Interview on "Knowledge management based on informationtechnology is a mistake", (in Korean), in *Maeil Kyungjae Shinmoon* (an economic daily published in Seoul), July 3.

Tacit knowledge is the key to the long-term growth of a firm: it provides the fertile intellectual ground for all knowledge management (Gelwick, 1976) and for the effective performance of an economy[59]. In the face of increasing uncertainties in globalization, tacit knowledge becomes even more important[60]. Many have attempted to unpackage the blackbox of tacit knowledge[61]. For our purpose, the following classification, first coined by Collins (1993)[62] and later expanded by Blackler (1995)[63], appear to be most useful. Tacit knowledge may become part of the human body as skills (*embodied* knowledge); part of human being as cognitive capacity (*embrained* knowledge); routinized in organizational practice (embedded knowledge); and inculcated in the organization as basic assumptions, beliefs and norms (*encultured* knowledge). Different types of tacit knowledge are associated with different aspects of organizational activities and with different degree of difficulties in transferring it.

4.2 Knowledge Transfer Mechanisms

Flagships transfer knowledge across borders through various mechanisms. First, the transfer may be mediated through the market, involving a formal contract for terms and conditions between the knowledge supplier and the knowledge buyer with payment involved. Knowledge may also be transferred informally without any payment involved. Second, the flagship may play an active role, exercising significant control over the way in which knowledge is disseminated to and used by the local supplier. Alternatively, the flagship may play a passive role, having almost nothing to do with the way the local supplier takes advantage of available knowledge that is either embodied in or disem-bodied from the physical items. These two dimensions —market— mediation and the role of flagships — offer a useful two-by-two matrix, as shown in Figure 2, to identify different mechanisms of knowledge transfer through global production networks[64].

59. Nelson, R. and S. G. Winter, (1982), An Evolutionary Theory of Economic Change.
60. Ernst, D. and Bengt-Åke Lundvall, 2000, "Information Technology in the Learning Economy - Challenges for Developing Countries" in: Erich Reinert (editor), *Evolutionary Economics and Income Inequality,* Edward Elgar Press, London.
61. Sparrow, John, 1998, *Knowledge in Organizations: Access to Thinking at Work,* London, Sage Press; Antonelli, C., 1998, *The Microdynamics of Technological Change,* Routledge, London etc.; Spender, J.-C., 1996, "Making Knowledge the Basis of A Dynamic Theory of the Firm," *Strategic Management Journal,* 17, 45-62.
62. Collins, H., 1993, "Structure of Knowledge," *Social Research,* 60, 95-116.
63. Blackler, Frank, 1995, "Knowledge, Knowledge Work, and Organizations: An Overview and Interpretation," *Organization Studies,* 16, 6, 121-146.
64. Kim, Linsu 1991, "Pros and Cons of International Technology Transfer: An Developing Country View" in Tamir Agmon and Mary Ann von Glinow (eds.) 42 Universidad Nacional Autónoma de México *Technology Transfer in International Business,* New York, Oxford University Press, 223-239.

Figure 2: Knowledge transfer mechanisms

Market mediation	Active	Passive
Market mediated	**Formal mechanisms** (FDI, FL, turnkey plants technical consultancies) (1)	**Commodity trade** (standard machinery transfer) (2)
Nonmarket mediated	**Informal mechanisms** (flagship provides Nonmarket technical assistance to local suppliers) (3)	**Informal mechanisms** (reverse engineering, observation, literature) (4)

Source: Adapted from Kim, 1997, page 101.

First, network flagships use largely formal mechanisms such as foreign direct in-vestment (FDI), foreign licensing (FL), technical consultancies, etc. in quadrant 1 to transfer knowledge to local suppliers, if the latter are subsidiaries or joint venture part-ners. For instance, when such flagships as Intel, Motorola, Texas Instruments, and Fairchild decided to outsource assembly operations of their semiconductor devices, they took the mechanisms of FDI, FL, and technical consultancies to establish their subsidiaries in the Philippines[65] and other countries in Southeast Asia. They owned a majority ownership in the subsidiaries, licensed and transferred a complete production system.

Second, independent local suppliers rely heavily on standard machinery in quadrant 2 to improve their productivity in production operations. Machinery is a major source of process innovation for their users[66]. Flagships are not necessarily the suppliers of the machinery, but they can play an important indirect role, by forcing independent local suppliers to purchase more sophisticated equipment to improve their production capabilities. For instance, Mando, one of the major auto components suppliers from Korea, purchased a series of robots to automate their production processes. Each of the robots embodied state-of-the-art production knowledge. The suppliers of the robots, however, had little influence over the way Mando used it.

65. Antonio, Emillio T., 2000, “Country Sector Study: Philippines,” paper presented at the Progress Review Meeting of the International Competitiveness of Asian Economies: A Cross-Country Study, Asian Development Bank, Manila, February 9-11, 2000.
66. Abernathy, William J. and Phillip L. Townsend, 1975, “Technology, Productivity, and Process Change,” *Technological Forecasting and Social Change,* 7.

Third, a more direct way for flagships to transfer knowledge to independent local suppliers are informal mechanisms in quadrant 3, largely through the original equipment manufacturing (OEM) arrangements. As in the quadrant 1, flagships actively transfer knowledge in the form of blue prints, technical specifications, and technical assistance, mostly free of charge, to independent local suppliers to ensure that products and services produced by the latter meet the former's technical specifications. For instance, Boeing outsources some parts of fuselage from independent local suppliers in Japan, Taiwan, and Korea. In doing so, Boeing actively provides the local suppliers technical literature, product specifications, and technical assistance to help them meet its specifications.

Fourth, independent local suppliers can also rely on knowledge transfer mechanisms in quadrant 4. Like in quadrant 2, flagships exert little direct influence over the way inde-pendent local suppliers use such mechanisms as reverse engineering, observations, and human mobility to expedite upgrading their capabilities. For instance, lower-tier suppliers in Asia undertake reverse engineering of foreign products not so much to produce imitative products as to acquire knowledge embodied therein. A group of lowertier suppliers often take an observation tour of foreign firms as a way to acquire new knowledge. The Small Industry Promotion Corporation and industry-related SME associations in Korea often organizes such observation tours. Human mobility in quadrant 4 includes not only the repatriation of top-rated engineers trained abroad but also the active use of experienced foreign engineers who are hired for short periods as socalled "moonlighters".

To what degree do the flagships use the knowledge transfer mechanisms? The shift from MNCs to global network flagships has expanded both the mechanisms and the volume of knowledge transfer. MNCs relied heavily on the mechanisms in quadrant 1 of Figure 2 in setting up their plants either for the penetration of protected markets or for exploiting differential factor costs. In contrast, flagships transfer knowledge not only through mechanisms in quadrant 1 but also through mechanisms in quadrant 3. Flagships also tend to transfer more knowledge to local suppliers than vertically integrated MNCs. These transfers are necessary to enable local suppliers to provide the flagship with competitive products and services, in line with the changing requirements of markets and technology. Section 4.2 explores how flagships transfer explicit and tacit knowledge to local suppliers. Let us now turn to the local prerequisites for effective knowledge diffusion: Under what can local suppliers internalize transferred knowledge and use it to enhance their own capabilities?

5. Local Capability Formation

Local suppliers can only effectively absorb knowledge disseminated by global network flagships, if they have developed their own capabilities. Knowledge internalization and capability building require individual and organizational learning. Individuals are the primary actors in learning and knowledge creation (Hedberg, 1981). They constitute local capabilities that may be combined at the organizational level. Organizational learning, however, is not the simple sum of individual learning. Only effective organizations can translate individual learning and capabilities into organizational learning and capabilities.

5.1 Concepts

Firms create knowledge primarily through the dynamic process of conversion between explicit and tacit knowledge[67]. Tacit-to-tacit conversion (called *socialization*) takes place when tacit knowledge of one individual is shared with others through training, whereas explicit-to-explicit conversion (*combination*) takes place when an individual or a group combines discrete pieces of explicit knowledge into a new whole. Tacit—to—explicit conversion (*externalization*) occurs when an individual or a group is able to articulate the foundations of individual tacit knowledge. Finally, explicitto— tacit conversion (*internalization*) takes place when new explicit knowledge is shared throughout the firm and other members begin to use it to broaden, extend, and reframe their own tacit knowledge. Such conversion tends to become faster in speed and larger in scale in a spiral process, as more actors in and around the firms become involved in knowledge conversion. Using Japanese examples, Nonaka and Takeuchi[68] develop a model that pictures organization knowledge creation as an upward spiral that starts from the individual and moves up to the organizational level.

For effective knowledge conversion to lead to productive learning, it requires two important elements are required (See Figure 3): an existing knowledge base (most of it tacit knowledge), and the intensity of effort. Of the two, the intensity of effort or commitment is more important than the knowledge base, as the former creates the latter, but not vice versa[69]. Cohen and Levinthal[70] call this "absorptive capacity". How fast and successfully the local suppliers internalize and translate transferred knowledge into their own capability through learning will be largely determined by their absorptive capacity and their ability to upgrade it continuously.

67. Nonaka, Ikujiro, 1991, "The Knowledge-Creating Company," *Harvard Business Review,* November-December, 96-104.
68. Nonaka, Ikujirpo and Hirotake Takeuchi, 1995, "The Knowledge Creating Company".
69. Ullrich, Dave, 1998, "Intellectual Capital = Competence x Commitment," *Sloan Management Review,* winter, 15-26.
70. Cohen, Wesley M. and Daniel A. Lavinthal, 1990, "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly,* 35, 1, 128-152.

Figure 3: Absorptive capacity of local suppliers

		Intensity of effort	
		High	Low
Existing knowledge base	High	High and rising rapidly (1)	High but falling (2)
	Low	Low but rising (3)	Low and falling rapidly (3)

Source: Adapted from Kim, 1997, page 98.

A large part of the existing knowledge base is tacit knowledge. We have seen that this type of knowledge shapes individual and organizational learning. Tacit knowledge enables the individual as well as the organization to use both explicit and tacit knowledge available elsewhere and to create new knowledge through various knowledge conversion activities in production and R&D. Tacit knowledge also influences the nature and direction of learning and is responsible for its path-dependency. For instance, it is the richness of tacit knowledge accumulated as part of the existing knowledge base that enables leading suppliers in Korea, Singapore, and Taiwan to implemented more sophisticated technological and organizational innovations than firms in other Southeast Asian countries.

The intensity of effort, on the other hand, determines the speed of knowledge conversion. It represents the amount of emotional, intellectual, and physical energy that members of an organization invest in acquiring and converting knowledge.

Exposure of individuals and firms to relevant external knowledge is insufficient, unless they make a conscious effort to internalize and use it. Learning how to solve complex problems is usually accomplished through trial-and-error involving a series of knowledge conversions. Hence, considerable time and effort must be directed to learning. For instance, Samsung was a late entrant in electronics but has evolved from OEM to ODM (own design manufacturing) and to OBM (own brand man-ufacturing) in both consumer and industrial electronics. It is on a par with Japanese and American competitors in areas such as semiconductor memory chips, flat panel display, and certain telecommunications technologies. These achievements are due to heavy investments in the development of the domestic knowledge base. For instance, Samsung`s R&D expenditures have soared from $8.5 million in 1980 to $905 million in 1994 and to $1.3 billion by 1999. As a result, its U.S. patents increased from 2 to 752 and to 1,549 during the same period. Samsung ranked 4th in 1999 only after IBM, NEC, and Cannon.

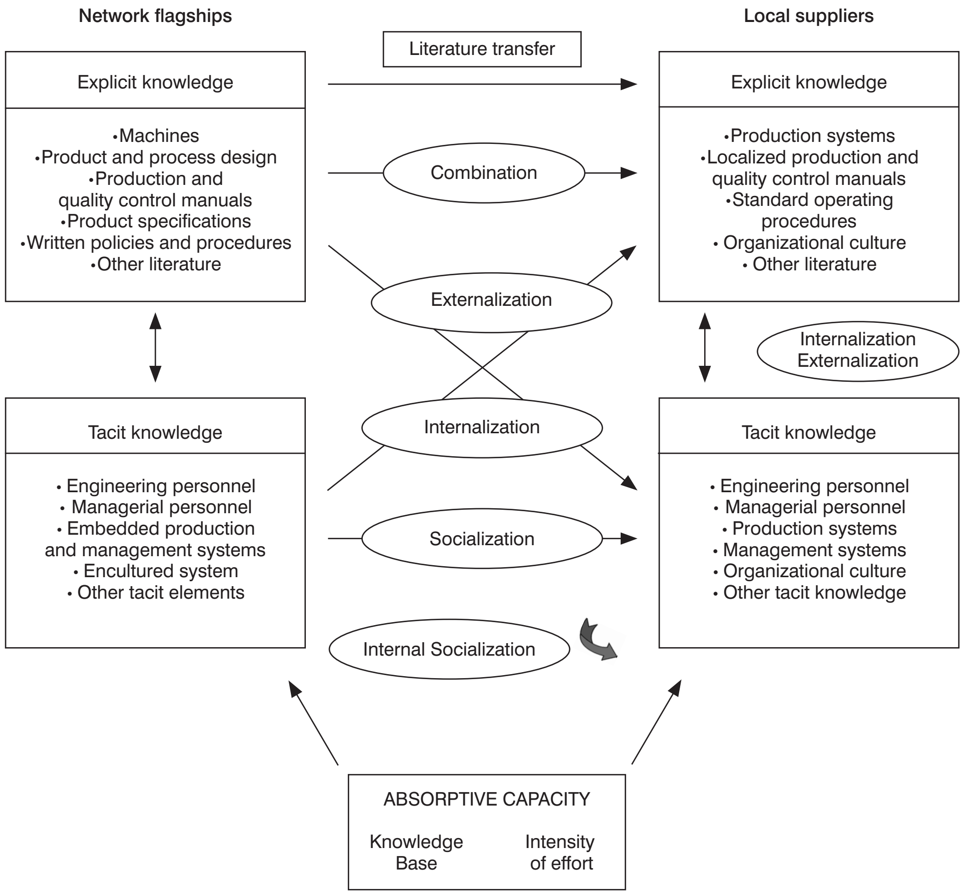
5.2. GPN as Mediators of Local Capability Formation

Let us now examine how GPN affect the development of capabilities by local suppliers. Let us first look at explicit knowledge. Flagships typically provide the local suppliers with encoded knowledge, such as machinery that embodies new knowledge, blueprints, production and quality control manuals, product and service specifications, and training handouts. This is done to assist the suppliers in building capabilities that are necessary to produce products and services with the expected quality and price. Personnel at the local suppliers read and try to assimilate the transferred explicit knowledge into their tacit knowledge (*internalization* in Figure 4). In most cases, the acquisition of explicit knowledge alone is not sufficient for the local suppliers to assimilate and use it in production, as the translation of explicit knowledge into actual operations requires a significant amount of tacit knowledge. Thus, to augment the explicit knowledge, flagship companies also invite engineers and managers of the local suppliers to the former's site to observe how actual production systems work and to receive a systematic training.

This can help to translate knowledge gained from the literature into actual operations *(internalization)*. It also enables local engineers to internalize how the flagships' organization and production systems are managed (*internalization* of *embedded* knowledge), and to absorb tacit knowledge directly transferred from foreign engineers through training *(socialization)*. Once they return home, however, these engineers confront various unforeseen problems in their attempts to translate what they have learned at the flag-ships into the operational systems that exist at home. For this reason, the flagships also send their own engineers *(embodied* and *embrained* knowledge) to help local engineers debug problems in engineering and manufacturing systems *(socialization).*

Take the case of subsidiaries or joint ventures. For instance, when Sony established Hwashin Electronics Company in Korea as a joint venture to outsource its Consumer electronics products, it supplied not only machinery and equipment for the mass-production system of its joint venture partner. Sony also provided blue prints of products, product specifications, and production and quality control manuals (encoded knowledge). In addition, the flagship invited a number of Korean engineers, technicians, and managers to undergo training at Sony's plant in Japan on production, organization, and human resource management, transferring embedded and encultured knowledge. Sony also dispatched a number of engineers and technicians to Korea to help Korean engineers debug problems encountered in operating and

Figure 4: The process of local capability formation



maintaining the production system and controlling the quality of products to ensure that Hwashin meet the technical specifications of Sony's products (*embodied* and *embrained* knowledge). Sony had done these knowledge transfer activities formally as part of its FDI and FL to Hwashin.

In the case of independent local suppliers, when General Electric decided to outsource its microwave ovens from Samsung under the OEM arrangements, it sent its engineers to Samsung to explain its technical specifications (*encoded* knowledge) and taught Samsung engineers master the engineering details of the product (*embrained* knowledge)[71]. GE had done all these knowledge transfer activities free of charge to ensure that Samsung's products meet GE's technical specifications.

Second, local suppliers may attempt to translate such explicit knowledge as production and quality control manuals, human resource management handbooks, and other literature transferred from flagships into their own production and quality control manuals and human resource management handbooks. They may be more compatible with local institutions and business behavior. Then a *combination* takes place from a set of explicit knowledge to a new set of explicit knowledge at the local suppliers. In this process, *externalization* of knowledge also takes place from tacit knowledge of local engineers and managers to explicit knowledge in the form a new set of manuals and handbooks. For instance, when Volvo took over the ownership of Samsung's heavy machinery division after the Asian crisis to turn it into its Asian supplier, Volvo introduced its own management systems, which reflects both Volvo's requirements and those shaped by local institutions. In developing a new set of manuals and handbooks, the ground was laid for *internal ization, combination* and *externalization.*

Third, the link with GPN also induces knowledge conversions within local suppliers. The key is the diffusion of locialized and internalized knowledge accumulated by a limited number of engineers and managers of the local suppliers through training provided by the network flagship. This knowledge needs to be diffused within local suppliers through spiral processes of socialization, as more actors in and around the firms get involved in knowledge conversion activities. *Externalization* and *internalization* take place internally, as actors convert from/to explicit to/from tacit knowledge within the local supplying firms, gradually developing embedded knowledge. For instance, Samsung Electronics recently sent a group of human resource management (HRM) specialists to GE to learn the latter's HRM system. Upon return, these special¬ists have conducted a series of seminars for HRM specialists in the firm to share the knowledge, leading to the development of new HRM policy and procedures and to the gradual formation of new embedded knowledge. Fourth, knowledge conversion cannot take place without the active intervention of tacit knowledge. This is true even for the conversion from explicit knowledge to explicit knowledge. Once again, this highlights how important it is for local suppliers to develop a rich tacit knowledge base. In other words, the effectiveness and speed of knowledge conversion will be determined not so much by quantity and quality of the knowledge transferred by the flagships as by the absorptive capacity of the local suppliers. This holds regardless of the knowledge transfer mechanisms. The strength of the domestic knowledge base determines the level of sophistication of the converted knowledge, while the intensity of effort accelerates the speed of the conversion pro-

71. Magaziner, Ian and Mark Patinkin, 1989, "Fast Heat: How Korea Won the Microwave War," *Harvard Business Review,* January, 83-93.

cesses. In turn, spiral processes of knowledge conversion determine the level of the company's internal knowledge base. Leading local suppliers thus invest heavily in recruiting the cream of the crop from universities; they also develop intensive training programs to upgrade the existing knowledge base.

Conclusions

Liberalization, digital convergence, and intensifying global competition have produced a major organizational innovation: a transition from "multinational corporations" that exploit labor cost differentials in different countries to "global network flagships" that integrate their dispersed supply, knowledge, and customer bases into global (or regional) production networks. The paper demonstrates that these networks have boosted international knowledge diffusion, providing new opportunities for capability formation by local suppliers in developing countries. Under pressure from flagships, local suppliers have a strong incentive to internalize transferred knowledge through various forms of knowledge conversion. The baseline however is the absorptive capacity of the local suppliers: it determines the effectiveness of capability formation.

Policy and Management Implications

Our analysis has important implications for global flagships and local suppliers. First, flagships should actively transfer to local suppliers not only encoded knowledge but also embrained, embedded, and encultured knowledge. Such a broad-based transfer of knowledge enhances the capabilities of local suppliers; it also strengthens the competitiveness of the flagships' global production networks.

Second, flagships might worry about a possible switching of local suppliers to other flagships, once the suppliers have reached a certain level of capabilities. The flagships can avoid this by raising the local suppliers' switching costs. This can be done by helping the local suppliers develop the network-specific embedded systems and organizational culture through the active transfer of such knowledge. Once the local suppliers develop a strong embedded procedures and culture, which is tuned to those of the flagship, it is costly to switch to other GPN.

Third, local suppliers need to take an active approach to maximize their benefits from network participation. Flagships place business orders and transfer valuable knowledge to local suppliers with only one objective in mind: to strengthen the competitiveness of their GPN. To maximize the benefit of such transfers, local suppliers must constantly upgrade their absorptive capacity. Their existing knowledge base is largely determined by the embrained knowledge of the firm. Local suppliers, therefore, should tap, develop, and retain highly skilled human resources for developing existing their knowledge base. More important is the intensity of effort. There may be various means to intensify effort. One possibility, illustrated by some Korean firms, is to construct a deliberate crisis by establishing ambitious goals[72].

Fourth, as flagships transfer valuable knowledge to the first-tier local suppliers to strengthen the competitiveness of their GPN, higher-tier local suppliers should also help lower-tier suppliers build capability by transferring valuable knowledge to them in order to strengthen their own competitiveness. The competitiveness of GPN is determined by the competitiveness of each of the nodes in the networks.

Priorities for Future Research. We have seen that GPN transform the production and use of knowledge, considerably enhancing the mobility of knowledge. This may have far-reaching implications for an evolutionary theory of economic change. We suggest four main priorities for future research.

A first priority is to move beyond the “flagship bias”. We need research on GPN, undertaken from the perspective of local suppliers that are located in small open economies and in developing countries. Some of the research questions include: Why do local suppliers join GPN? What are the advantages and disadvantages for local suppliers to take part in GPN? What are differences in learning and capability building between intra-firm suppliers and inter-firm suppliers?

A second research priority is to move beyond the current “production bias.” Digital convergence has created new opportunities for the exchange of knowledgeintensive services across organizational and national boundaries. We need research on the evolving global networks of business and information services, and especially on the transformation of these networks through the Internet[73]. Possible research questions include: What are idiosyncratic features of service- oriented GPN? How do production GPN and service GPN differ in terms of their mobility, location dynamics, and their capacity to enhance knowledge transfer? And how does knowledge transfer take place in service GPN?

Third, research needs to move beyond the current “R&D bias” and an exclusive preoccupation with the location of R&D and patents among major industrialized countries. We need to establish what forces explain that flagships are now beginning to outsource certain R&D activities to a handful of newly industrializing economies (NIEs) and even to some developing countries, and how this affects international knowledge transfer. Possible research questions include. What rationale explains such R&D outsourcing strategies to some NIEs? What distinguishes these arrangements from R&D alliances among leading American Japanese and European flagships? And how successful are the former arrangements?

Finally, we still know little about how GPN differ by country of origin. GPN are no longer the exclusive playground for American flagships. Asia´s electronics industry for instance is shaped to a large degree by the patterns of cooperation and competi-

72. Kim, Linsu 1997, *Imitation to Innovation;* 1998, “Crisis Construction and Organizational Learning: Dynamics of Capability Building in Catching-up at Hyundai Motor,” *Organization Science,* 506-521.
73. These issues are addressed in an international collaborative research project, coordinated by the East- West Center, on “How the Internet Transforms Global Flagship Networks? And What This Implies for Knowledge Diffusion?”

tion between networks that center on American flagships as well as on flagships from Japan, Europe, Taiwan, Singapore and Korea (Borrus, Ernst, and Haggard, 2000). This raises questions like[74]: How do these networks differ in terms of their basic characteristics, such as accessibility, permanence, flexibility to respond to market and technology shifts, and governance? How do they differ in terms of their impact on international knowledge transfer? Does nationality of ownership matter? And is diversity primarily a result of peculiar features of national institutions, or are there other forces at work?

74. Ernst and Ravenhill, 1999, explore the diversity of these networks in Asia, and the limits to convergence

Standards, Innovation, and Latecomer Economic Development – A Conceptual Framework

Dieter Ernst

Introduction

There is an abundance of theoretical and econometric studies of how standards shape market competition, but most of these studies have focused on Western economies, primarily those with Anglo-Saxon institutions. And even for Western economies, fundamental public policy issues of standards setting remain grossly under-researched. According to two leading scholars of standards policy, "… general agreement about appropriate public policy toward government standard setting does not exist. The most basic questions remain unaddressed[1]".

We know even less about the impact of standards on the economic development of countries which are latecomers to industrial manufacturing and innovation. Most of these countries are focused on upgrading their economies through innovation, as measured by patents. Standardization is regarded primarily as a technical issue, and hence receives only limited high-level policy support. However, China as well as Korea and Taiwan are now searching for ways to strengthen and upgrade their standardization systems and strategies.

In fact, standards contribute at least as much as patents to economic growth. As a key mechanism for the diffusion of technological knowledge, technical standards contribute to productivity growth. The macroeconomic benefits of standardization thus exceed the benefits to companies alone. For Germany, a widely quoted study conducted for the German Institute for Standardization (DIN) finds that a 1% increase in the stock of standards is positively associated with a 0.7 to 0.8% change in economic growth[2].

1. Greenstein, S., and V. Stango, 2007, "Introduction." *In Standards and Public Policy,* S. Greenstein and V. Stango (eds.), Cambridge, Cambridge University Press: 1–2.
2. Blind, K., A. Jungmittag, A. Mangelsdorf, 2011, *The Economic Benefits of Standardization,* DIN German Institute for Standardization, Berlin. Similar findings are reported for Australia, New Zealand, the UK, France, and Canada.

But these econometric studies only scratch the surface. Equally important are qualitative impacts for instance of environmental, health, food and work safety standards. In fact, broad qualitative impacts of standards are essential for latecomer economic development — a well-functioning standardization system and strategy can work as a catalyst for translating new ideas, inventions and discoveries into productivity-enhancing innovation. Standards are the missing link in a growth strategy which seeks to create quality jobs in higher-value added advanced manufacturing and services[3]. This poses an especially demanding challenge for countries which only recently begun to build up their standards systems and strategies.

Furthermore, rapid and disruptive technical change (such as the transition to the *Internet of Everything*[4]) creates new challenges for standardization. Of critical importance are interoperability standards that are necessary to transfer and render useful data and other information across geographically dispersed systems, organizations, applications, or components[5]. Rising complexity and increasing uncertainty are two defining characteristics of the new world of ubiquitous globalization. Technology-based competition is intensifying, and competitive success critically depends on control over intellectual property rights and on "a capacity to control open but owned architectural and interface standards"[6]. This process has increased the economic importance of standardization, but especially so for countries (like China and Korea) which are deeply integrated into international trade and global corporate networks of production and innovation[7].

In short, we need a conceptual framework that allows us to study how standards are created and used in countries with economic institutions that differ from those in Western economies. We need to place standardization in the larger context of late-

3. On the American standards systems, see: Ernst, D., 2013, "America's Voluntary Standards System – A "Best Practice" Model for Asian Innovation Policies", *Policy Studies 66,* March, East-West Center, Honolulu, USA, http://www.eastwestcenter.org/pubs/33981; Wang, P., 2013, "Global ICT standards Wars in China, and China's Standard Strategy", manuscript, China National Institute for Standardization, Beijing; Ernst, D., 2011, *Indigenous Innovation and Globalization: The Challenge for China's Standardization Strategy,* UC Institute on Global Conflict and Cooperation; La Jolla, CA and East-West Center, Honolulu, http://www.EastWestCenter.org/pubs/3904 [Published in Chinese at the University of International Business and Economics Press in Beijing, 自主创新与全球化：中国标准化战略所面临的挑战]; Suttmeier, R.P., S. Kennedy, J. Su, 2008, *Standards, Stakeholders, and Innovation: China's Evolving Role in the Global Knowledge Economy,* National Bureau of Asian Research. September.
4. "The Internet of Everything" brings together people, process, data and things to enhance the relevance and productivity of networked connections, turning information into actions that create new capabilities, richer experiences and unprecedented economic opportunity for countries, businesses, communities and individuals.
5. Gasser, U. and J. Palfrey, 2013, "Fostering Innovation and Trade in the Global Information Society: The Different Facets and Roles of Interoperability", *Law, Policy & Economics of Technical Standards eJournal,* Vol. 1, No. 1.
6. Ernst, D., 2002, "Global Production Networks and the Changing Geography of Innovation Systems: Implications for Developing Countries", *Economics of Innovation and New Technologies* 11 (6): 330.
7. On Korea's global network integration, see: Ernst, D., and Linsu Kim, 2002, "Global Production Networks, Knowledge Diffusion and Local Capability Formation", *Research Policy,* special issue in honor of Richard Nelson and Sydney, 31(8/9) (Winter): 1417–29; Ernst, D., 1994, *What are the Limits to the Korean Model? The Korean Electronics Industry Under Pressure,* A BRIE Research Monograph, The Berkeley Roundtable on the International Economy, University of California at Berkeley, Berkeley. An economic analysis of integration into global corporate networks of production and innovation, see: Ernst, D., 2009, *A New Geography of Knowledge in the Electronics Industry?Asia's Role in Global Innovation Networks,* Policy Studies No. 54, August, East-West Center, Honolulu.

comer economic development in countries that seek to catch up with the productivity and income levels of the US, the EU and Japan.

This paper is a very first step toward developing such a framework, with a focus on practical policy-oriented research. Part One reviews the evolving tasks of standardization and explores why standards are the lifeblood of innovation in the global knowledge economy. Part Two uses a stylized model of standardization tasks, capabilities and strategies to demonstrate that the costs of developing and implementing effective standards can be substantial, especially for latecomer countries.

Part Three describes the challenge faced by latecomer economies in their quest for economic and technology development and explores what this implies for standardization. Part Four asks what standardization research can learn from recent work on the role of intellectual property rights for economic development. Part Five highlights the tension between standards and innovation, examines the critical role that patents play for standardization and argues that "strategic patenting" to generate rents from de *facto* industry standards can stifle latecomer economic development.

The paper concludes with reflections on what constitutes success or failure of standardization for latecomer economic development and presents generic policy implications.

1. Evolving Tasks of Standardization

There is an almost infinite number of standards that differ in their form and purpose. To shed light on the evolving tasks of standardization, we first need to open the black box of standards and introduce an operational definition. A state-of-the-art definition that serves our purpose well is provided by the National Institute of Standards and Technology (NIST) as part of its Smart Grid Interoperability Standards project[8]. Standards are

> *"…[s]pecifications that establish the fitness of a product for a particular use or that define the function and performance of a device or system. Standards are key facilitators of compatibility and interoperability. …* Interoperability… [is].. *the capability of two or more networks, systems, devices, applications, or components to exchange and readily use … meaningful, actionable information - securely, effectively, and with little or no inconvenience to the user. …* [Specifically, standards] *define specifications for languages, communication protocols, data formats, linkages within and across systems, interfaces between software applications and between hardware devices, and much more. Standards must be robust so that they can be extended to accommodate future applications and technologies."*

8. NIST (National Institute of Standards and Technology), 2010, "Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0, Office of the National Coordinator for Smart Grid Interoperability." NIST *Special Publication* 1108, Washington, DC, US Department of Commerce, January: 19-20.

In the literature, standards are normally categorized as 'proprietary' versus 'open', and as "*de facto* versus" "*de jure*"[9]. Proprietary standards are owned by a company that may license them to others, while open standards "are available to all potential users, usually without fee"[10]. *De facto* standards achieve adoption through standards competition among rival standards consortia. Finally, *de jure* standards are adopted through consensus, which is sometimes formally expressed through industry committees or formal standards organizations.

At the most fundamental level, standards help to ensure the quality and safety of products, services and production processes, and to prevent negative impacts on health and the environment. Hence, an important function of standards is to reduce "risks for makers of compliant products and users of these products."[11]

In addition, standards enable companies to reap the growth and productivity benefits of increasing specialization, analyzed long ago in chapter III ("That the Division of Labor is Limited by the Extent of the Market") of Adam Smith's "The Wealth of Nations"[12]. According to economic historian Charles Kindleberger, "… for the most part, standardization was originally undertaken by merchants" to facilitate a progressive specialization through trade."[13]

Today however, specialization extends well beyond trade into manufacturing and services, including engineering, product development and research. Equally important is the international dimension. As globalization has been extended beyond markets for goods and finance into markets for technology and knowledge workers, standards are no longer restricted to national boundaries. Standards have become a critical enabler of international trade and investment — they facilitate data exchange as well as knowledge sharing among geographically dispersed participants within global corporate networks of production and innovation[14]. As network sociologists emphasize, the "creation and diffusion of standards underlying new technologies is a driving element of contemporary globalization."[15]

In short, standards are the lifeblood of innovation in the global knowledge economy. Today, standards are necessary not only to reap economies of scale and scope, but also to reduce transaction costs and to prevent a duplication of efforts. In addition, standards are required to enable data transfer and knowledge exchange and to facilitate interoperability of components and software within increasingly complex technology systems (e.g., a smart phone or a switching system). Without

9. Stango, V., 2004, "The Economics of Standards Wars," *Review of Network Economics* 3:1–19.
10. Steinfield, C. W., et al., 2007, "Promoting E-Business Through Vertical IS Standards: Lessons from the U.S. Home Mortgage Industry." In *Standards and Public Policy,* S. Greenstein and V. Stango (edits.), Cambridge, Cambridge University Press: 163.
11. Alderman, R., 2009, "Market Inefficiencies, Open Standards, and Patents." Available at http://www.vita.com: 2-3.
12. Smith, Adam, 1776, *The Wealth of Nations.* Book I, chap. III, Reprint, London, Penguin Books, 1970.
13. Kindleberger, C. P., 1983, "Standards as Public, Collective, and Private Goods", *Kyklos* 36 (3): 378–379.
14. Ernst, D., 2005, "Complexity and Internationalization of Innovation: Why is Chip Design Moving to Asia?", *International Journal of Innovation Management* 9 (1): 47–73 and 2005, "Limits to Modularity: Reflections on Recent Developments in Chip Design", *Industry and Innovation* 12 (3): 303–35.
15. Grewal, D.S., 2008, *Network Power: The Social Dynamics of Globalization,* New Haven, CT, Yale University Press: 194.

interoperability standards, it would be impossible to achieve 'network externalities' which shape competition in markets for products and services that use information and communication technologies[16]. In these markets, "…as the set of users expands, each user benefits from being able to communicate with more persons (who have become users of the product or service)."[7] 'Network externalities' imply that a company succeeds "when customers expect that the installed base of … [the company's] … technology [will] become larger than any other," with the result that the customers "adopt that technology to the virtual exclusion of others"[18].

Developing these interoperability standards is a moving target. The challenge is to allow for a continuous adjustment to cope with technical progress. Take the example of the rapidly evolving processor technology that drives the world's computers. The central processing units (CPUs) made by Intel and AMD under Intel's "x86" designs are now rivaled in importance by graphic processing units (GPUs) as PCs are used for multimedia tasks. For a computer company to use the GPU technology, it needs at least three things: "a license … [from Intel] … to the "x86" design of the CPU, a clear agreement about interoperability between the GPU and the CPU, and finally a strong enforcement mechanism —with clear standards and a timetable for prompt resolution of disputes."[19]

To cope with these critical challenges, standardization has become a complex and multi-layered activity that involves multiple stakeholders who differ in their objectives, strategies, resources and capabilities. Most importantly, standardization is a highly knowledge-intensive activity that requires well educated and experienced engineers and other professionals. While engineers originally created this discipline, key concepts are now shaped by legal counselors as well as corporate executives and government officials.

A dynamic analysis is required to capture the continuous changes and adjustments in the processes of standardization. A fundamental insight of Schumpeter's "creative destruction" theory is that economic institutions incessantly need to adjust to changes in markets and technology[20]. This implies that there is no one best way of organizing standardization. According to the American Engineering Standards Committee Yearbook of 1925, "… [s]tandardization is dynamic, not static. It means, not to stand still, but to move forward together."[21]

This fundamental insight still holds today, but unfortunately there is a tendency in current debates about standardization to neglect this dynamic aspect. Standardiza-

16. Katz, M., and C. Shapiro, 1985, "Network Externalities, Competition, and Compatibility," *American Economic Review* 75 (3): 424–40.
17. Rohlfs, J. H., 2001, *Bandwagon Effects in High-Tech Industries,* Cambridge, MA, MIT Press: 8.
18. Sheremata, W. A., 2004, "Competing Through Innovation in Network Markets: Strategies for Challengers,"*Academy of Management Review* 29 (3): 359.
19. David Balto, a former antitrust attorney at the Federal Trade Commission, quoted in "Intel Nears Settlement in Market Abuse Probe," *Financial Times,* July 21, 2010, 15.
20. Schumpeter, J. A., 1950, *Capitalism, Socialism, and Democracy*, 3d ed., New York, Harper & Brothers.
21. Russell, A., 2005, "Standardization in history: a review essay with an eye to the future", in Sherrie Bolin (ed.), *The Standard Edge, Future Generation* 2005, Ann Arbour, MI, Sheridan Press.

tion systems are in constant flux, and one needs to apply this fundamental insight to the study of contemporary standards systems, and this is true for an advanced economy like the US and a latecomer economy like Korea or China.

2. A Stylized Model of Standardization Costs

Equally important is that considerable financial resources are required to develop and implement effective standards. A rough estimate of such costs can be gained from a stylized model that distinguishes important tasks of standardization and that highlights differences in capability sets and in standardization strategies[22].

Standardization Tasks

Based on the author's interviews with leading standards experts in the United States, the European Union and China, we use a taxonomy of standardization that involves, but is not restricted to, the following tasks (Table 1).

Table 1: A Taxonomy of Standardization Tasks

1	Develop the technology to support the standard
2	Cost-benefit analysis of whether to adopt existing international standard or whether to create a new standard
3	Licensing fees for essential patents (both for existing standards and for newly created standards)
4	Pass testing, conformity assessment, and certification
5	Membership fees for formal and informal standard development organizations
6	Logistics (travel etc.)
7	Cost/risk of including one's own patents into a standard
8	Patent pool management
9	Back-end support
10	Legal (litigation)
11	Lobbying

Source: Interviews with leading standards experts in the US, the EU, and China

22. For details, see: Ernst, D., 2011, Indigenous *Innovation and Globalization.*

Typically, tasks 1, 3 and 4 are the most costly, but in case of litigation, legal costs in the United States can easily run into the hundreds of millions of U.S. dollars. In China, however, while costs of patent litigation are rising, they still remain significantly lower than in the United States[23].

Capability Sets

As for capability sets, the model distinguishes two countries. Country A (the "innovator") has a long history of standardization, a proven ability to operate successfully within standardization bodies and to shape international standards, a fairly diversified production and innovation system, and a broad base of accumulated knowledge and intellectual property rights (IPR) that helps to generate product and process innovations. Country A thus is able to ""control much of the technological input necessary to meet the standards." (Pai, 2013: p. 5) As a result, a primary concern of law and policies in country A is the protection of IPR, and the "openness" of standards is subordinated to IPR protection.

Country C (the "global factory"), on the other hand, is a relative latecomer to standardization. Country C is a standard taker, manufacturing products that are developed and standardized by Country A. Country C still has to learn how to operate successfully within standardization bodies. Most importantly, country C still has a long way to go to establish a fairly diversified production and innovation system and a broad base of accumulated knowledge and IPR that would allow it to shape or at least co-shape international standards. In country C, laws and policies are focused on economic development and the diffusion of knowledge inherent in IPR. Standardization is viewed as an enabling platform for innovation and latecomer economic development.

Standardization Strategies

In principle, countries and companies can choose one of the following standardization strategies described in Table 2 (or a combination of them).

Table 2: Standardization Strategies

Free rider:	Let others develop standards and save costs
Fast follower:	Get existing standard fast so that products with the standard's technology can be deployed quickly
Co-shaper:	Adjust existing international standards to suit a country's specific needs, and deploy these adjusted standards in current and future products
Leader:	Create new standards and embed own essential patents in the standard

23. Top judgments (or settlements) range from RMB 30 million to RMB 157 million. Top cases include domestic firms litigating against foreign firms, with only one top case of a foreign firm litigating against a domestic one. (Interview with Zhang Yan, IBM senior counsel international property law, April 8, 2010.)

Country A and its leading firms are likely to pursue standards leader or co-shaper strategies, while country C and its leading firms will initially focus on free rider or fast follower standardization strategies.

The diversity of standardization capabilities and strategies explains why there are significant differences in the organization and governance of standardization processes. These differences reflect differences across industrial sectors in technology, demand patterns and competitive dynamics. But standardization processes also differ across countries, reflecting the underlying conditions of population, resources, technological capabilities, products and tastes. Standardization processes reflect peculiar characteristics of a country's economic institutions, its level of development, its economic growth model, as well as its culture and history[24].

Unfortunately, an important weakness of the standardization literature is that we still lack systematic research that compares different national standards systems and their divergent development trajectories[25]. Existing comparative studies are focused on the American, the European and the Japanese standardization systems, neglecting important developments in latecomer countries like Korea, India, Brazil, and, most importantly, China[26].

3. Latecomer Economic and Technology Development – A Dual Challenge

A central proposition of this paper is that the study of standardization needs to be "nested" in the larger context of latecomer economic and technology development. The essence of latecomer economic development is narrowing the gap in productivity and income relative to a leading country like the US.

Latecomers to industrial manufacturing and innovation, such as Korea and China, are facing a dual challenge. They need to overcome very substantial barriers to entry ("latecomer disadvantages") that result from being backward in market size and sophistication and in the level of technology. At the same time, however, latecomers need to exploit new opportunities as they are facing fewer legacy constraints to technology development, strategy and organization ("latecomer advantages").

24. Kindleberger, C. P. 1983. "Standards as Public, Collective, and Private Goods": 383.
25. There are of course many specialized data bases for engineers that compare technical standards for particular technologies. But very little research exists that compares institutional arrangements and strategies that shape different national standards systems.
26. An example of this outdated view of the global map of national standards systems can be found in: Mattli, W., and T. Buethe, 2003, "Setting International Standards: Technological Rationality or Primacy of Power?" *World Politics* 56 (Oct.): 1–42. See however a new project by the *National Academy of Sciences* that seeks to compare different national systems of managing intellectual property in standard development organizations (http://sites.nationalacademies.org/PGA/step/IPManagement/index.htm); see also: Lee, H. and Huh, J., 2012, "Korea's Strategies for ICT Standards Internationalisation: A Comparison with China," *International Journal of IT Standards and Standardization Research* (IJITSR), Vol.10 #2.

The distinction between “latecomers” and incumbent “leaders” who have accumulated “first-mover advantages” goes back to debates among economic historians on how “relative economic backwardness” in the 19th century has shaped the patterns and strategies of industrialization of countries such as the US, Germany, Japan and Russia[27]. It was argued that, under certain conditions, economic advantages are conferred on countries which are latecomers to industrial development. The basic idea is that those who are behind have the potential to make a larger leap. According to a classical study, “the larger the technological and, therefore, the productivity gap between leader and follower, the stronger the follower’s potential for growth in productivity: and, other things being equal, the faster one expects the follower’s growth rate to be. Followers tend to catch up faster if they are initially more backward.”[28] In one of its more sophisticated versions, this argument contents that, since the cost of changing to each more advanced level of technology progressively increases, latecomers do have a chance of bypassing industrial early starters. (Ames and Rosenberg, 1963)

Case studies of latecomer industrialization however have identified a great variety of entry barriers for countries that are late adopters of a technology[29]. Such entry barriers include but are not restricted to

- Production-related scale economies, including learning economies, threshold barriers and economies of scope;
- Barriers related to intangible investments required for developing the knowledge and competence base as much as complementary support services;
- Barriers to entry and exit of network transactions, particularly in the context of sourcing arrangements for core components;
- Barriers related to customer relations, including market intelligence, sales channels, and maintenance and repair;
- And the growing number of regulatory barriers (including standards) which, directly or indirectly, affect the costs of entry.

None of these entry barriers however are absolute— they can be reduced under certain conditions. Take *economies of scale* which can constrain the entry of latecomers for at least three reasons: the existence of learning economies, the lumpiness of investment and the need to reduce the cost of increasing product variety[30]. In prin-

27. Gerschenkron, A., 1962, *Economic Backwardness in Historical Perspective,* Belknap Press of Harvard University, Cambridge, Mass; Nelson, R.R. and G. Wright, 1992, “The Rise and Fall of America’s Technological Leadership: The Postwar Era in Historical Perspective,” *Journal of Economic Literature,* 30/4: 1931-1964; Landes, D., 1965, “Japan and Europe: Contrasts in Industrialization”, in: Lockwood, W.W. (ed.), *The State and Economic Enterprise in Japan,* Princeton University Press, Princeton.
28. Abramovitz, M., 1989, “Catching up, forging ahead, and falling behind”, chapter 7 in Abramovitz, M., *Thinking about Growth. And Other Essays on Economic Growth and Welfare,* Cambridge University Press, Cambridge etc.: 221.
29. The following sections draw on: Ernst, D. and O’Connor, D., 1992, *Competing in the Electronics Industry. The Experience of Newly Industrialising Economies, Development Centre Studies,* OECD, Paris.
30. See for instance: Bain, J.S., 1959, Barriers to New Competition, Harvard University Press, Cambridge, Mass.; Scherer, F.M., 1980, *Industrial Market Structure and Economic Performance,* Houghton Mifflin Company, Boston.

ciple, this could be avoided, if the market expanded rapidly. In that case, market leaders might even welcome the entry of at least some new competitors, as the leaders' production capacity could fall well short of existing demand. With demand booming, new entrants might be willing and able to sustain at least some initial losses, given the prospects for future profits.

For quite some time, the information technology (IT) industry was the archetypical growth industry. Today, however, new entrants are confronted with a situation where rapid demand growth is no longer assured. It is due to this market growth constraint that economies of scale have become an important barrier to market entry[31]. In such a situation a latecomer faces a major challenge. He must expand the market through non-price means, i.e. through product differentiation and the creation of new markets and distribution channels, and through the development of strong and sophisticated standards systems.

The problem of course is that economies of scale for such activities may even be higher than economies of scale in manufacturing. For instance, a latecomer may be disadvantaged relative to a large incumbent market leader who can spread her budget for standards development over a large output and who can purchase international standards at negotiated discounted prices if it has sufficient negotiation power in the market.

Latecomer strategies for standardization are even more constrained by the "first mover advantages" which market leaders have been able to establish relative to latecomers in terms of cost, quality and speed-to-market of standards development. Such "first mover advantages" usually result from accumulated experience in managing standard development organizations, and privileged access to the best sources of knowledge. At the same time, first movers have been able to amass a vast amount of market intelligence, technological capabilities and organizational competence which, in principle at least, allows them to calibrate and quickly adapt standards to changes in demand, technology and production economics.

As a consequence, latecomers, "… face higher unit costs in providing the good and service involved — and therefore earn a lower rate of return."[32] This, in turn, constrains their capacity to finance standards development. It also limits funds available for the purchase of international standards and for the intangible investment that is essential for organizational upgrading and for more active participation in international standards development organizations and private consortia — all of which are necessary preconditions for catching-up with industry leaders. Latecomer disadvantages thus have a built-in tendency of mutual reinforcement.

31. Ernst, D., 2002, "The Economics of Electronics Industry: Competitive Dynamics and Industrial Organization", in Lazonick, William (ed.), T*he International Encyclopedia of Business and Management (IEBM), Handbook of Economics,* London, International Thomson Business Press.
32. Ergas, H., 1987, "A Survey of the Role of Entry Barriers," in Henry Ergas et. al (eds.), Corporate Strategies in Transition, New York.

However, the new world of ubiquitous globalization also provides new opportunities for latecomer economic development. Countries like Korea and China have been able to catch up and to forge ahead, even in complex technologies like advanced information and communications technology. New entry possibilities may open up for instance, as technological change erodes established market structures and leadership positions. In addition, "first mover advantages" are sometimes constrained by weak intellectual property protection that facilitates copying and knowledge leakage. Also, incumbent market leaders may become complacent and neglect to fight against latecomer attacks.

Furthermore, latecomers are fast followers of established technology roadmaps. Hence, they have the great advantage of being able to set clear targets for product development and related research. Finally, latecomers can compare and learn from the experience of incumbent leaders, particularly their failures in reducing costs and in adapting products and the distribution system to changing customer needs. Through judicious strategies of lower-cost innovation, latecomers can avoid being trapped into huge R&D cost burdens. By acting as suppliers for OEMs, whether as EMSs or ODMs, latecomers can also avoid the huge investment outlays required for distribution networks and marketing.

Industrial latecomers however face fundamental trade-offs in their attempts to catch up with industry leaders. New technologies figure prominently in shaping success or failure. Latecomers can either use these technologies to upgrade traditional industries or they can seize new market opportunities spawned by those technologies in high-tech industries. In the former, latecomers may already be well established and cost-competitive, whereas in the latter they are newcomers and are trying to catch up technologically in intensely competitive markets.

Another trade-off latecomers must address is that between timely access to new technologies and the ability to develop such technologies indigenously. Given the sizeable technology gap, especially in high-tech industries, that separates latecomers from technology leaders in the US, Japan and the EU, relying principally on their own R&D capabilities might well condemn the latter to using obsolete technologies. Importing the technologies would provide readier access to the latest vintages but at the expense of perpetuating technological dependence.

In short, conscious efforts are required in latecomer economies, both by firms and governments, to invest in R&D infrastructure and Higher Education. Most importantly, latecomer economic development requires a careful coordination of innovation and standards policies that combine the protection of intellectual property rights and the development of a broad portfolio of high-quality intellectual property rights, with a focus on patents that are widely quoted and essential for the definition of important standards.

4. Intellectual Property Rights and Economic Development: Lessons for Standardization Research

To calibrate standardization research to the needs of latecomer economies, important lessons can be drawn from recent work on the role of intellectual property rights (IPR) for economic development[33].

Learning advanced technologies is critical for successful catching-up. The protection of intellectual property rights is a necessary, but by no means sufficient, condition. Detailed case studies of earlier historical experience in the United States, the Scandinavian countries, Japan, Korea, and Taiwan demonstrate that IPR protection can only contribute to economic development if it takes place as part of a multi-faceted innovation strategy that seeks to strengthen absorptive and innovative capabilities of firms, and to develop a broad-based innovation infrastructure (including standards)[34].

The relationship between intellectual property protection and innovation is complex - "although stronger IPR protection directly increases the incentive to innovate, it also discourages innovation in the long run by suppressing the process of 'learning by doing.' … This implies that both very strong and very weak IPR policies decrease innovation, so a moderate approach is preferable"[35].

Of particular interest for the study of standardization is that IPR regimes significantly vary across industries and across countries of different economic size or different technological capacity. Case studies "document again and again the very great differences across industries in the extent to which IPR regimes, indigenous or foreign, affect the catch-up process….[Hence], it makes no sense to talk about the influence of IP on development in general. One has to specify the sector one is concerned with"[36].

Latecomer countries face a fundamental dilemma: A weak IPR regime may stimulate imitation (without patent holder consent), while discouraging the development of advanced technology through licensing or inward FDI, or through domestic innovation efforts. In a developing country, "utilization of knowledge invented abroad should be given priority over incentive for invention and, hence, a weaker patent regime that targets diffusion … [rather]…than creation should be adopted"[37].

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33. See: Goldstein, P. and J. Straus, 2009*, Intellectual Property in Asia: Law, Economics, History and Politics,* Springer, Berlin and Heidelberg; An, Baisheng, 2009, "Intellectual Property Rights in Information and Communications Technology Standardization: High-Profile Disputes and Potential for Collaboration between the United States and China," *Texas International Law Journal* 45: 195.
34. See case study chapters 2–6 in: Odagiri, H., A. Goto, A. Sunami, and R. R. Nelson (eds.), 2010, *Intellectual Property Rights, Development, and Catch-Up,* London, Oxford University Press.
35. Furukawa, Y., 2010, "Intellectual Property Protection and Innovation: An Inverted-U Relationship," *Economics Letters* 109:99–101.
36. Odagiri, H., A. Goto, A. Sunami, and R. R. Nelson (eds.), 2010. *Intellectual Property Rights.*
37. Ibid.: 11.

Hence, a country's IPR regime needs to evolve with the development of its domestic innovative capacity. "… The relative merits of different IPR regimes change over the stages of economic development…. Typically, countries try to alter their IPR regime in response to changing needs. In consequence, a country's IPR regime likely coevolves with its economy"[38]. As long as a country's innovative capacity is weak, it benefits from a relatively loose IPR regime. Once the country's innovative capacity begins to improve, its IPR regime needs to be gradually strengthened.

In addition, there is an important international dimension. In-depth research on Asia's export-oriented economies finds that, while their own IPR regimes matter, of at least equal importance for their economic growth have been the IPR regimes of their main export markets in the United States, the European Union and Japan. That research also shows that a sophisticated domestic IPR regime is important, as it forces Asian firms to learn about IPR legal issues and to accumulate capabilities for IPR management.

5. The Tension between Standards, Patents and Innovation

The relationship between standards, patents and innovation is much more complex than acknowledged thus far in innovation theory. Policy-oriented research needs to highlight a fundamental tension that sets standards apart from innovation.

By freezing a given technology, standards are supposed to provide stability for industry and customers, as well as for international trade and investment. Yet, at the same time, innovations continuously upset this stability by introducing new products based on new standards. J. A. Schumpeter's theory of "creative destruction" provides a useful analytical framework. For Schumpeter, capitalism

> *"is by nature a form or method of economic change and not only never is but never can be stationary. And this evolutionary character of the capitalist process … [is driven by innovation]…, the fundamental impulse that sets and keeps the capitalist engine in motion.… [Innovation] … incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. The process of Creative Destruction is the essential fact about capitalism. … In other words, the problem that is usually being visualized … [by economic and legal theories] … is how capitalism administers existing structures, whereas the relevant problem is how it creates and destroys them"*[39].

38. Ibid.: 12.
39. Schumpeter, J. A., 1950, *Capitalism, Socialism, and Democracy:*83-84.

On the positive side, there is no doubt that standards can be a critical enabler of innovation. There is no automatic link, of course, but standards can foster economic growth by reducing transaction costs and achieving economies of scale through interchangeability[40]. Economic standardization theory has shown that "… [s]tandards affect the R&D, production, and market penetration stages of economic activity and therefore have a significant collective effect on innovation, productivity, and market structure"[41].

That does not imply that standardization per se is good under all conditions. For instance, standards that fail to address critical societal concerns with regard to climate change, health, or product safety may actually give rise to wasteful and even destructive innovation. Standards may also effectively limit innovation and economic growth when they are used as a weapon to block competition[42].

Patents provide the missing link to such anti-competitive conduct. Their role for standards has increased with rising technological complexity. Increasingly, standards include technologies that are protected by IPR. In theory, a neat distinction is possible between standards that are a "public good" (free, collective good) and patents that are a "private good" (for private, exclusive use by patent owners)[43]. But in reality, tensions are rising between patents and standards: "… (w)hile technical standardization is meant to transform ideas into a public good, patent protection transforms them into a private good"[44].

As globalization has increased technology-based competition, the key to competitive success is a broad portfolio of "essential patents," which are necessary to produce any product that meets the specifications defined in the standard[45]. In fact, each of the major interoperability standards in the IT industry is protected by multiple patent families, giving rise to patent thickets. With increasing complexity of technologies, these patent thickets become denser. For instance, for the GSM standard (for second-generation mobile telecommunications systems), 140 essential patents were claimed by their respective patent holders[46].

For the third-generation mobile standards, the number of essential patents has substantially increased. For example, W-CDMA (one of the three competing 3G stan-

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40. Kindleberger, C. P., 1983, "Standards as Public, Collective, and Private Goods".
41. Tassey, G., 2000, "Standardization in Technology-based Markets,"*Research Policy* 29: 587.
42. Lemley, M., 2002, "Intellectual Property Rights and Standard-Setting Organizations," *California Law Review* 90:1889–1981.
43. Economists typically define "public goods" by two qualities: "non-rivalry in consumption (i.e. they are not depleted by an additional user) and non-excludability (i.e. it is generally difficult or impossible to exclude people from its benefits, even if they are unwilling to pay for them)", see: Baumol, W. J., and A. S. Blinder, 1991, *Economics: Principles and Policy,* 5th ed., Fort Worth, TX, Harcourt Brace Jovanovich: 617.
44. European Patent Office, 2007, *Scenarios for the Future.* Munich: European Patent Office. http://www.epo.org/news-issues/issues/scenarios.html: 93.
45. Patents are "essential" to a standard when it is not possible to comply with the standard without infringing that intellectual property right.
46. Bekkers, R., G. Duysters, and B. Verspagen, 2002, "Intellectual Property Rights, Strategic Technology Agreements, and Market Structure: The Case Of GSM," *Research Policy* 31:1141–61.

dards) is protected by more than 2,000 patent families comprising more than 6,000 individual patents from some 50 companies and consortia (Davey 2006). At the same time, the number of standards required for a single mobile device has grown exponentially. Today's typical smart phone combines hundreds of standards coming from dozens of standard-setting organizations, for camera, video, web browser, PDA, WiFi, Bluetooth, Linux, USB, and so on. As a result, smart phones have become the latest patent battleground. In 2010, nearly 8,000 patents held by 41 companies apply only to the 3G wireless communications capabilities of a typical smart phone[47].

The use of "essential patents" as a strategic weapon to prohibit, delay or obstruct standardization processes is well documented in the literature[48]. This is the case for instance when incumbent market leaders pursue so-called 'platform leadership' strategies through allegedly open but de facto proprietary standards[49]. While nominally "open", these standards are designed to block competitors and to deter new entrants.

Two highly influential studies on the licensing and disclosure of private standard-setting organizations by M. Lemley document the difficulties of finding fair and reasonable non-discriminatory (FRAND) compromises in private standard-setting organizations to reduce the negative impact of strategic patenting[50].

This is especially difficult for industries, like the information and communications technology sector, where interoperability standards are required to make products or services compatible with each other in order to maximize the benefits of network externalities. The emergence of a "winner-takes-all" competition model, described by Intel's Andy Grove, implies that companies need to combine economies of scale and scope with flexibility and speed-to-market[51]. Only those companies thrive that succeed in bringing new products to the relevant markets ahead of their competitors. Of critical importance is that a firm can build specialized capabilities quicker and at

47. Confidential interview with smart phone company.
48. See the seminal article: Lemley M.A. and C. Shapiro, 2007, "Patent Holdup and Royalty Stacking", in *Texas Law Review,* Vol. 85: 1991 to 2041. For an analysis of implications for standard development organizations and policy makers, see: Weiss, M.B.H. and M. B. Spring, 2000, "Selected Intellectual Property Issues in Standardization", in Kai Jacobs (ed.), *Information Technology Standards and Standardization: A Global Perspective,* Idea Group Publishing, Hershey USA, London UK: 63-79.
49. The overriding purpose of "platform leadership" strategies is to leverage the existing market power of industry leaders into the control of "systemic architectural innovations," see: Gawer, A. and M.A. Cusumano, 2002, *Platform Ledership. How Intel, Microsoft and Cisco Drive Industry Innovation¸* Harvard Business School Press, Boston, Mass. For example, Intel has attempted to extend its control over microprocessors by creating widely accepted architectural designs that increase the processing requirements of electronic systems and, hence, the market for Intel's microprocessors, see: Gawer, A. and R. Henderson, 2007, Platform Owner Entry and Innovation in Complementary Markets: Evidence from Intel, *NBER Working Paper,* National Bureau of Economic Research, http://www.nber.org/papers/w11852.pdf, accessed June 1st, 2010.
50. Lemley, M., 2002, "Intellectual Property Rights and Standard-Setting Organizations"; Lemley M.A. and C. Shapiro, 2007, "Patent Holdup and Royalty Stacking". See also the recent systematic study by Jorge Contreras who lays out an alternative approach focused on a reform of standard-setting organizations: Contreras, J., 2012, "Rethinking RAND: DSO-Based Approaches to Patent Licensing Commitments", presented at ITU Patent Roundtable, October 10.
51. Grove, A.S., 1996, *Only the Paranoid Survive. How to Exploit the Crisis Points that Challenge Every Company and Career,* Harper Collins Business, New York and London

less cost than its competitors[52]. Hence, competitive success critically depends on "a capacity to control open-but owned architectural and interface standards."[53] It is hardly surprising that, under such conditions, as John Alic puts it, "firms may be tempted to seek profits through collusion rather than technological innovation. And when innovations do result, the costs may be high."[54]

According to a recent study by the Federal Reserve Bank of Philadelphia, finding fair and non-discriminatory compromises is made even more difficult by "the potential for opportunistic behavior by participants who own patents on a technology essential to the standard. There is a risk that without sufficient transparency and sufficiently strong mutual interests, network participants could make large investments to implement a standard only to be held up by a firm threatening to withhold a key piece of technology"[55]. The study argues that "… in all likelihood some kind of agreement would be reached, but on terms substantially worse than the participants initially expected. Indeed, the risk of such an outcome may discourage firms from adopting a standard or even participating in the standard-setting process. In other instances, awareness of a key blocking patent might lead to the adoption of a standard that poses less risk to participants but which is also technologically inferior."[56]

In short, the use of "strategic patenting" to generate rents from de facto industry standards has transformed the dynamics of the international standards system, with potentially very negative implications for latecomer economic development. Within the WTO framework of TRIPS (trade-related aspects of intellectual property rights) and TBT (technical barriers to trade) agreements, only very few remedies are available to address the fundamental tension between patents and technical standards.

This enables patent holders to engage in anticompetitive conduct within national and international standard-development organizations and from outside. The weapons at their disposal include patent hold ups, patent ambush, royalty staking, strategic injunctive reliefs, unilateral refusal to license, and violation of FRAND (Fair, Reasonable and Non-discriminatory) contracts. In short, patent holders can increase their market power "when they demand 'unreasonable' royalties for their patents that are embedded in standards. *Thus, standards generate a market power far beyond*

52. Kogut, B. and U. Zander, 1993, "Knowledge of the firms and the evolutionary theory of the multinational corporation", *Journal of International Business Studies,* 24 (4).
53. Ernst, D., 2002, "The Economics of Electronics Industry: Competitive Dynamics and Industrial Organization. In Lazo nick, William (ed.), *The International Encyclopedia of Business and Management (IEBM), Handbook of Economics,* London, International Thomson Business Press.
54. Alic, J., 2009, "Energy Innovation from the Bottom Up." Project background paper prepared for the joint project of the Consortium for Science, Policy, and Outcomes (CSPO), Arizona State University, and the Clean Air Task Force (CATF), March: 3.
55. Hunt, R. M., S. Simojoki, and T. Takalo, 2007, "Intellectual Property Rights and Standard Setting in Financial Services: The Case of the Single European Payments Area." *Working Paper No. 07-20,* Research Department, Federal Reserve Bank of Philadelphia. Available at http://www.phil.frb.org/research-and-data/publications/working-papers/2007/wp07-20.pdf, accessed May 17, 2010.
56. Ibid.: 3.

the power of exclusion and the freedom of contract granted by patent law [italics added, DE]."[57]

By stifling innovation and knowledge diffusion, this type of "strategic patenting" is likely to have a quite negative impact on latecomer economic development.

6. Conclusions and Policy Implications

This paper has explored how standards and innovation interact in countries that are latecomers to industrial manufacturing and innovation. These countries seek to catch up with the productivity and income levels of the US, the EU and Japan, but they have only recently begun to build up their innovation and standards systems and strategies.

A central proposition is that latecomer economies like Korea and China face opportunities and challenges in their standards and innovation policies that differ quite considerably from the opportunities and challenges faced in today's advanced economies. Latecomers typically are standards takers, and have a long way to go in their efforts to shape or at least co-shape international standards. Latecomers also typically are more vulnerable to the impact of "strategic patenting" strategies that large patent holders use to generate rents from controlling *de facto* industry standards.

Furthermore, latecomers lag behind advanced economies in the sophistication of their standardization capabilities and strategies, and hence are likely to face higher costs of developing and disseminating effective standards. At the same time, ubiquitous globalization and rapid and disruptive technical change (such as the rising complexity of digital networks) create new challenges for standardization. No Korean or Chinese company can succeed in international trade without mastering interoperability standards that are necessary to transfer and render useful data and other information across geographically dispersed systems, organizations, applications, or components. This process has increased the economic importance of standardization, but especially so for latecomer countries which, like China and Korea, are deeply integrated into international trade and global corporate networks of production and innovation.

Given all of these challenges for standards development in latecomer economies —some of them quite new and little understood —is it really sufficient to reduce the debate to a static assessment of the compliance of latecomer standards institutions and strategies with existing approaches to IPR management in standards? In light of the different institutions and weaker standardization capabilities in latecomer countries, couldn't one argue that standards and innovation policies that worked well for

57. Pai, Y.A., 2013, "The International Dimension of Proprietary Technical Standards: Through the Lens of Trade, Competition Law and Developing Countries", *Law, Policy & Economics of Technical Standards eJournal,* Vol. 1, No. 1, March 1: 5.

advanced economies may not necessarily be the optimal choice for fostering latecomer economic and technological development? And, specifically, what constitutes success or failure of standardization for latecomer economic development?

In the US, where standards are developed primarily by private firms, success is typically defined by commercial criteria, like market share, return on investment, and rents that innovators can reap from a particular technology. In latecomer societies, we need a definition of success that links standardization to the broader challenges of innovation and economic development[58]. In essence, a standards project will be considered a success if it:

- maximizes learning effects and standardization capabilities;
- avoids strategic patenting by owners of essential patents that could block innovation;
- reduces licensing costs to avoid getting caught in the so-called patent trap;
- broadens the scope for innovation to avoid technology lock-in by not blocking foreign standards[59];
- protects confidentiality, integrity, and availability of data through information security industry standards;
- facilitates and broadens the diffusion of best-practice productivity-enhancing generic technologies;
- initiates open and transparent standardization processes that are in line with WTO and other international regulations;
- helps to adjust the governance mechanisms and institutional architecture of international standards-setting bodies;
- and develops a capacity for flexible and fast adjustments, in cases where policies do not produce the expected results.

This broader definition of success has important *policy implications*. The international community should acknowledge that the challenges faced by latecomers are significant and that one should not always apply the same criteria in judging performance of latecomers as one would to the advanced industrial economies. In light of very different political and economic institutions, it is unrealistic to argue that latecomers should converge to a U.S.–style, market-led system of voluntary standards. Countries like Korea and China will need to find their own institutional and legal approaches to develop a standards system that can both foster innovation and cope with the challenges of globalization and rising technological complexity.

Latecomers, in turn, would benefit from studying inherent advantages of the deeply-rooted U.S. tradition of decentralized, market-led approaches to standardization.

58. The following definition of success draws on: Ernst, D., 2011, *Indigenous Innovation and Globalization.*
59. Brian Arthur provides the classic analysis of "technology lock-in." He shows that the economy, over time, can become locked in by "random" historical events to a technological path that is not necessarily efficient, not possible to predict from usual knowledge of supply and demand functions, and not easy to change by standard tax or subsidy policies, see: Arthur, W. Brian, 1989, "Competing Technologies, Increasing Returns, and Lock-In by Historical Events," *Economic Journal* 99 (March): 116–31.

This may lead to new ways of blending elements of a U.S.–style voluntary system through independent standards development organizations and consortia with a government-led coordination of standards, innovation, and competition policies.

For instance, a hybrid of the best elements of the U.S. and Chinese standards systems could help latecomers to foster indigenous innovation while maintaining open markets. The Chinese model of an integrated government-coordinated innovation and standardization strategy can help to generate the massive investments needed to upgrade a country's innovation system and its standardization capabilities. At the same time, elements of a US-style decentralized market-led standardization system can help to increase the flexibility of policy tools and institutions in order to cope with sometimes disruptive effects of unexpected changes in technology, markets, and business strategies.

In a world of rising complexity and uncertainty, it is always preferable to have built-in redundancy and freedom to choose among alternatives rather than seeking to impose from the top the "one best way" of doing things. First, rising complexity drastically reduces the time available for standards development and implementation, which makes it practically impossible to get solutions right the first time. There may have to be many policy iterations, based on trial and error, and an extended dialogue with all stakeholders to find out what works and what doesn't.

Second, rising complexity makes it difficult to predict possible outcomes of any particular policy measure, especially unexpected negative side effects, of which there is an almost endless variety. In fact, a small change in one policy variable that describes a particular procedure for achieving compliance with a particular standard can have far-reaching and often quite unexpected disruptive effects on many other policy variables and outcomes.

And, third, it is next to impossible to predict the full consequence of interactions among an increasingly diverse population of both domestic and international standardization stakeholders. Given the diversity of competing stakeholders in standardization, the results of a particular national standards policy depends much more on negotiations, gaming, and compromises than on the logical clarity and technical elegance of that policy.

To conclude, countries like Korea and China today provide an experimentation field for new approaches to standardization that seek to combine the advantages of a bottom-up, market-led approach with a unified strategy designed and implemented in close cooperation between industry and government. These new approaches to standardization may also influence debates about international trade agreements. This is true especially for Asia where US-led efforts to create a Trans-Pacific Partnership trade agreement compete with a China-backed Regional Comprehensive Economic Partnership (RCEP) and CJK, i.e. negotiations between China, Japan and Korea to strengthen trade integration between these three Northeast Asian countries.

In short, policy-makers and corporate executives in the United States, as well as in the European Union and Japan, would be well advised to study these new hybrid institutional approaches to standardization for latecomer economic development, and to learn from them.

From Catching Up to Forging Ahead? China´s Prospects in Semiconductors[1].

Dieter Ernst

Overview of Topic and Why it is Important

On the 24th of June 2014, China's government issued the *"Guidelines to Promote National Integrated Circuit Industry Development"* which spells out concrete and ambitious development targets for China's semiconductor industry[2]. This strategy has the support from the top leadership. The goal is to move from catching-up to forging ahead in semiconductors, by strengthening simultaneously China's integrated circuit (IC) design industry and domestic IC foundry services.

This study takes a close look at objectives, strategy and implementation policies of China's new push in semiconductors and examines what this implies for China's prospects in this industry. The following questions are addressed in particular: *In light of the mixed results of earlier support policies in this industry, how realistic are the expectations, outlined in the Guidelines? Does the Semiconductor Strategy signal a resurgence of state-led mercantilist industrial policies? In other words, is the Government just filling Old Wine into New Bottles? Or are there signs of a real shift in strategy and policy implementation that seeks to address global transformations in markets and technology and the rise of private firms in China's semiconductor industry?*

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1. Earlier versions of the paper have been presented at the University of California Institute of Global Conflict and Cooperation (IGCC) conference in San Diego on the Political Economy of China's Technology and Innovation Policies, June 27, 2011; the University of Chicago/Tsinghua University conference on Industrial Co-Development, at the University of Chicago Beijing Center, July 13-16, 2011; the University of Chicago/MIT/ Copenhagen Business School conference on Industrial Co-development with China, Sept 24 and 25, 2012; the Information Technology and Innovation Foundation (ITIF) conference on China's Indigenous Innovation Policy and the Semiconductor Industry , Washington, D.C., December 13, 2012; the 2013 American Association for the Advancement of Science (AAAS) Annual Meeting, 17 February 2013; the East-West Center/University of Frankfurt China conference in Honolulu, April 7, 2014; the US Semiconductor Industry Association (SIA), Washington, D.C., September 18, 2014; and the Peterson Institute for International Economics, Washington, DC , September 19, 2014.
2. USITO, 2014, *"Guidelines to Promote National Integrated Circuit Industry Development"* (unauthorized translation of document published by the Ministry of Industry and Information Technology, the national Development and Reform Commission, the Ministry of Finance, and the Department of Science and Technology, June 24, United States Information Technology Office, Beijing.

In addressing these questions, the study contributes to the literature three observations: First, top-down state-led "old industrial policies" simply don't work in a knowledge-intensive and highly globalized industry like semiconductors, where basic parameters that determine how China will fare may change at short notice and in unpredictable ways[3]. Rising complexity of technology, business organization, and competitive dynamics are the root causes for such uncertainty[4]. If China wants to forge ahead in the semiconductor industry, it needs to move towards a bottom-up, market-led approach to "industrial policy". There is ample evidence in the literature that latecomers like China need industrial support policies to catch up and develop a robust industrial ecosystem[5]. But this does not imply old-style top-down industrial policy. In fact, successful catching-up, and even more so forging ahead, requires market-driven approaches to investment finance, and a capacity for flexible policy adjustments based on multi-layered industrial dialogues with private firms.

Second, the rise of private firms in China's semiconductor industry further strengthens the argument for a bottom-up, and gradually more market-led approach to industrial policy. Over the last 60 or so years, China's semiconductor industry has come a long way from a completely government-owned part of the defense technology production system, with SOEs as the only players, towards a gradually more market-led development pattern. The role of SOEs has dramatically declined, and a deep integration into international trade and global networks of production and innovation has transformed decisions on pricing and investment allocation, with private firms as the main drivers[6].

Third, while China's progressive integration into the international economy has unshackled market forces in the semiconductor industry, China's policies to develop this industry still carry the legacy burden of the old-style top-down industrial policy. The result has been an unresolved friction between State and Market, where policy makers and planners prescribe desired outcomes (in terms of growth rates,

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3. A growing literature on "new" industrial policies argues that, under conditions of uncertainty, *"..[t]he right model for industrial policy is not that of an autonomous government applying … taxes or subsidies, but of strategic collaboration between the private sector and the government with the aim of uncovering where the most significant obstacles to restructuring lie and what type of interventions are most likely to remove them. …[T]he analysis of industrial policy needs to focus not on the policy outcomes—which are inherently unknowable ex ante—but on getting the policy process right."* (Rodrik. D., 2004, Industrial Policy for the Twenty-First Century, Research Working paper 04-047, John F. Kennedy School of Government, Harvard University, November: p.3). See also Foray, D., 2014, *Smart Specialisation. Opportunities and Challenges for Regional Innovation Policy,* Routledge, London and New York.
4. See, for instance, Ernst, D., 2005, "Complexity and Internationalisation of Innovation: Why is Chip Design Moving to Asia?", *International Journal of Innovation management,* special issue in honor of Keith Pavitt, 9 (1), March: pp.47-73.
5. Classic sources include Kim, L., 1997, *Imitation to Innovation. The Dynamics of Korea's Technological Learning,* Harvard Business School Press, Boston/Mass.; Nelson, R.R. , 2005,Technology, Institutions, and Economic Growth, Cambridge: Harvard University Press. See also Stiglitz, J.E. and B.C. Greenwald, 2014, *Creating a Learning Society. A New Approach to Growth, Development and Social Progress,* Columbia University Press.
6. See Ernst, D. and B. Naughton, 2008, "China's emerging industrial economy. Insights from the IT industry", chapter 3 in: C.A. McNally (ed), *China's Emergent Political Economy. Capitalism in the dragon's lair,* Routledge and East-West Center Studies, London and New York. China's semiconductor firm fits the pattern observed by Nick Lardy: "Private firms have become the main source of economic growth… and the major contributor to China's growing and now large role as a global trader."(Lardy, N., 2014, *Markets over Mao. The Rise of Private Business in China, Peterson Institute for International Economics,* Washington, D.C., September: page 4.)

technology, and “indigenous innovation” products), but fail to take into account the need of industry, and in particular private firms, for global technology sourcing.

The study explores whether China’s new policy on semiconductors signals at least incremental movements towards a more bottom-up, market-led approach to “industrial policy”. Part I demonstrates that China’s achievements in semiconductors are overshadowed by persistent weaknesses, despite massive earlier support of the Government. It is argued that China is still playing second fiddle in this industry, because the State’s “Indigenous Innovation Policy” collides with the “Global Technology Sourcing” needs of Chinese semiconductor firms. China’s indigenous innovation policy focuses on the challenges (licensing costs; cyber-security), but tends to neglect the vast opportunities that result from China’s deep integration into the global semiconductor value chain, in terms of learning , the development of innovation capabilities and of best-practice management techniques and institutions. This raises a fundamental question: What changes in policy would be needed to combine the benefits of both innovation strategies — “Indigenous Innovation” and “Global Technology Sourcing”?

Part II of the study reviews what we know about objectives and strategy that shape China’s New Push in Semiconductors. In the leadership’s view, the new strategy needs to address both persistent domestic weaknesses and new opportunities resulting from global transformations in semiconductor markets and technology. Part Two also takes a closer look at two Policy Initiatives to implement the new strategy: (a) the IC Industry Support Small Leading Group to enhance strategy coordination; and (b)“market-driven” IC Industry Equity Investment Funds to improve investment allocation, and to enhance firm size and capabilities through strategic partnerships, joint ventures and mergers and acquisitions, involving both foreign firms and domestic firms. The implementation of both policies signals a genuine effort to experiment with new and hybrid approaches to industrial policy.

Part Three explores the basic economics that shape China’s efforts to upgrade its semiconductor industry. The focus is on global transformations in semiconductor markets and technology which provide a demand pull from mobile devices for domestic IC design companies, and upgrading opportunities for China’s IC foundries in trailing-node integrated circuit process technologies (28nm and above). To exploit the headwinds from the market, the government is encouraging strategic partnerships and acquisitions, both among domestic firms and with leading global players. An important finding is that, in response to the rising complexity and uncertainty of today’s semiconductor industry, the government seems more open to experimentation with new more market-driven approaches to investment finance and flexible, bottom-up policy implementation, based multi-layered industrial dialogues with private firms. It is unclear however to what degree China’s semiconductor strategy takes into account its impact on China’s critically important exports of electronic final products.

The study concludes with a brief discussion of three factors that could derail China’s industrial upgrading scenario in semiconductors (i.e. over-capacity, the Leadership’s cyber-security objectives, and new international trade and investment agreements), and lays out implications for future research.

1. Unresolved Friction Between State and Market Explains why China still Playing second Fiddle in Semiconductors

1.1. Current Status - China's Achievements are Overshadowed by Persistent Weaknesses

To understand the motivations behind China's new push in semiconductors, it is useful to take stock of China's current status in the semiconductor industry.

Achievements

Achievements are impressive for a country that, before 2000, was considered to be a minnow in this industry. The country's rise as the global electronics factory drastically increased China's demand for semiconductors.

In fact, China is the largest semiconductor market in the world since 2005. In 2013, China's semiconductor consumption market grew by more than 10 % (compared to a worldwide semiconductor market growth of 4.8%). This has increased China's share in world semiconductor consumption to almost 56% (up from less than 19% in 2003). As result, China is by far the most important market for US semiconductor firms.

However, roughly 70% to 75% of all the semiconductors consumed in China (based upon revenue value) are re-exported as components of exported electronic systems that are produced in China, primarily by foreign companies from the US, Korea, Japan and Taiwan[7]. Hence, China's huge and rapidly growing semiconductor market is not reflective of an indigenous demand for semiconductors in China. In fact, buying decisions for integrated circuits (ICs) consumed in China are mostly made in Taiwan, Korea, US (for mobile devices), Japan, Singapore[8].

Another important achievement is the rapid growth of China's IC design industry, from \$200m in 2001 to \$13.2bn in 2013 (growing by 33% from 2012). As a result, the share of IC design in China's semiconductor industry has increased from 14% in 2010 to 20% in 2013 (PwC, 2014). In fact, IC design has consistently been the fastest growing segment of China's semiconductor industry, and the rate of growth continues to accelerate. For instance, the number of Chinese IC design companies has increased from 518 in 2012 to 683 by the end of 2013. That phenomenal increase of

7. These foreign companies are either contract manufacturers (the so-called electronic manufacturing service providers) like Taiwan's Foxconn, or global brand name companies with China-based factories, like Samsung. *(PwC, 2014, A Decade of Unprecedented Growth. China's Impact on the Semiconductor Industry 2014 Update,* http://www.pwc.com/gx/en/technology/chinas-impact-on-semiconductor-industry/2014-section-1.jhtml)
8. In 2013, almost 17% of semiconductors consumed in China were purchased outside and transshipped/ consigned into China for consumption (PwC, 2014).

165 net additional IC design houses during 2013 is by far the largest net increase in the last ten years. It has only been exceeded once in China's semiconductor history in 2002[9].

There are however serious limitations in terms of scale and product range. The more than 600 Chinese IC design companies that have sprung up may have combined annual sales exceeding NT$400 billion [ca $ 13.2bn] — beating Taiwan's IC design sector — but most of them are "one-generation champions" that are broken up by their founders after going public and lack staying power[10]. With the exception of a few industry leaders (such as Huawei's HiSilion affiliate, ZTE Micro, SPRD, RDA, Rockchip, and a few others), most Chinese IC design firms are too small to invest in sophisticated design capabilities and are bound to focus on low-end applications for mature and standardized products[11].

Important qualitative weaknesses that constrain the growth of China's IC design industry include a narrow focus on consumer products, especially low- and middle-end products such as color TVs, sound systems, clocks, electronic toys, small home appliances and remote controls. As long as China depends on these mature and relatively standardized products, this will constrain China's R&D and capability development in IC design.

As for IC design capabilities, the Government has promoted the development of an 8-core microprocessor that departs from the established design architectures of Intel and AMD. Introduced at the San Francisco IEEE International Solid-State Circuits Conference (ISSCC) in February 2012, China's flagship microprocessor Godson-3B1500 features 32 nm process technology, which is considerably behind the leading-edge. In addition, the 40-watt Godson CPU is targeted for desktop, laptop or servers, and a modified version (the so-called ShenWei processor SW1600)can be used for supercomputers. However, this type of processor does not address the low energy consumption needs of China's booming mobile devices market.

This neglect of basic market requirements is shared by a related project, the development of an indigenous operating system (OS) to replace Windows and Android for running China's desktop and mobile devices. Led by Ni Guangnan, a former CTO of Lenovo and an Academician of the Chinese Academy of Engineering, the OS Development Alliance, established in March 2014, seeks to benefit from the government ban on the procurement of Windows 8. However, according to Xinhua,

9. Data are from the China Center of Information Industry Development (CCID) Consulting and the China Semiconductor Industry Association (CSIA), as quoted by PwC's Ed Pausa, in email to the author, dated July 6, 2014.
10. Wang, Hsiao-Wen, 2014, "China's Semiconductor Grab – TSMC, MediaTek in the Bull's Eye", CommonWealth Magazine, 21 August 2014, http://english.cw.com.tw/article.do?action=show&id=14830
11. For instance, the combined revenues of the top ten Chinese IC design companies of $ 1.57 B is much lower than the individual results posted by each of the top five global fabless companies (*China's Fabless Profile, EE Times Confidential Special Report 2011).* According to MIIT research, the total combined revenue of China's 500 or so IC design companies equals around 60 to 70% of the revenue of Qualcomm. USITO, 2014, Interview with, Miao Wei, MIIT, Director of Department of Informatization, on the background, significance and key points from the *"Guidelines"* June 25: p.3.) According to industry sources, 223 Chinese fabless companies lost money in 2013, and many of the fabless companies have fewer than 50 people.

the Alliance faces many problems, "including a lack of research funds and too many developers pulling in different directions."[12] And according to interviews conducted by EETimes with domestic handset vendors and fabless companies, "it's far from clear how quickly and seriously the Chinese OS will attract local Chinese technology companies whose business is supplying products not only to domestic consumers but to the global marketplace."[13]

More important achievements however are IC designs developed by Spreadtrum and RDA for lower-end smart phones, and IC designs for mid-range tablets, developed by Fuzhou Rockchip[14]. A vital achievement in technology terms is HiSilicon's introduction in late September 2014 of the world's first multi-core networking processor for next-generation wireless communications and routers, and the fact that Taiwan's global foundry leader has accepted to produce this device using 16nm FinFET leading-edge fabrication technology[15].

Overall however China IC design capabilities continue to lag far behind the US, Japan, Taiwan and Korea, in terms of process technology and design line width. In addition, China lacks strong domestic suppliers of EDA tools and software and domestic licensors of IC design-related intellectual property.

Another noteworthy achievement of China's semiconductor industry is a successful diversification into Optical devices (especially LED), sensors and discrete devices, where China now is approaching self-sufficiency. By 2013, a Chinese supplier has entered for the first time the top 10 ranking of packaged LED makers, competing with leading global players, such as Nichia, Osram, and Samsung.

Of particular interest however is the surge of China's semiconductor assembly, packaging and testing (APT) industry, which has become the global market leader. Measured in terms of value added, production revenue, employees and manufacturing floor space, China's APT industry has now moved ahead of Taiwan and Japan (PwC, 2014). The focus on APT clearly stands out as a pragmatic and successful strategic decision. Not only is there a huge market for APT services. And while entry barriers are lower than for front-end IC fabrication, the technological requirements are considerable, providing a cost-effective entry strategy for Chinese firms to build up their management and technological capabilities[16].

12. "Chinese OS expected to debut in October", *Xinhuanet,* August 24, 2014, http://news.xinhuanet.com/english/china/2014-08/24/c_133580158.htm
13. Yoshida, Y., 2014, "China Launching its Own OS, Seriously?", EETimes, August 25, 2014, http://www.eetimes.com/document.asp?doc_id=1323638
14. See Part Three below for details.
15. Shilov, A., 2014, "TSMC builds world's first 32-core networking chip using 16nm Fin FET process",*Kitguru,* September 25, http://www.kitguru.net/components/cpu/anton-shilov/tsmc-builds-worlds-first-32-core-networking-chip-using-16nm-finfet-process-technology/
16. China's successful catching-up and forging ahead in semiconductor assembly, test and packaging supports Ken Lieberthal's important observation: "*Pragmatism has been a hallmark of China's reforms over the past 30 years, as Chinese leaders have not flinched from a realistic view of their challenges. They typically experiment with various approaches before deciding on the best ways to address major concerns."* (Lieberthal, K., 2011, *Managing the China Challenge. How to Achieve Corporate Success in the People's Republic,* Brookings Institution Press, Washington, D.C.: p.7.)

Persistent Weaknesses

China's achievements in the semiconductor industry are impressive. Yet, they cannot hide the fact that, despite massive government efforts to build indigenous innovation and production capabilities, China still plays a very limited role in semiconductor production, IC design, and as an innovator. Of particular concern is the large and growing gap between semiconductor consumption and production. From $5.7bn in 1999, this gap has ballooned to a record $108.2 bn in 2013, and it is projected to increase to $ 122bn in 2015. According to Chinese sources, only 8.2% of China's total semiconductor consumption in 2013 (estimated at $ 145 billion) are supplied by Chinese semiconductor firms[17].

As a result, up to 80% of the semiconductors consumed in China-based electronics manufacturing needs to be imported. As up to 75% of these electronics end products are exported, this requires growing imports of advanced ICs that satisfy the demanding performance requirements of overseas markets. In fact, China's trade deficit in semiconductors doubled since 2005 to $138 billion in 2011. And in 2012, the value of China's semiconductor imports (US$232.2 billion) even exceeded the amount it spent on crude oil (US$221 billion).

Equally important are qualitative weaknesses. China's patent applications for semiconductors show that its innovative capacity is improving, but China still has a long way to go to catch up with the US. While China's share of worldwide semiconductor technology-focused patents increased from 13.4% in 2005 to a peak 21.6% in 2009, it has since declined to 14% in 2012[18].

China continues to lag behind in innovation, especially for advanced semiconductors. The US is way ahead in Multi-Component Semiconductors (MCOs) and Multi-Chip Packages (MCP)[19] — the two semiconductor product groups that are at the heart of the current stalemate of negotiations to expand the Information Technology Agreement (ITA)[20]. And Qualcomm, one of the leading global fabless IC design companies leads in "multimode" wireless communication chips that integrate various wireless standards (including the 4G LTE standard, derived from China's TD-SCDMA standard).

In short, China's IC design industry still has a long way to go to catch up with the leading IC design industries in the US, Japan, the EU, Taiwan and Korea. There is no Chinese IC design company in sight that might be able to challenge current global industry leaders. According to a recent industry panel on China's IC design industry, "the center of gravity for chip design has not shifted to China. Despite a few well-known Chinese companies like HiSilicon and Spreadtrum, the top ten fabless

17. CCID and CSIA data quoted in Jones, H., 2014, "China Wants to be No.1", EETimes, August 20.
18. *Derwent Worldwide Patent* data quoted in PwC, 2014.
19. NRC 2012, *The New Global Ecosystem in Advanced Computing.*
20. For details on China's position in ITA, see Ernst, D., 2014, *The Information Technology Agreement, Industrial Development and Innovation - India's and China's Diverse Experiences,* Think Piece prepared for the E15 Expert Group on Trade and Innovation and the International Center for Trade and Sustainable Development (ICTSD), Geneva, http://e15initiative.org/wp-content/uploads/2014/03/Dieter-Ernst.pdf.

companies are all in the US, Taiwan, or Japan. These companies are spending billions of dollars to invest in new development."[21]

As for wafer fabrication, China continues to play second fiddle. While wafer fabrication has moved to East Asia (primarily Korea and Taiwan)[22], China's 2015 share of total worldwide semiconductor wafer production is projected to remain below 11%. Global IC industry leaders dominate (i.e. Intel, Samsung, Hynix) China's wafer fabrication. For instance, a recent survey of investments in chip fabrication equipment finds that China is the fastest growing market, this is primarily due to the ramp-up of the Samsung NAND Flash Memory fab in Xi'an, which is a $ 6.2 billion project[23].

Chinese foundries however are lagging two generations behind in process technology and wafer size. In fact, China has made substantial new investments in wafer fabrication plants, but these plants are using older technology and used equipment, which reflects China's focus on LED and other applications that do not require leading-edge semiconductors. Further, as demonstrated in a case study of SMIC, China's leading foundry, Chinese foundries lack process innovation capabilitie[24].

And Chinese foundries have a long way to catch up with the leading Taiwanese foundries, which have 60% share of worldwide 2013 foundry revenues versus less than 5% for leading Chinese foundries (PwC, 2014). Table 1 documents the huge gap in foundry capacity that separates SMIC, China's largest foundry, from the three global foundry industry leaders.

This describes a fundamental challenge for China's new policy to strengthen its semiconductor industry: China's domestic semiconductor manufacturing (i.e. wafer fabrication) technology and capabilities have failed to keep up with the country's IC design capabilities and needs.

Table 1.
2013 Foundry Capacity Comparison

Foundry	Capacity / year
TSMC	16,423,625
Global Foundries	7,326,000
UMC	6,313,500
SMIC	2,682,000

IC. Insights. Production capacity fgures converted to 8-inch equivalent wafers in order to enable comparison

21. Limin He, Corporate vice president of Cadence, a leading provider of computer-aided IC design tools, as quoted in " China Fabless Semiconductor Panel: Don't pack your Bags Just Yet", http://community.cadence.com/cadence_blogs_8/b/ii/archive/2014/06/18/china-fabless-semiconductor-panel-don-t-pack-your-bags-just-yet.
22. According to SEMI, the global industry association serving the manufacturing supply chain for the micro- and nano-electronics industries, Asia's share in worldwide wafer fabrication capacity is now 54%, and is expected to increase to more than 66% in 2015. See SEMI – *World Fab Watch 2014,* http://www.semi.org/en/Store/MarketInformation/fabdatabase/ctr_027237 . Capacity comparisons are in equivalent 8-inch wafers.
23. *SEMI Forecasts Back-to-Back Years of Double-Digit Growth in Chip Equipment Spending,* July 7, 2014, http://www.semi.org/node/50436
24. Shih, W., 2009, *Semiconductor Manufacturing International Corporation (SMIC):* "Reverse BOT", HBS SMIC Case study, http://www.hbs.edu/faculty/Pages/item.aspx?num=36733

1.2. Root causes - "Indigenous Innovation Policy" collides with the "Global Technology Sourcing" needs of Chinese semiconductor firms.

The semiconductor industry has been a poster child of China's innovation policy as codified in the Strategic Emerging Industries (SEI) plan published in 2012[25]. What explains that, despite massive government efforts to catch up and forge ahead in semiconductors, China still plays a quite limited role in semiconductor fabrication, IC design, and, most importantly, as an innovator?

To explain this puzzle, it is necessary to examine two conflicting innovation strategies which co-exist in China's semiconductor industry, reflecting an unresolved friction between State and Market. On the one hand, there is the government's indigenous innovation policy which seeks to correct the failure of the earlier FDI-based export strategy to develop and enhance absorptive capacity and innovation capabilities of Chinese firms. On the other hand are the "global technology sourcing" strategies of Chinese semiconductor firms which are eager to source core technologies and capabilities from global industry leaders[26].

"Indigenous Innovation"

Indigenous innovation was adopted as a policy in the Medium and Long-term Plan for Science and Technology Development 2006-2020 (MLP)[27], as a domestically controlled alternative for developing core technologies that are (asserted to be) unavailable on the international marketplace. It should be stressed that, "indigenous innovation" policies do not advocate technological autarchy. Global technology sourcing and the integration of acquired technologies into new technological solutions are explicitly mentioned in the MLP as types of indigenous innovation.

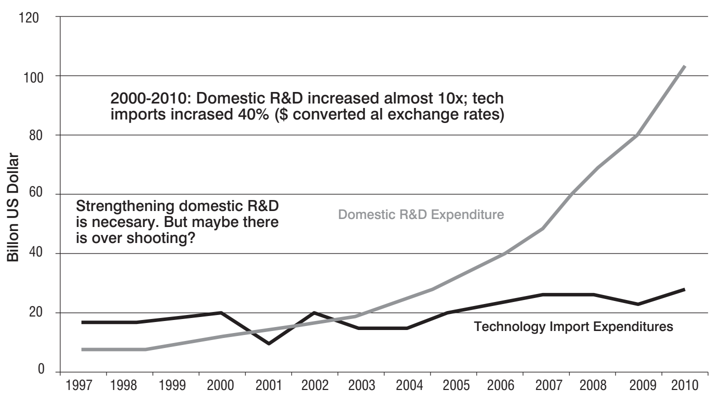
However, the policy's main objective is to shift the balance from global technology sourcing via FDI to domestic R&D in order to replicate as much as possible the semiconductor value chain in China. An important objective is to leverage control of intellectual property to reduce licensing fees and to extract rent. In the end, the indigenous innovation policy seeks to "change the rules of the game to fit China" to break the technological dominance of the West and to strengthen the country's position in the cybersecurity war[28].

25. 国务院关于印发"十二五"国家战略性新兴产业发展规划的通知 [The State Council Notification on the Long-term Development Plan for Strategic Emerging Industries during the 12th Five Year Plan], 国发〔2012〕28号. July 7, 2012.
26. As analyzed in Ernst, D. and B. Naughton, 2012, Global Technology Sourcing in China's Integrated Circuit Design Industry: *A Conceptual Framework and Preliminary Findings,* East-West Center Working Papers, Economics Series, No. 131.
27. See http://www.gov.cn/jrzg/2006-02/09/content_183787.htm, and http://www.gov.cn/english/2006-02/09/content_184426.htm . For details, see Ernst, 2011, chapter 2.
28. *"We will strive to catch up with and overtake advanced countries in … new-generation mobile communications, integrated circuits, big data, advanced manufacturing, …, and to guide the development of emerging industries."* PM LI Keqiang, *Government Work Report March 2014* which specifically mentions "integrated circuits" in the context of "using innovation to support and lead economic structural improvement and upgrading."

The MLP specifically sets as a target the increase in domestic R&D expenditures relative to expenditure on technology import, which is unlikely to be compatible with aggressive global technology sourcing. Moreover, the strong stress on indigenous innovation undoubtedly discourages firms in practice from deep partnership strategies with foreign firms which are leaders in important core technologies. In any case, the actual outcome, as Figure 1 shows, is that China has dramatically increased domestic outlays for R&D, while expenditures for technology import have grown much more slowly. Between 2000 and 2010, domestic R&D increased by nearly a factor of ten (in dollar terms, converted at exchange rates), while technology import expenditures increased by about 40%. China obviously needs to strengthen domestic R&D, but the current indigenous innovation policy seems to have led to some considerable over-shooting.

While well-intentioned, the indigenous innovation policy fails to take into account the dramatic changes in markets and technology that have transformed the semiconductor industry, both in the global semiconductor value chain, and with the rise of private firms in China.

Figure 1.
"Indigenous Innovation" has changed the balance between global sourcing and domestic R&D
Expenditure on Domestic R&D and Technology Import



Ernst and Naughton 2012; China Statistical Yearbook 2012

New Opportunities for Global Technology Sourcing

China's semiconductor industry is deeply integrated into the global semiconductor value chain through markets, FDI and investment. In the demand chain, for instance, end users, global brand name companies and electronic manufacturing service providers define performance and cost, while in the supply chain, design tool vendors, design services, materials vendors, equipment vendors and semiconductors producers (including foundries) are important sources of technology and capabilities.

The process of dis-integration started decades ago, as the semiconductor industry re-organized around so-called “fabless IC design companies” who sent their designs to be made into silicon-based products at “pure play foundries” (IC contract manufacturers)[29]. While a few of the largest integrated device manufacturers, such as Intel and Samsung, continued to combine IC design and manufacture (and thrive), most firms moved to the disaggregated model. Apart from moving wafer fabrication to Asia (as discussed before), this dis-integration of the semiconductor value chain has also led to the spread of global innovation networks, shifting important segments of electronics system design and IC design to Asia[30] (Ernst, 2009).

This massive process of slicing and dicing the global semiconductor value chain has substantially reduced entry barriers for newcomers like Chinese IC design firms. According to Dr. Leo Li, the CEO of China’s leading IC design company Spreadtrum, *“the availability of IC design tools, semiconductor fab services, and open-source smartphone software [Android] allows Chinese firms to circumvent their weak spots and develop their strengths in hardware, IC design, and integration”*[31]

In short, deep integration into the global semiconductor value chain enables Chinese firms to globally source technology and capabilities on a scale never thought possible before. In addition, as the global semiconductor industry critically depends on the China’s huge and rapidly growing market, this enhances China’s bargaining power in negotiations on global technology sourcing.

Add to this fundamental changes in global end user markets for wireless communication chips which have further transformed the organization of the global semiconductor industry, and have opened up new possibilities of an increasingly fine division of the IC design value chain. One of these possibilities is the much larger space for Chinese firms to introduce new innovative and disruptive business models that foster and reward significant innovation in system and IC design. In fact, global value chain integration has enabled Chinese firms to disrupt the existing competitive order. This happened when MediaTek, a leading chip design company fromTaiwan, a few years ago offered integrated baseband chip sets to Chinese handset producers in Shenzhen for low-cost white good counterfeits of branded handsets, the so-called “Shanzhai” handsets[32].

With the introduction of Google’s open-source smart phone operating systems Android, this disruption is now repeated, in the form of “Shanzhai 2.0” budget smart phones. This enables Chinese IC design firms to concentrate on hardware

29 For the economics of global vertical disintegration in IC design, see Ernst, D., 2005, “Complexity and Internationalization of Innovation: Why is Chip Design Moving to Asia?”, *International Journal of Innovation Management:* and Ernst, D., 2005, “Limits to Modularity - Reflections on Recent Developments in Chip Design”, *Industry and Innovation*.

30. Ernst, D., 2009, *A New Geography of Knowledge in the Electronics Industry? Asia’s Role in Global Innovation Networks,* East-West Center Policy Studies # 54. provides a detailed analysis of the spread of global corporate networks of production and innovation in the electronics industry.

31. Interview, June 22, 2012.

32. Shanzhai (山寨) refers to Chinese imitation and pirated brands and goods, particularly for low-cost handsets. Literally “mountain village” or “mountain stronghold”, the term refers to the mountain stockades of regional warlords or bandits, far away from official control.

design first, before developing and catching-up in software design capabilities. At the same time, the availability of mature and inexpensive chip set solutions provided by Taiwan's Mediatek has furthered lowered the entry barriers, giving rise to a renaissance of China's Shanzhai sector, but this time the focus is on incremental innovations in low-cost smart phones.

As a result, a local ecosystem for budget smart phones is emerging that links IC designers, OEMs and Chinese customers The primary focus is on the China market, but increasingly other Asian emerging economies (like India and Malaysia) are becoming important targets[33].

Today, not only is China the biggest market for mobile handsets, with China Mobile being the world's biggest carrier by a margin. Since 2011, China has also emerged as the biggest market for smart phones, ahead of the US, and third generation (3G) mobile telecommunications is finally taking hold. In addition, massive investments are underway to accelerate the build-up of China's 4G network infrastructure. Together, these changes in markets and technology have created new strategic opportunities for Chinese IC design firms to upgrade their product portfolios, process technologies and business models.

China's indigenous innovation policy is still struggling to adjust to these fundamental transformations in technology, as well as in global and domestic markets. In essence, China's indigenous innovation policy focuses on the challenges (licensing costs; cyber-security), but tends to neglect the vast opportunities that result from China's deep integration into the global semiconductor value chain, in terms of learning, the development of innovation capabilities and of best-practice management techniques and institutions.

The View from Industry

As documented in an earlier paper (Ernst and Naughton, 2012) some of the Chinese IC design companies which we interviewed emphasized that the indigenous innovation policy provides new opportunities (through government procurement and participation in China's TD-SCDMA standard) to gain market share against established global players. However, there also was a palpable sense of frustration about certain aspects of the Indigenous Innovation policy which these companies felt were constraining their efforts to engage in global technology sourcing.

In fact, many aspects of China's innovation policy collide with the needs of Chinese semiconductor firms. For them, commercial considerations are a primary concern. As late entrants, Chinese semiconductor firms struggle to survive and grow in a highly competitive global market that keeps changing at lightning speed and where technology often has unexpected disruptive effects. China's persistent innovation

33. For details, see Part 3.2. of the paper (Demand pull for mobile devices as a catalyst).

gap in IC fabrication and IC design implies that Chinese firms continue to need access to core technologies and capabilities from global industry leaders. In fact, Prof. Wei Shaojun, one of the drivers of China's new policy on the Semiconductor industry, emphasizes that collaboration between US and Chinese semiconductor companies is badly needed: "The most advanced technology is in the US, and the most experienced talent is in the US… .But Chinese companies are closer to the end customers and they understand the domestic demands."[34]

Hence, global technology sourcing across the semiconductor value chain is of critical importance if Chinese semiconductor firms want to reap the strategic opportunities that current changes in markets and technology are creating in for instance in wireless communications.

Of particular concern is that, while strategy and vision are developed by the top leadership and the central government, implementation is left to the local governments. Due to misaligned incentives that emphasize GDP growth above everything else, local government officials are generally impatient and always expect big breakthroughs immediately after an investment was made. There is often little understanding that it takes time to move from an idea to a competitive product. In addition, there is a tendency for top-down technology leapfrogging by fiat that neglects the enormousrisks of ramping-up complex technology systems in record time[35]. Furthermore, reflecting a lack of transparency and trust, administrators and government bureaucrats are seeking to design tighter and tighter controls which frequently result in unrealistic deliverables and project schedules[36].

Persistent Friction

However, there are additional reasons for the friction between China's innovation policy and the "Global Technology Sourcing" needs of Chinese semiconductor firms. There is no reason to doubt that China's leaders are firmly committed to indigenous innovation as the key to removing poverty and to accelerating China's catching up with the US, EU and Japan. Indigenous innovation is considered essential not only for moving beyond the precarious export-oriented growth model. At stake really is the survival of the system.

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34. Prof. Wei Shaojun, as quoted in "China Fabless Semiconductor Panel: Don't pack your Bags Just Yet", http://community.cadence.com/cadence_blogs_8/b/ii/archive/2014/06/18/china-fabless-semiconductor-panel-don-t-pack-your-bags-just-yet. Dr. Wei, who is Dean of the Microelectronics Institute at Tsinghua University, and President of the China IC Design Association, has played an active role in drafting China's new IC industry policy.
35. The collision between two high-speed trains in Wenzhou on 23 July 2011, the third-deadliest HSR accident in history, provided an example of the high risks of top-down technology leapfrogging. (Rabinovitch, S., 2011, "Crash threatens China's high-speed ambitions", *Financial Times,* July 24.
36. An important insight of innovation theory is that, in general, catching-up in hi-tech industries like semiconductors takes time, in order to develop the necessary skills, as well as the critically important intangible knowledge and a great variety of complementary soft innovation capabilities that are necessary to develop a strong absorptive capacity. See, for instance, Kim Linsu, 1997; Ernst, 2002, and Ernst, 2009).

But the implementation of this strategic vision is hampered by the fragmentation of China's innovation system that involves diverse stakeholders with conflicting interests. This is hardly surprising. Like most latecomers, China's innovation system is constrained by multiple disconnects between research institutes and universities on the one hand and industry on the other; between 'civilian' and 'defense' industries[37] ; between central government and regional governments; and between different models of innovation strategy[38].

Other constraining features of China's indigenous innovation policy include the widely discussed quality problems in education; plagiarism in science and derivative research; a privileged treatment of SOEs in public R&D support and procurement that neglects SMEs; lists of "indigenous innovation" products used for government procurement focus on existing technologies and hence stifle innovation; weak complementary capabilities(for instance in the legal; in patent law; and in standardization); and weak coordination of complex innovation networks.

In the end, it is this friction between the current form of indigenous innovation policy and the global technology sourcing needs of Chines semiconductors firms which defines the dual challenge for China's new policy on semiconductors: Is China adequately accounting for the unintended costs of its "indigenous innovation" policy? And can China combine the benefits of both innovation strategies — "Indigenous Innovation" and "Global Technology Sourcing"?

2. China's New Push in Semiconductors – What do we know about Objectives, Strategy and Policies?

2.1. Background

It is useful to recall that China's strategy to develop the semiconductor industry has experienced many changes in a relatively short period of time. Frequent vacillation between statist and more market-friendly policies reflect a tension between two conflicting objectives: As a latecomer to this industry, China needs to develop and upgrade a robust domestic production and innovation system, while at the same time Chinese firms are eager to reap the benefits of global knowledge sourcing through deep integration into the industry's global value chain. This unresolved friction between State and Market may explain why, despite massive government efforts to build indigenous innovation and production capabilities, China still plays a very limited role in semiconductor production, IC design, and as an innovator.

37. See for instance Walsh, K., 2011, *The Chinese Defense Innovation System,* presentation at IGCC Chinese Defense Industry Conference, June 30-July 1.

38. Creating university-industry linkages has been the focus of much of Chinese attempts to reform its innovation system. More recently, attempts are under way to address the other disconnects, but so far with mixed results. See for instance chapter 2 in Ernst, D., 2011, Indigenous *Innovation and Globalization: The Challenge for China's Standardization Strategy,* UC Institute on Global Conflict and Cooperation; La Jolla, CA and East-West Center, Honolulu, HI., 123 pages http://www.EastWestCenter.org/pubs/3904 [Published in Chinese at the University of International Business and Economics Press in Beijing, 自主创新与全球化：中国标准化战略所面临的挑战].

In fact, until 2000, practically all the semiconductor companies were state-owned enterprises, foreign direct investment was heavily restricted, and decision-making was controlled by the Chinese government. In June 2000, the State Council Rule 18 brought an important shift in policy, focusing on reducing the role of SOEs, encouraging FDI and offering tax incentives[39].

Rule 18 expired in December 2010, and was succeeded by State Council Rule 4, as part of the 12th Five-Year Plan published in February 2011[40]. The new policies, set to expire in 2017, signal an important shift from an emphasis on quantitative growth of production capacity and output value growth to a focus on improving R&D capabilities for advanced technology. Rather than pouring funds indiscriminately into the industry in a "shot-gun" approach, the focus now is on selectively supporting a small group of semiconductor firms with global market share and the capacity for technological innovation. In contrast to rule Rule 18, Rule 4 places much greater emphasis on pragmatic choices, based on a careful selection of what are key bottlenecks and what medium-term goals might be achievable with the current set of accumulated capabilities.

2.2. Objectives

The focus of China's new policy on semiconductors, as codified in the June 2014 *Guidelines,* is on deeply entrenched weaknesses that the new policy needs to address head on:

- A persistent funding gap prevents Chinese IC companies to finance investment and R&D.
- Firm-level innovation capabilities remain weak, and the industry continues to lag far behind the US in its competitiveness and in its capacity to support innovation and China's cyber security.
- There is little coordination between different parts of the IC industry value chain with the result that industry development remains disconnected from market demand.
- Most importantly, the *Guidelines* single out the large and growing gap between semiconductor consumption and production as a critical roadblock to catching-up and forging ahead in this industry.

For China's leadership, the resultant growing pressure on the trade balance defines an important objective of the new policy for semiconductors - to reduce the consumption/production gap through selective import substitution. It is reported that

39. Simon, D., 2001, "The Microelectronics Industry Crosses a Critical Threshold", *The China Business Review,* 28(6):pages 8-20.
40. *State Council Document 4 on Issuing Several Policies on Further Encouraging the Development of the Software and Integrated Circuit Industries* (28 January 2011).

by 2020, the Government's goal is to push the share of Chinese semiconductor companies in China's semiconductor consumption up to as close as possible to 50 percent (Jones, 2014).

Such an ambitious target may not be realistic. However, as China's manufacturing strategy shifts from exports to the domestic market, China may realistically expect to reduce the exported value of its electronic systems manufacture. In turn, this may open up at least some opportunities for reducing the imported content of its semiconductor consumption. There is of course no straightforward causal link. As discussed below in Part Three of the paper, much depends on the requirements of the electronics system manufacturers, in terms of performance, price, and timing. Equally important are the technological and management capabilities of China-based fabless companies.

To reduce the production/consumption gap through import substitution, the Guidelines describe fairly concrete targets for 2015, 2020 and 2030. In the fast-moving semiconductor industry, projections that extend beyond a few years should of course be treated with a grain of salt. Nevertheless, it is useful to document the expectations of China's leadership.

For 2015, the focus is on strengthening what could be called the IC design-Foundry nexus[41]. By leveraging the demand pull from mobile devices (especially budget smart phones) to strengthen the IC design industry, the goal is to turn IC design into an engine of growth for China's IC foundry industry. In turn, the target for IC fabrication is to enable Chinese IC foundry services providers to upgrade from 40nm to 32 nm and 28nm process technology[42]. For IC assembly,packing and testing (APT), the 2015 target is that at least 30% of APT revenue should come from mid- to high-end packing and testing technology.

The target for 2020 is to gradually increase China's local value-added and to upgrade China's position in the global semiconductor value chain. In addition, China should join global industry leaders in IC design for mobile devices, cloud computing, the Internet-of-Everything (IoE) and Big Data. Finally, by 2030, Chinese firms are expected to compete with global industry leaders across key sector of the IC industry supply chain and create disruptive technological breakthroughs.

2.3. Strategy

China's new Strategy to Promote IC Industry Development has both a defensive and a more assertive and self-confident element.

41. See detailed discussion below in Part Three of the paper.
42. A single nanometer (nm) is one million times smaller than a millimeter. Since integrated circuits, such as computer processors, contain microscopic components, nanometers are useful for measuring their size. In fact, different eras of processors are defined in nanometers, in which the number defines the distance between transistors and other components within the CPU. The smaller the number, the more transistors that can be placed within the same area, allowing for faster, more efficient processor designs. (http://www.techterms.com/definition/nanometer)

The Defensive View

The defensive view holds that China needs to respond to a combination of persistent domestic weaknesses and new threats to China's security and international competitiveness resulting from global transformations[43].

MIIT for instance emphasizes that, despite rapid growth, Chinese IC companies generate low profit margins, and hence have limited means to finance investment. SMIC is mentioned as an example of this financial bottleneck: "In 2013, SMIC realized a record profit of about $ 170 m, but it needs to invest around $ 5bn to produce a month (50,000) of its 12 inch 28nm chips. TSMC, on the other hand, realized a net profit of $ 6.2bn, which allowed it to cover its investments for more than six months"[44]

An equally important concern is that China's IC fabrication technology "remains two generations behind global leaders, and we are still dependent on imported equipment and materials." (ibid.) As documented earlier in this paper, Chinese foundries do indeed lack considerably behind in process technology and wafer size, and they have a long way to go to improve their absorptive capacity and process innovation capabilities. And most Chinese IC design firms are too small to invest in sophisticated design capabilities.

China's new policy on semiconductors seeks to break this vicious cycle, where weak IC design capabilities feed into weak IC fabrication capabilities. According to Tsinghua University's Wei Shaojun, Chinese IC design houses must upgrade in order to secure access to limited foundry capacity. It is worthwhile quoting Dr. Wei's blunt statement: *"As chip production becomes increasingly sophisticated and expensive, the number of customers dedicated chip contractors can fully support will become increasingly limited, giving control of production capacity added importance….Capacity is king…[in the global foundry industry.]… If Chinese chip designers cannot squeeze into the global top 10, they will have trouble securing capacity. ...This predicament is of even greater concern to Chinese authorities than the high value of IC imports."*[45]

Of particular concern for China's leadership is the persistent innovation gap in advanced semiconductors relative to the US, described earlier in this paper. According to MIIT, China continues to remain focused on its role as the "Global Electronics Factory", while remaining weak in high-value added activities in IC fabrication, IC design and software. An equally disturbing domestic weakness is the disconnect between IC design and domestic electronics manufacturing. In terms of policy implementation, MIIT highlights the deeply entrenched inter-agency rivalries which give rise to a lack of coordination among different stakeholders in China's semiconductor industry.

43. See MIIT Vice-Minister YANG Xueshan, keynote speech at the third Science and Technology Committee Annual Meeting in Beijing, August 19, 2014, http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/16113093.html . See also USITO, 2014, *China IC Industry Support Guidelines – Summary and Analysis,* September 1, Beijing.
44. USITO, 2014, Interview with, Miao Wei, MIIT, Director of Department of Informatization, on the background, significance and key points from the "Guidelines" June 25:p.3.
45. Wei Shaojun, quoted in Wang, Hsiao-Wen, 2014, "China's Semiconductor Grab – TSMC, MediaTek in the Bull's Eye", CommonWealth Magazine, 21 August 2014, http://english.cw.com.tw/article.do?action=show&id=14830

Global transformations, from the perspective of China's government, create competitive pressure for China, but they also provide opportunities. In response to the Global Recession, developed countries have accelerated their structural adjustments, focusing on policies to enhance their international competitiveness. They all seek to expand exports, especially for high-value-added high-tech industries.

In the view of China's leadership, the U.S. now has shifted to more aggressive industrial, innovation and trade policies to retain its leadership in the semiconductor industry, which is considered to be one of the main drivers of economic growth.

Chinese technology planners have studied the global ICT industry enough to conclude that this is an industry in transition, if not in turmoil. They observe that, both for IC design and process technology, limitations to the existing technology trajectory are increasing. Traditionally, R&D in the semiconductor industry was based on Moore's Law, i.e. the observation that the number of transistors on a given chip can be doubled every two years[46], and that the resultant "…[a]dvances in semiconductor technology have driven down the constant-quality prices of MPUs and other chips at a rapid rate over the past several decades."[47] Chinese planners realize that today this traditional approach to semiconductor R&D may no longer work - chips may still be getting smaller and faster, but further miniaturization no longer necessarily involves them getting cheaper[48].

At the same time, China's new push in semiconductors realizes that potentially disruptive new technologies transform the parameters of semiconductor demand and supply. Examples mentioned by MIIT include Cloud Computing, the Industrial Internet, and the Internet-of-Everything. China's IC strategy assumes that these internet-based networking technologies require complex multi-component semiconductors (MCOs) in order to integrate systems on chips which consume little energy and which protect against cyber-attacks. China's leadership considers the design and fabrication of these MCOs as an essential prerequisite for forging ahead in the semiconductor industry.

In addition, Chinese technology planners realize that new materials, nanotechnologies and 3D printing will further disrupt existing technology roadmaps. In some sectors of the semiconductor industry value chain, such radical changes in technology are expected to foster the emergence of global oligopolies where a handful of technology leaders control profits and sales, raising the barriers to entry for latecomers like China. Today, for instance, the Big Three in semiconductor fabrication

46. Moore, Gordon E. (1965). "Cramming more components onto integrated circuits" (PDF). Electronics Magazine. p. 4. http://www.cs.utexas.edu/~fussell/courses/cs352h/papers/moore.pdf
47. Byrne, David M.; Oliner, Stephen D.; Sichel, Daniel E. (2013-03). "Is the Information Technology Revolution Over?", *Finance and Economics Discussion Series Divisions of Research & Statistics and Monetary Affairs Federal Reserve Board.* Washington, D.C.: Federal Reserve Board Finance and Economics Discussion Series (FEDS), http://www.federalreserve.gov/pubs/feds/2013/201336/201336pap.pdf
48. "Chip-makers are betting that Moore's Law won't matter in the internet of things", June 10, 2014, http://qz.com/218514/chip-makers-are-betting-that-moores-law-wont-matter-in-the-internet-of-things/

(Intel, Samsung and TSMC) account for around 60% of global capital expenditures for semiconductor facilities, and only these three firms have what it takes to build the next-generation facilities that can produce 450mm wafers with leading-edge process technologies (20nm and below)[49].

The assertive view

In other sectors, however, Chinese technology planners expect that disruptive changes in technology may weaken existing global oligopolies. In the IT industry, this was the case when the spread of mobile Internet-related devices eroded the erstwhile seemingly incontestable leadership positions of Intel and Microsoft in PCs.

In the assertive view, global transformations in markets and technology like the ones discussed before, open up new opportunities for China to forge ahead in semiconductors, while domestic weaknesses call out for and provoke new policies to reduce or at least mitigate these weaknesses.

As for China's persistent domestic weaknesses, MIIT asserts that a BIG Push policy response is required to strengthen the "weak parts of China's supply chain."[50] The Big Push approach ("Make a firm decision and push forward") constitutes a remarkable departure from the traditional focus of China's leadership on incremental policies[51]. Even more remarkable is that the Big Push approach is combined with a commitment to "the decisive role of the market in allocating resources" (p.4) . In a way, it seems that the semiconductor industry is used as an early trial case where the government can see how policies that rely on the "decisive" role of the market might work in practice.

According to MIIT's Miao Wei, in China's new semiconductor strategy, "… [c] ompanies take the lead, with market orientation….Let the market determine the development of products, the technological path, and allow the market to unleash the vitality and innovative capacity of industry…. Make better use of the government to create and environment for fair market competition, and strengthen and improve public service."[52] Specifically, mergers and acquisitions (M&A), both among Chinese companies and with global industry leaders, are now considered to be an important

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49. G.Dan Hutcheson, VLSI Research, quoted on 450mm wafer transition, in Izumiya, W., 2014, "450mm wafer transition won't happen till 2020 at the earliest", *The Semiconducctor Industry News, June 5,* https://www.semiconportal.com/en/archive/news/news-by-sin/140605-sin-izumiya-may-vlsi.html
50. USITO, 2014, Interview with, Miao Wei, MIIT, Director of Department of Informatization, on the background, significance and key points from the "Guidelines" June 25:p.3.
51. The established view is that, in the words of a senior banker at HSBC, "…[t]he Chinese authorities don't like the 'big bang' approach. That's why they test something – and if it works – they do more of it." (Justin Chan, co-head of markets for Asia-Pacific at HSBC, quoted in Noble, J., 2014, "Grand global ambitions for currency sow domestic risks". FT Special Report *The Future of the Renminbi,* September 30: page 2.)
52. USITO, 2014, Interview with, Miao Wei, MIIT, Director of Department of Informatization, on the background, significance and key points from the "Guidelines" June 25:p.4.

short-cut to strengthen financial resources, as well as management and technological capabilities.

As for global transformations in semiconductor markets and technology, there is a new confidence on the Chinese side that China now has a strong hand to play in international competition. Specifically, Chinese decision-makers in government and industry seem to focus their attention on global transformations in semiconductor markets and technology which provide a demand pull from mobile devices, and a window of opportunity for China's catching-up and forging ahead in trailing-node integrated circuit process technologies (28nm and above)[53].

These global transformations might indeed provide new opportunities for China to move from catching-up to forging ahead in the semiconductor industry. But as discussed in Part Three, China would need to move towards a bottom-up, market-led approach to "industrial policy", in order to seize these opportunities.

2.4. Implementation - What is different about the new policies?

Before however, it is necessary to take a closer look at the policies that the Government has introduced to implement the new strategy on the semiconductor industry. In reviewing these policies, it is useful to ask: Is China's government adjusting its support policies for semiconductors, drawing on multi-layered industrial dialogues with private firms, both domestic and foreign? Or will policies again rely heavily on control and micro-managing investment decisions, and thus possibly waste the opportunities provided by global transformations in markets and technology?

Efforts to implement China's new semiconductor industry strategy gathered strength through support from Yu Zhengsheng, a prominent member of the current Standing Committee and a former Party Secretary of Shanghai[54]. Yu has long been involved in the development of China's electronics industry[55]. Yu nominated Vice Premier Ma Kai (who was chairman of NDRC from 2003 to 2008) to head China's new policies on IC industry development.

Tax breaks and subsidies continue to play a role. In addition to keeping the tax breaks mentioned in the State Council Document 4 (2011) document for IC design houses and foundries, the tax benefits have now been expanded to semi-

53. For details, see Part Three of this paper.
54. http://en.wikipedia.org/wiki/Yu_Zhengsheng
55. Yu started working as a technician in several radio factories in Hebei Province (1968–1975) before he joined the Research Institute for the Promotion and Application of Electronic Technology under the Fourth Ministry of Machine-Building Industry, where he served as a technician, engineer, and assistant chief engineer (1975– 1982). He was promoted to deputy director in 1982, after which he was transferred to the Ministry of Electronics Industry (MEI) where he served as head of the Department of Microcomputer Management, and later the MEI deputy director of planning (1982–84). Today, he is a strong promoter of China's IC industry's development. http://www.brookings.edu/about/centers/china/top-future-leaders/yu_zhengsheng.

conductor testing firms. This means testing firms now also enjoy savings on corporate income, value-added, and operation taxes.

In addition, the government seeks to create new mechanisms to improve the efficiency of Government financial support instruments, especially through the Ex-Im Bank and the China Development Bank. A particular emphasis is placed on debt-financing tools, to be issued especially for SMEs. Priorities include companies seeking to go public; R&D tax credits; and the improvement of loan insurance and credit insurance tools. In addition, the Guidelines emphasize efforts to strengthen tax support policies and use Import Tax exemptions for critical equipment, components and materials that are needed for strengthening China's IC industry[56].

Overall however, the government is playing down the role of tax breaks and subsidies in the initiative, as those policies are easily attacked by foreign governments as violating World Trade Organization (WTO) anti-subsidy agreements.

Instead, the government emphasizes the central role to be played by two new policy initiatives[57]:

- An IC Industry Support Small Leading Group, chaired by Vice Premier Ma Kai, for ministerial coordination of high-level national strategies
- To improve investment allocation, a set of "market-driven" regional and national IC Industry Equity Investment Funds are created "with limited government intervention".

To support these two key policies, the Government (through NDRC) pursues a much more active anti-monopoly policy to reduce market abuse by IT companies. If such anti-monopoly policies are well designed, they could enhance the impact of the above two policies to upgrade China's semiconductor industry. Among U.S. IT companies, prominent examples include the pressure on Qualcomm to reduce licensing fees, and investigations of business practices of Google, Apple, Microsoft, Cisco and IBM. In Qualcomm's case, NDRC is expected charge a $ 1.2bn fee for using its dominant position as a supplier of critical MCOs to overcharge licensing fees for Chinese smart phone manufacturers. According to Scott Kennedy, director of the Research Center for Chinese Politics and Business at Indiana University,

"…[t]he Chinese government has credibility to pick on Qualcomm because of investigations into the company in other countries. …But it also definitely fits their

56. If implemented, these policies are of quite some interest to current negotiations to expand the Information Technology Agreement (ITA). For instance, suppose China can use selective import tax exemption, what does this imply for China's interest in ITA-2? Can import tax exemptions provide access to lower-cost critical inputs, so that import reductions via ITA-2 would be unnecessary?

57. The following quotes are from USITO's unauthorized translation of the *"Guidelines to Promote National Integrated Circuit Industry Development".*

industrial policy goals if they can squeeze in lower licensing fees or other technology-sharing arrangements."[58] It now looks like Qualcomm will admit guilt and pay cash[59].

NDRC's anti-monopoly policy is controversial — Multinational executives and industry associations believe the NDRC is deliberately targeting foreign companies. In fact, data compiled by the Financial Times show that foreign companies or their joint ventures have paid almost 80% of the Rmb3bn ($490m) in anti-monopoly penalties handed down by the NDRC since 2011. However, half of those Rmb 2.4bn in fines for foreign companies was assessed against 10 Japanese auto parts makers who admitted in August 2014 to price collusion. In addition, NDRC argues that its price supervision and anti-monopoly bureau is too inexperienced and understaffed, to organize a conspiracy against foreign companies, although they are now recruiting new staff.

At the same time, there are efforts to strengthen the role of trade diplomacy, as a necessary complement of the above industrial support policies for the semiconductor industry. During the current round of negotiations to expand the product list of the Information Technology Agreement (the so-called ITA-2), China seems to have experimented (apparently quite successfully) with a combination of delay tactics and a slowly evolving and still precarious strategy of co-shaping the design of an expanded ITA[60].

The IC Industry Support Small Leading Group

On November 29th, 2013, China's Semiconductor Industry Association announced that China's State Council was to establish an IC Industry Support Small Leading Group[61]. An important objective of the Leading Group is to reduce inter-agency rivalries in order to improve strategy coordination and to mobilize and consolidate resources. A Consulting Commission that reports to the Leading Group acts as a Think Tank to assess policy measures, and to suggest solutions and adjustments in policies. An important objective is to speed up government response time and to improve the capacity for flexible response, by navigating around entrenched bureaucratic hurdles and rigid regulations. An additional function of the Leading Group seems to be to mobilize and consolidate public and private resources through Public-Private Partnerships.

58. Mozur, P., 2014, "Using Cash and Pressure, China Builds its Chip Industry", *The New York Times,* October 26
59. Chang, G.G., 2014, "Qualcomm In Quicksand, Its China Problem Not Fixable", July 27, http://www.forbes.com/sites/gordonchang/2014/07/27/qualcomm-in-quicksand-its-china-problem-not-fixable/ . The article quotes the following statement of Qualcomm's CEO: "We just believe whatever the resolution may be, will likely include some form of payment."
60. See detailed analysis of China's approach to current ITA-2 negotiations, in Ernst, D., 2014, *The Information Technology Agreement, Industrial Development and Innovation - India's and China's Diverse Experiences,Think Piece prepared for the E15 Expert Group on Trade and Innovation and the International Center for Trade and Sustainable Development (ICTSD), Geneva,* http://e15initiative.org/wp-content/uploads/2014/03/Dieter-Ernst.pdf.
61. http://www.csia.net.cn/Article/ShowInfo.asp?InfoID=38790 and http://www.csia.net.cn/Article/ShowInfo.asp?InfoID=38789 .

Leading Groups have a long tradition in China as a sort of ubiquitous tool to act against or mitigate the silos within the government that bedevil the implementation of strategies laid out by the leadership. To bypass bureaucratic inertia and inter-agency rivals, the State Council occasionally establishes such "leading groups" of high level officials to improve coordination across China's many ministries and other government organizations[62].

In the IT sector, various Leading Groups have been established since the 1980s to issue key strategies and guidelines for the electronics industry[63]. Today's IC Industry Support Small Leading Group however differs substantially in terms of organization and governance. An important main difference is the direct involvement of China's top leadership. Vice Premier Ma Kai acts as chair, and prominent local government leaders, like Beijing Vice-Mayor Zhang Gong, play an active role. Participants include key players from four powerful ministries (MIIT, MoST, MoF, NDRC), top industry leaders, and senior academics with an established research and patenting record.

In addition, it seems that the expertise of participants both from industry and research institutes has substantially improved. It is now more common to have experts who have studied and worked abroad and are internationally well connected. Take the example of Dr. Wei Shaojun, who played an active role in drafting China's new IC industry policy. As Dean of the Microelectronics Institute at Tsinghua University, and President of the China IC Design Association, Dr. Wei is well-connected within Leadership circles. Dr. Wei studied and worked in Belgium, and is internationally well connected and respected, as a frequent speaker at the Global Semiconductor Alliance (GSA), and as a key Chinese delegate to the World Semiconductor Council. Chinese experts like Dr. Wei know the international scene well, are familiar with the intricacies of the global semiconductor industry value chain, and thus have a better understanding of what policies might work in this knowledge-intensive and highly globalized industry.

In short, while the institution of a Leading Group is nothing new for China, it nevertheless seems that new wine is now being filled into these old bottles.

Regional and National IC Industry Equity Investment Funds

Arguably the most interesting new policy initiative is the announcement by MIIT and NDRC to establish a National IC Industry Equity Investment Fund, endowed with

62. Leading groups have been extensively used since the early 1980s to foster the reform of China's Science and Technology system, see Saich, Tony. "Reform of China's Science and Technology Organizational System." *Science and Technology in Post-Mao China.* Ed. D.F. Simon and M. Goldman. Council on East Asian Studies, Harvard University, 1989, 69-88.

63. In 1982, the State Council funded a permanent Leading Group called the "Leading Group for Electronics, Computers, and Large-Scale Integrated Circuits". In 1984, the group's name was changed to the "State Council Leading Group for the Revitalization of Electronics [Industry]". The following year, the Leading Group published a document called "The Strategy for the Development of China's Electronics and Information Industries" which laid out strategies for the 7th five year plan. For details, see Simon, D., 1988, Technological Innovation in China: The Case of the Shanghai Semiconductor Industry. Massachusetts: Ballinger Publishing.

RMB 120bn ($ 19.5bn) over a three to five-year period, to be complemented by a series of Regional IC Industry Equity Investment Funds.

Table 2 provides information on the structure and the investors of the initial National Fund. It is noteworthy that so-called “Societal Funds”, i.e. private equity investment funds, are responsible for 36% of the National Fund.

Table 2.
Initial National Found: RMB 120 bn ($19.5 bn) / 3-5 years - Structure & investors

Investor	Amount (RMBbn/%share)
MoF	36 (30%)
China Develoment Bank	32 (26%)
Beinjing E-Town Capital & minucipal government	10 (8%)
Societal funds (non governmental)	42 (36%)

Wuhan, Shangai, Shenzhen to follow the Beijing Found model
USITO 2014, quoting data from E-town Capita web site

Potentially, the idea behind the IC Industry Equity Investment Fund could signal an important break with previous policies. According to an industry observer who has requested anonymity, “this is the first time that the Chinese has set up a fund jointly with public investors and asked professional fund management companies to raise, invest and manage the funds, in contrast to direct subsidy or investment in selected projects or companies.” Under the new approach, the investment fund will take stakes in companies proportionate to the amount invested, and the fund manager will insist on a rate of return. The ultimate goal is to leverage the ownership structure to change corporate and industry structures.

However, at this stage, these are declarations of intent, and it may be advisable to take such claims with a grain of salt. One might wonder for instance to what degree the decision to establish an Investment Equity Fund is primarily motivated by an attempt to avoid being accused of violating WTO anti-subsidy agreements. Whether the establishment of an IC Industry Equity Investment Fund signals a more professional approach to overcome the critical bottleneck of insufficient long-term investment funds depends to a large degree on the selection of the fund managers and the discretion they will have in allocating funds.

Publicly available knowledge on these questions is limited. We know that the primary purpose of the National Fund is to mobilize private and public funding sources to reduce the investment bottleneck faced by domestic semiconductor firms. According to the Guidelines, the Fund covers the whole industry value chain (design, manufacturing, R&D, plus commercialization and knowledge-intensive support services). The Fund also is supposed to play a catalytic role in promoting industry consolidation, through M&A among domestic firms and the acquisition of foreign firms which control important technologies or markets.

As for Regional Funds, some information is now in the public domain on the Beijing IC Industry Equity Investment Fund. According to USITO, more regional IC Industry support plans have also been released over the summer of 2014, for instance for Anhui Province, Suzhou, Hefei city government, Sichuan province, and Gansu Province. However, none of these announcements provide details on the selection of fund managers and their degree of decision autonomy on allocating funds.

The Beijing IC Industry Equity Investment Fund

A closer look at the Beijing IC Industry Equity Investment Fund finds that two fund managers have been selected thus far:

- The main fund and the sub fund #1 for equipment and manufacturing is to be managed by China Grand Prosperity Investment (CGP);
- As for the sub fund for IC Design, Packaging and Testing, Beijing Qingxin Huachuang Investment Management Ltd. was initially selected as fund manager[64]. However, in June 2014 it was reported that Hua Capital Management Ltd (HCM), a Chinese investment management company, was chosen to manage the chip design and testing fund under the Beijing government's 30 billion-yuan (HK$37.8 billion) Semiconductor Industry Development Fund[65 66].

While CGP is headquartered in Hong Kong, it is definitely not a global player[67]. But, according to CGP's Chinese web site, they have a long history of managing investment funds in China[68]. Cheng Hairong, the chairman of CGP has over 20 years of experience as an executive director and consultant in establishing and managing listed companies in Hong Kong. Mr. Cheng has knowledge in China finance and investments in life sciences, biotech, energy saving, tourism, trading and finance sectors[69].

64. http://usito.org/news/beijing-picks-investment-firms-manage-beijing-ic-support-fund
65. "Hua Capital hires Bank of America for OmniVision deal", *South China Morning Post,* September 19, 2014, http://www.scmp.com/business/companies/article/1595559/hua-capital-hires-bank-america-omnivision-deal
66. There is no information available in the public domain on what role (if any) Beijing Qingxin Huachuang Investment Management Ltd. is supposed to play.
67. An informal inquiry, conducted by the author in spring 2014 among fund managers in a leading global bank, showed that none of the interviewees knew CGP.
68. http://www.prosperityinvestment.hk/index.php?lang=tc
69. CGP's business philosophy is summed up in the following statement of its chairman: "*Following the economic recovery of the United States of America, it started to reduce the scale of debt purchase in 2014 which affected the international fund flow. This may lead to the withdrawal of fund from various countries including China and Hong Kong which in turn causes the instability of the stock market and the economy of these countries. However, this "tight funding" situation may be an opportunity for the Group to identify potential investment at a lower investment cost. All in all, we will continue our investments in both China and Hong Kong with caution."* Message from the Chairman of CGP, Annual report 2013, http://www.prosperityinvestment.hk/vtuploads/201404/LTN201404161316.pdf

CGP seems to have learnt how to walk the fine line between adapting to the requirements of the government, while at the same time making sure that the fund produces enough profits. On the one hand, one could argue that this type of Chinese fund manager just fits nicely with the implementation requirements set by the government. In short, while elements of the market are now introduced, at the same time the government can continue to exercise control. An industry observer who requested anonymity provided a telling example of this hybrid model of Chinese-style fund management. In a meeting with the Beijing Municipal Government, partners of the CGP (China Grand Prosperity Investment Limited Holding Co) fund manager were present, and displayed a "highly deferential behavior" *vis-à-vis* the government representatives.

Initially, the Beijing subfund for IC Design, Packaging and Testing was supposed to be managed by Beijing Qingxin Huachuang Investment Management Ltd[70]. But very little is known about this fund, and a web search did not produce a company web site.

In June 2014, it was reported that Hua Capital Management Ltd (HCM) would take over the management of the Beijing subfund for IC Design, Packaging and Testing. Hua Capital Management Ltd (HCM) is a private equity firm specializing in buyouts, based in Beijing. Funds managed by HCM include the Shanghai Pudong Science and Technology Investment Co. Ltd, a wholly state-owned limited liability company, established directly under the Pudong New Area government of Shanghai[71].

According to industry observers, the real driving force behind HCM is Chen Datong, who is HCM's chairman as well as Co-Founder and Managing Partner of WestSummit Capital, a leading China-based global growth equity firm focused on helping high growth technology companies access the China market[72]. Another major player is Liu Yue, the deputy chairwoman of HCM, who also has a wealth of experience in China's IC industry. Of particular interest is her role as an early investor in SMIC through Walden Capital, and her continuous involvement with SMIC.

HCM's President, Xisheng (Steven) Zhang, started in 1994 out as a postdoc researcher at UC Berkeley, and then worked in senior management positions in Agilent and Silicon Valley start-up IC design companies, before joining Beijing-based private equity investment company West Summit Capital Management in 2013. Mr. Zhang

70. http://usito.org/news/beijing-picks-investment-firms-manage-beijing-ic-support-fund
71. As discussed below, Hua Capital Management Ltd (HCM) is also managing China's acquisition of the US IC design company OmniVision.
72. Chen Datong got his BS, MS, PhD from Tsinghua University, and worked as a Post-Doctoral research fellow at Stanford University. Dr. Chen has more than 20 years of investment and operations experience in the technology and semiconductor industry,and he owns 34 US and European patents. Prior to WestSummit, Datong was a Venture Partner at Northern Light Venture Capital, a leading technology VC fund, where he led investments in the semiconductor industry. Datong was the Co-Founder and CTO of Spreadtrum Communications, and hence has deep insider knowledge of that company. Prior to Spreadtrum, Dr. Chen was the Co-Founder and Senior VP for Omnivision, again providing him with insider knowledge for the acquition of that company, discussed below. Datong serves on the Board of Directors for two other important Chinese IC design companies, GigaDevice and VeriSilicon.

has over 20 years industry experience in Semiconductors and EDA, and in managing start-up companies in Silicon Valley and in Beijing.

Based on this information, it is possible to conclude that HCM qualifies as a professional fund manager with considerable knowledge of key aspects of the semiconductor industry value chain, especially related to IC design. In the view of USITO, the use of professional investment fund managers, as opposed to government subsidies or investment, "suggest a new approach to industrial policy that focuses on building a strong and sustainable investment environment in China."[73] But a final assessment has to wait until more information is available on how funds will ultimately be deployed.

For instance, while selecting private fund managers might seem to indicate a stronger role for the market, this may actually not be the case if the selected company (i.e. CGP) owes its selection to its close personal connections to the leadership. It is important to establish who makes the key decisions on the allocation of funds, bureaucrats or technocrats with deep industry knowledge.

Another unresolved question is whether the availability of IC Industry equity funds will again lead to a competitive race that pits Beijing against Shanghai, Shenzhen etc, with the result of duplicative investments that will end up giving rise to overcapacity. Furthermore, are there signs that policy decisions are less constrained by elaborate priority lists of "indigenous innovation" products and technologies? If these lists were still important, this would indicate that nothing much has changed.

In any case, the establishment of the Semiconductor Equity Investment Fund does not necessarily imply that China is converging to a US-style market driven policy approach. More likely is the development of a hybrid model that seeks to combine the logic of equity investment fund management with the objectives of China's IC development strategy.

3. China's Semiconductor Industry Upgrading Scenario – Economic Reasons for a Bottom-Up, market-led "Industrial Policy"

3.1. Perceived Opportunities[74]

China's leadership is very conscious that the US is way ahead in advanced semiconductors and that China has a long way to go to close this gap. At the same time however, the policy documents which define China's new push in semiconductors, also convey a new sense of optimism. Global transformations in semiconductor markets and technology are no longer only perceived as threats. In fact, China's technology planners now seek to identify upgrading scenarios for China's semiconductor industry that could benefit from those global transformations.

73. USITO, 2014, *China IC Industry Support Guidelines – Summary and Analysis,* 1 September: p.6

74. The following analysis is based on interviews with observers and insiders of China's semiconductor industry. Where publicly available, key policy documents have been consulted which shape China's new push in semiconductors.

Specifically, their attention seems to focus on four global transformations, which are expected to create new opportunities for China to move from catching-up to forging-ahead in semiconductors: a) the demand pull from mobile devices; b) new opportunities for China's foundries in trailing-node semiconductor technologies; c) changes in the IC foundry industry landscape; and) a new interest in strategic partnerships and mergers and acquisitions (M&A).

The following analysis will examine the economic rationale behind each of these four perceived opportunities and what factors might determine China's chances of success. While the opportunities are real, they all involve considerable uncertainty. An important finding is the precarious nature of these opportunities. In other words, basic parameters that determine how China will fare may change at short notice and in unpredictable ways. This implies that flexible policy implementation is required to cope with such uncertainty. If China wants to exploit the above opportunities, it needs to move towards a bottom-up, market-led approach to "industrial policy "guided by the principle of "smart specialization".

3.2. Demand pull for mobile devices as a catalyst for IC design

Chinese decision-makers, both in government and industry, are convinced that, for mobile devices, China is now becoming a lead market, and hence can shape demand and technology trajectories. It is expected that the demand-pull from mobile devices will catalyze an upgrading of China's fabless IC design industry. Chinese IC foundries in turn may be more motivated to invest in capacity expansion and technology upgrading, once demand from local chip design houses increases. Quoting again MIIT's Miao Wei, China's market for mobile devices and for a wide variety of IT equipment is booming and hence should provide "favorable conditions for China to leapfrog ahead of others"[75] As demand for low-end budget smart phones is driving volume growth, it is expected that China can leapfrog into emerging markets for sub-$50 smart phones.

Today, China has four times as many mobile handset subscribers as in the US (almost 1.3bn compared to 327.6m)[76]. China now is the world's largest smart phone market with almost 700m smartphone connections, surpassing the US (197m), Brazil (142m), India (111m), and Indonesia (95m)[77]. Low-cost smartphones designed in China are flooding the market - Android phones designed in China now represent more

75. USITO 2014 interview with Miao Wei: p.3.
76. China data are for December 20, 2013, http://www.reuters.com/article/2013/12/20/china-mobilesubscribers-idUSL4N0J51ZN20131220 , while US data are from "U.S. Wireless Quick Facts". http://www.ctia.org/your-wireless-life/how-wireless-works/wireless-quick-facts .
77. GSMA, 2014, *Smartphone forecasts and assumptions, 2007-2020,* http://www.gsma.com/newsroom/smartphones-account-two-thirds-worlds-mobile-market-2020/

than 50 percent of the global market[78]. In 2015, Chinese original-equipment manufacturers (OEMs) are expected to design more than half of the world's phones[79].

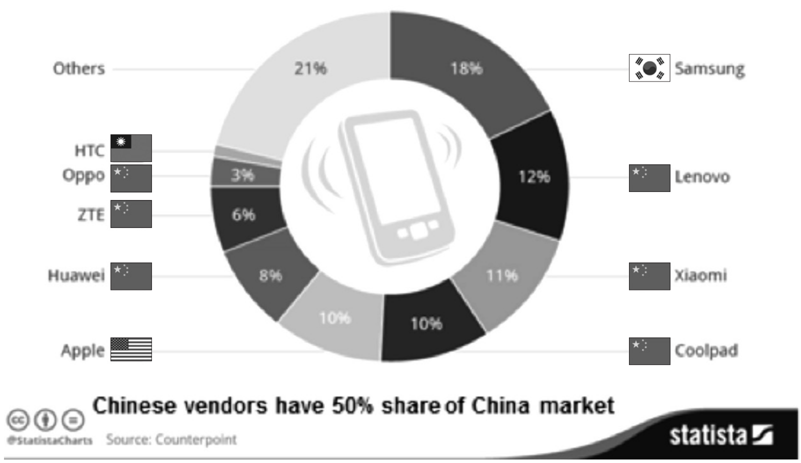
Data from the first half of 2014 indicates that smartphone shipments in China will exceed 400 million units in 2014, accounting for 93 percent of total mobile phone shipments in that market[80]. China now is the ultimate prize for global smartphone vendors. In the first quarter of 2014, China contributed 15.8% of Apple's total revenues, due primarily to sales of iPhone devices in China. Most recently, in the second quarter of 2014, China accounted for 37% of global smart phone shipments – some 108.5 million units[81].

Since 2008, the global market share of mobile phones produced in China has almost doubled from 44% to 81% in 2013[82]. In addition, China is now in a position to co-shape international mobile telecom standards. Both TD-SCDMA and TD-LTE standards have fostered the development of technical capabilities of IC design companies based in Greater China (Taiwan's MediaTek, and China's Spreadtrum and RDA)[83]. Global industry leaders (Qualcomm, Nvidia, Marvell, and Intel) are latecomers to China's TD mobile telecom standards, and they are constrained by high fixed costs. But they have other huge advantages, such as superior technology and system integration capacity, and deep pockets due to the high licensing fees they can charge for their technology.

Figure 2. shows that, in the first quarter of 2014, Chinese vendors accounted for a 50% share of the China market.

78. Data are from the Canalysis Country Market Tracker, October 2014, http://www.canalys.com/what-we-do/country-market-trackers . Examples include Chinese budget smart phones designed by Lenovo, Huawei, ZTE, and Xiaomi.
79. Mansfield, I., 2014, "Chinese phone manufacturers expected to take half the market in 2015," *Cellular News,* March 10, , cellular-news.com. The term original-equipment manufacturer (OEM)is used here to refer to the company that acquires a product or component and reuses or incorporates it into a new product with its own brand name. For details, see Ernst, D., 2004, "Global Production Networks in East Asia's Electronics Industry and Upgrading Perspectives in Malaysia", in Shahid Yusuf, M. Anjum Altaf and Kaoru Nabeshima (eds.), *Global Production Networking and Technological Change in East Asia,* The World Bank and Oxford University Press, 2004.
80. Goldstein, P., 2014, "Gartner, CCS Insight: Smartphone growth in 2014 will be fueled by low-cost models", http://www.fiercewireless.com/story/gartner-ccs-insight-smartphone-growth-2014-will-be-fueled-low-cost-models/2014-10-15
81. Canalysis, 2014, "Xiaomi becomes China's top smart phone vendor", 4 August, http://www.canalys.com/newsroom/xiaomi-becomes-china%E2%80%99s-top-smart-phone-vendor
82. PwC 2014, quoting data from CSIA, MIIT and Gartner.
83. For an analysis of China's TD-SCDMA standard, see Ernst, 2011, chapter 5.

Figure 2.
Domestic Vendors Stand Strong in China's Smartphone Market
% of smartphone shipments in China in Q1 2014



There are of course reasons to ask how sustainable will be this shift towards China becoming a lead market in mobile devices. Take Xiaomi, which has been catapulted from practically nothing a few years ago to the third-largest smart phone vendor in China[84] and fifth largest globally. Xiaomi's handsets have achieved almost cult-like status in China, and they are the darling of global media and investors. Yet, as a review of Xiaomi's flagship Mi3 smart phone, concludes: "Xiaomi has promise, but it is far from the world-dominating juggernaught that western media makes it out to be."[85] Its success has been for 3G smartphone only, but not for leading-edge 4G/LTE devices[86].

In fact, China's 4G smartphone market has failed to surge as expected and most Chinese vendors' domestic shipments did not achieve any growth[87]. It is too early

84. Note however that, according to Canalysis, "… Xiaomi has risen from being a niche player to become the leading smart phone vendor in the world's largest market, overtaking Samsung in volume terms in Q2. Xiaomi took a 14% share in China, on the back of 240% year-on-year growth. http://www.canalys.com/newsroom/xiaomi-becomes-china%E2%80%99s-top-smart-phone-vendor . While these data need to be taken with a grain of salt, the often quite substantial differences in market share estimates of different consulting firms indicate the fluidity and unpredictability of the rapidly evolving smart phone market.
85. Sambandaraksa,D., 2014, "Living with the Xiaomi MI3", *Telecom Asia,* September 10, http://www.telecomasia.net/blog/content/living-xiaomi-mi3?section=INSIGHT&utm_source=silverpop&utm_medium=newsletter&utm_content=&utm_campaign=telecomasia
86. *Foreward Concepts Wireless Newsletter,* August 14, 2014: p.1.
87. Chen, A. and L. Lin, 2014, "China 4G smartphone demand fails to surge: CoolPad, Lenovo, Xiaomi unlikely to achieve 2014 targets", *DigiTimes,* 1 October.

to assess whether this slow growth of 4G smartphone demand indicates that the demand pull effect from mobile devices is already being weakened.

Further, Xiaomi continues to depend on foreign companies for core technologies (especially application processors and system platforms). For instance, Xiaomi's latest smartphone, the Mi4, will be available only for China's 3G networks (both for the Chinese TD-SCDMA standard and WCDMA). Like earlier Xiaomi handsets, the Mi4 is based on Qualcomm's Snapdron 801 platform[88], reflecting a long established relationship with Qualcomm.

In addition, if Chinese smartphone makers really want to move from catching-up to forging ahead, they are faced with a very tight global oligopoly in this industry, and hence face severe upgrading barriers. The latest data available for the first quarter of 2014 show that the combined global market share for the two dominant smartphone operating systems (Google's Android and Apple's iOS) has increased to 96.4%, leaving little space for latecomers like Xiaomi to differentiate themselves through alternative operating systems[89].

This of course raises the question whether China now really has a broad enough portfolio of core technologies and the ecosystem required to sustain the move towards becoming a lead market for mobile devices. Or are these expectations a bit premature?

In any case, both the Chinese government and MNCs clearly believe that the shift towards China becoming a lead market in mobile devices is real. As a result, MNCs are all trying to position themselves so that they can sustain market access in the future. It is this perception which seems to drive some of the other global transformations, discussed below, and especially the strategic partnerships between Chinese companies and global industry leaders discussed below under section 3.5.

3.3. The Trailing-Node Upgrading Trajectory - New Opportunities for China's Semiconductor Foundries

Part One of the paper described a fundamental challenge for China's new policy to strengthen its semiconductor industry: China's domestic semiconductor manufacturing (i.e. wafer fabrication) technology and capabilities have failed to keep up with the country's IC design capabilities and needs.

This raises the question which of the following propositions might carry greater weight in shaping China's policy responses:

- China's technology gap in wafer fabrication today may matter less, as China's IC design houses can use a great variety of fabs and design services across Asia to tape out their design needs, ranging from top-tier, leading-edge pro-

88. *Foreward Concepts Wireless Newsletter,* August 14, 2014: p.2.
89. Data are from the IDC Worldwide Quarterly Mobile Phone Tracker, August 17, 2014, http://www.idc.com/search/other/perform_.do?sortBy=RELEVANCY&_xpn=false&cg=5_1321&srchIn=ALLRESEARCH&src=&athrT=10&lang=English&cmpT=10&page=1&hitsPerPage=50

cess technology foundries (like Taiwan's TSMC) down to highly specialized niche foundries for analog devices which do not require leading-edge processes.
- China's technology lag in wafer fabrication may, in the medium and longer term, substantially constrain efforts to upgrade its design industry, because access to leading-edge foundry capacity may be denied during high growth periods, and because proximity between design and wafer fabrication may still be critical for effective tape-out of leading-edge devices?

A survey of IC design firms in 2013 reported that proximity to foundries is perceived to be more important by Chinese IC design housesthan by US design houses, because Chinese firms have weaker technology capacity and hence weaker bargaining power in negotiations with large foundries like TSMC[90].

That broad proposition however needs to be differentiated. Industry observers emphasize that the advantages or disadvantages of proximity to foundries differ, depending on the capability sets and bargaining power of different firms. The pros and cons also differ across product markets and market segments — design houses for instance that focus on analog, mixed-signal designs do not need access to leading-edge process technology, but are well served with trailing-node process technology.

For policy purposes, this paper suggests to be more specific about the precise nature of the policy challenge. One could ask for instance specifically: *As China-based design houses are ramping up 28nm chip orders at TSMC, as reported in August 2014[91], would they be better off if SMIC or any other China-based foundry could have a proven 28nm process technology ready and could provide the full solution (fabrication of the design plus supporting design services that are especially important for latecomers like Chinese IC design firms)?*

China's technology planners who have shaped the Guidelines seem to have taken this more focused and pragmatic approach. Based on their research on the global semiconductor industry, the planners expect that significant and stable market for trailing-node semiconductor technology (i.e. 28nm and above) may open up new opportunities for Chinese foundries to gradually gain market share and improve their profit margins in these technologies. The primary beneficiary is expected to be SMIC, which after all is now the fifth largest global foundry.

The underlying economics works roughly as follows: At this stage of the semiconductor cycle, trailing nodes (28 nm and higher) actually carry higher margins than the

90. Anderson, E. et al, 2013, *Measuring the U.S.-China Innovation Gap: Initial Findings of the UCSD-Tsinghua Innovation Metrics Survey Project,* STI Policy Brief # 14, December, http://www-igcc.ucsd.edu/assets/001/505418.pdf
91. On August 4, 2014, TSMC reported that it has received 28nm chip orders from more than 10 China-based IC design houses and design service providers (Chao, C. and S. Shen, 2014, "China-based IC design houses ramping 28nm chip orders at TSMC", *DigiTimes,* August 4). The companies mentioned in the announcement comprise all ;eading China's IC design firms, i.e. HiSilicon, Spreadtrum, Rockchip, Allwiner, RDA and Datang.

leading-edge technology nodes below 28nm. This is so because most of the equipment used to produce trailing nodes are either partially or fully depreciated, so trailing nodes don't have the burden of depreciation. According to one observer, "trailing nodes may be returning higher margins, because they are being manufactured in fully depreciated wafer fab facilities."[92]

On the other hand, producing devices at 20nm and below is extremely expensive, resulting from the escalating cost of equipment and tools. There is an intense debate within the industry whether the cost of producing leading-edge devices will decline, and if so, at what pace. But it seems that the current consensus position within the industry is that barriers to such cost reductions will remain substantial for a considerable time.

Thus, second-tier foundries like SMIC may have a limited window of opportunity to compete in trailing node technologies. They may be able to catch up with the leaders in technology and gradually gain share and improve their margin in these trailing nodes. Industry sources report that both SMIC and UMC actually have been gaining market share away from TSMC in these trailing nodes[93].

This window of opportunity however may be closing soon. Once a second-tier foundry like SMIC is adding additional capacity, this will require new facilities with additional depreciation expenses which will reduce margins. And if more foundry capacity would be added, leading to excess capacity, the resultant cost increases would erode profit margins.

SMIC's new management seems to bet that the trailing node upgrading trajectory will work. But the challenge to achieve this goal will be formidable. According to industry observers, SMIC is two generations behind that of Taiwan Semiconductor Manufacturing Co. (TSMC), the world's largest contract chip maker. In the latest 2013 IC Foundries report, SMIC has retained its position as the fifth largest global IC foundry, and it has grown by 28% in 2013. However, Table Y clearly demonstrates that, in terms of foundry capacity, SMIC remains a minnow compared to the three global industry leaders.

Figure 3.
2013 Foundry Capacity Comparison

Foundry	Capacity / year
TSMC	16,423,625
Global Foundries	7,326,000
UMC	6,313,500
SMIC	2,682,000

IC. Insights. Production capacity fgures converted to 8-inch equivalent wafers in order to enable comparison

92. Ed Pausa, PwC, email to the author, August 18, 2014.
93. Li, M., 2014, "Chinese Fabless Industry to Outgrow Semiconductor Sector by Significant Margin", *The Wall Street Transcript,* May 26; 4 pages

In addition, SMIC's net profit is not even 1/30th of TSMC's, explaining why without government support China's semiconductor foundry sector lacks the capital needed to ramp up production and compete in the trailing-node processes. While the leading Taiwanese foundries (TSMC, UMC and Powerchip) have a combined 60% share of worldwide 2013 foundry revenues, the combined share of China's SMIC and Grace is less than 5%.

China's technology planners however seem convinced that SMIC may be able to reap latecomer advantages for trailing node technology (28nm), provided of course that appropriate support policies are in place. The underlying economic rationale is aptly summarized by Tsinghua University's Prof. Wei Shaojun: "If the advanced processes …[i.e. below 28nm]…cannot be brought into mass production on schedule, a major shortage of chips using the 28nm process could emerge before 2017. That would give SMIC, which received 28nm orders this year from Qualcomm, a chance to vault to the front of the pack. By 2017, global demand for the 28nm process will be 4 million wafers a month. Right now, capacity hasn't even reached 3 million."[94]

Will SMIC be Able to Narrow the Technology Gap?

China-based IC design companies (both domestic and foreign ones) are of critical importance – they account for 40% of SMIC's revenues[95]. To address the real needs of China-based fabless companies, SMIC pursues a flexible approach: "Over 28nm process technology is fungible. In other words, those new 28 nm process lines are also capable of 40nm products."[96]

According to SMIC's web site, the company's 28nm process technology was scheduled to be ready for foundry customers by the end of September 2014. A collaboration, announced in July 2014, between SMIC and Qualcomm on 28-nm wafer production in China, is expected to accelerate this upgrading process[97]. In addition, SMIC seeks to diversify into potentially profitable specialty foundry niche markets. For instance, SMIC developed an embedded EEPROM platform, which had been adopted by a majority of China's bankcard IC design houses. On microelectromechanical systems (MEMS), SMIC cooperates with Silicon Labs[98], a leading specialist US fabless design company. This cooperation foccuses on manufacturing CMEMS-based MEMS oscillators, designed to allow direct post-processing of high-quality MEMS layers on top of Silicon Labs' RF/mixed-signal CMOS technology. Another

94. Wei Shaojun, quoted in Wang, Hsiao-Wen, 2014, "China's Semiconductor Grab – TSMC, MediaTek in the Bull's Eye", CommonWealth Magazine, 21 August 2014, http://english.cw.com.tw/article.do?action=show&id=14830.
95. *SMIC Investor Fact Sheet,* 2014, http://www.smics.com/eng/investors/ir_sheet.php
96. Tzu-Yin Chiu, CEO of Semiconductor Manufacturing International Corp. (SMIC), quoted in Yoshida, Y., 2014, "Will SMIC Narrow Tech Gap". EETimes, March 27: page 3.
97. For a detailed discussion, see below (3.5. A new interest in strategic partnerships and mergers and acquisitions).
98. Silicon Labs is a fabless company in Austin/Tx, designing high-performance, analog-intensive, mixed-signal semiconductors. http://www.silabs.com/about/pages/default.aspx

joint venture with a US company, Toppan Photomasks Inc, Round Rock/TX seeks to to manufacture on-chip color filters and micro lenses for CMOS image sensors[99].

According to an industry observer who has requested anonymity, SMIC's strategy has been focused on "stable niche markets (sensors) and generic 180nm+ service, something that TSMC was not interested in…. It was a wise decision on SMIC's part to stop chasing Taiwanese and to seek growth opportunities beyond TSMC dominated leading-edge process markets."

An Emerging Division of Labor in China's Semiconductor Foundry Industry

Thus far, China's trailing-node upgrading strategy for its foundry industry has produced two results: a) an emerging 12-inch wafer fabrication cluster, centered on SMIC; and b) an 8-inch foundry cluster, focused HH Grace. As discussed below in section 3.4., it remains to be seen whether these achievements are sufficient to transform China's foundry industry into a credible global player.

The 12-inch Wafer Fabrication Cluster, Centered on SMIC

China has decided to develop a supply chain focused on 12 in IC manufacturing fabs, centered on SMIC[100]. As part of this target, SMIC seems to focus on 12-inch wafer fabrication facilities with trailing-node process technologies of 28nm and above.

In August 2014, SMIC and Jiangsu Changjiang Electronics Technology Co. Ltd (JCET) announced a joint venture for 12inch bumping and related testing, to be established in Jiangyin National High-Tech Industrial Development Zone in China's Jiangsu Province. The joint venture can benefit from Jiangyin's unique location and mature industrial environment to quickly set up the 12inch wafer bumping[101] and wafer testing production line (specifically for Circuit Probe (CP) testing)[102]. In addi-

99. SMIC's new R&D and manufacturing center seeks to develop proprietary MEMS process technology, as well as manufacturing capabilities for silicon-based sensors, and trailing-node wafer process technologies.

100. Yoshida, J., 2014, "China erects first 12in IC manufacturing supply chain", *EETimes,* August 11

101. "Wafer bumping" is replacing wire bonding as the interconnection of choice for a growing number of components. The broad term "wafer bumping" is defined as the process by which solder, in the form of bumps or balls, is applied to the device at the wafer level. The use of wafer bumping is driven either by performance, form factor or array interconnect requirements. The ability to properly design the device for bumping will have direct bearing on manufacturability, reliability, and cost savings from wafer fabrication through component assembly. (see Patterson, D.S., 2001, "The back-end process: Step 7 – Solder bumping step by step", *Solid State Technology,* Volume 44, issue 7, 1 July, http://electroiq.com/blog/2001/07/the-back-end-process-step-7-solder-bumping-step-by-step/

102. According to Wikipedia, wafer testing is a step performed during semiconductor device fabrication. During this step, performed before a wafer is sent to die preparation, all individual integrated circuits that are present on the wafer are tested for functional defects by applying special test patterns to them. The wafer testing is performed by a piece of test equipment called a wafer prober. The process of wafer testing can be referred to in several ways: Wafer Sort (WS), Wafer Final Test (WFT), Electronic Die Sort (EDS) and Circuit Probe (CP) are probably the most common

tion, the joint venture can also utilize JCET's nearby advanced back-end packaging production line. For SMIC, the JV with JCET will facilitate ramping-up of its 28nm mass production. For China's IC design industry, this emerging 28nm supply chain will shorten the overall manufacturing cycle time.

The 8-in Foundry Cluster, Focused HH Grace

HH Grace (incorporated through the merger of Shanghai Hua Hong NEC Electronics Company and Grace Semiconductor Manufacturing Corporation) focuses on 8-inch pure-play foundry services covering technology solutions from 1.0μm[103] to 90nm process nodes, focusing on advanced and differentiated technologies including eNVM (embedded Non-Volatile Memory), power management IC, power discrete, RF, CMOS image sensors as well as standard logic and mixed-signal.

With three 8-inch wafer fabrication facilities in Zhangjiang and Jinqiao of Shanghai, HHGrace offers production capacity over 124,000 8-inch wafers per month. HHGrace is also seeking to upgrade its capacity to provide foundry solutions for MEMS[104] solutions through a strategic partnership with Shanghai Quality Sensor Technology Corporation ("QST"), a Chinese company producing high-end magnetic sensors and MEMS sensors[105]. As SMIC is also diversifying into the MEMS market niche, there is reason to be concerned about a lurching threat of over-capacity[106].

3.4. Changes in the IC foundry Industry Landscape

Whether China might succeed in its trailing-node strategy, depends on the impact of significant recent changes in the IC foundry industry landscape. It is an open question at this stage how the new global foundry landscape might affect China's efforts to upgrade its semiconductor industry. It is unclear in particular whether the emerging new global foundry landscape will create new entry possibilities for SMIC and other Chinese foundries.

103. μm= micrometer

104. Micro-Electro-Mechanical Systems, or MEMS, are defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of microfabrication. The critical physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimeters. Likewise, the types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move. https://www.mems-exchange.org/MEMS/what-is.html

105. QST holds worldwide and exclusive license of Honeywell's AMR magnetic sensor technology. In addition, QST holds patents in a number of CMOS integrated multi-axis motion sensors.

106. See further discussion on threat of over-capacity in the Conclusions of this paper.

Apple acts as a Catalyst

As is so often the case in this industry, Apple acted as a catalyst for change. In response to acrimonious and unresolved patent wars, Apple switched from Samsung to TSMC as the sole supplier of Apple's next-generation application processors. As a result, the global foundry landscape is changing beyond recognition.

For a while, it looked like Apple would be TSMC's only relevant customer for 20nm, providing it with quite some bargaining power as a *monopsonist.* As long as TSMC would remain the only meaningful foundry supplier of 20nm process technology, this would imply that prices for 20nm foundry services would be negotiated between a *monopsonist* (Apple) and a *monopolist* (TSMC).

If such a market structure would prevail, Chinese IC design firms would find it quite difficult to gain access to TSMC foundry services. As lower-tier customers, Chinese IC design firms are likely to be charged higher prices. But higher chip fabrication cost is arguably not the main concern. The main barrier to using TSMC's foundry capacity is what the industry calls MOQ, i.e. "minimum-order-quantity". Chinese IC design firms clearly are vastly disadvantaged relative to Apple, and may well end up having to wait for a long time to get its chips fabricated ("taped-out" in industry parlance).

Already in the second quarter of 2014, it became clear that Chinese IC design firms are unlikely to have secure access to TSMC's foundry services. TSMC announced that its production capacity is almost fully booked for the fourth quarter of 2014. TSMC's nearly sold-out wafer production has placed most IC design houses in a dilemma as to whether they should queue up at TSMC for capacity. Since lead times for wafers usually extend to 4-6 months during peak business cycles, IC design houses may receive deliveries only in the first half of 2015 for wafer orders placed in the fourth quarter of 2014. Hence, Chinese fabless IC design companies would suffer, given that time-to-market is of critical importance for success.

As timely and cost-effective access to TSMC's capacity will become even more difficult, this would in principle provide new opportunities for SMIC and other Chinese foundries to gain business from Chinese fabless design companies, provided of course SMIC will succeed in accelerating its upgrading to 28nm process technologies. On the positive side, there are indications that SMIC's focus on trailing node technologies has already pushed down prices and MOQs. This is important for Chinese fabless companies, as it may facilitate timely and cost-effective access to foundry capacity in China. Most importantly, Chinese fabless companies will have to struggle less with TSMC's demanding MOQ requirements.

Intensifying Competition in the Leading-Edge Foundry Business

In the meantime, however, Apple's Big Bang move to drop Samsung as its foundry supplier, has now set in motion a chain of events that are likely to change further the global foundry landscape. But at this stage there is no way to predict possible outcomes. Nor is it possible to anticipate how all of this will affect China's efforts to upgrade its foundry industry.

For Samsung, the loss of Apple's foundry contracts is a massive setback. But Samsung is fighting back, and the company now seeks to compete head on with TSMC in the pure play global foundry business for leading-edge integrated circuits. Foundry work remains an important segment for Samsung, and the company has announced to invest $14.7 bn into a new, cutting-edge wafer fab that will use leading-edge wafer size and process technologies in order to attract foundry contracts from fabless IC design companies[107].

Samsung now has become the fourth largest IC foundry, behind TSMC, Global Foundries and UMC[108]. In 2013, Samsung had a 15% increase in its foundry sales and was less than $10 million behind the third-largest IC foundry in the world—UMC. According to IC Insights, "Samsung has the ability (i.e., leading-edge capacity and a huge capital spending budget) and desire to become a major force in the IC foundry business. It is estimated that the company's dedicated IC foundry capacity reached 150,000 300mm wafers per month in the fourth quarter of 2013. Using an average-revenue-per-wafer figure of $3,000, it is estimated that Samsung's IC foundry business segment has the potential to produce annual sales of about $5.4 billion."[109]

Another potentially transformative event is the decision of IBM to get rid of its semiconductor fabrication. Since the beginning of 2014, there was intense speculation about who would acquire IBM's semiconductor assets. For some observers, it seemed "… quite logical that a sale of IBM's chip manufacturing would be to China." [110] In the end, IBM's foundry operations were transferred to Global Foundries, as announced on October 21, 2014[111]. In a quite unusual arrangement, IBM pays Global Foundries $1.5 billion, simply to get rid of its unprofitable chip manufacturing business. In a statement, IBM seeks to justify this embarrassing retreat, stating that the move would save it billions of dollars IBM would otherwise have to spend to keep upgrading its facilities for the next generation of chip technology[112].

The deal involves two IBM fabs: a) East Fishkill,N.Y. with a 15,000 wafers per month capacity, that has just ramped up the 22nm process used to make IBM's Power 8 processors and where 14nm technology is under development; and b) Burlington, Vermont, with 45,000 wafers per month capacity — a specialty fab for analogue devices, much of it for the defense industry.

107. IC Insights, 2014, *Samsung Invests Big to Maintain Leadership, Support New Markets,* IC Insights Research Bulletin, October 15.
108. "Foundry Ranking by Capacity 2013-2014, http://anysilicon.com/foundry-ranking-capacity-2013-2014/
109. The 2014 McClean Report, http://www.icinsights.com/news/bulletins/Top-13-Foundries-Account-For-91-Of-Total-Foundry-Sales-In-2013/ . With annual sales of about $5.4 billion, Samsung would be ahead of the 2013 sales of Global Foundries, the current Number 2 in the IC Foundry ranking.
110. "IBM fabs for sale – the semiconductor shockwave", *Electronics Weekly,* 10 February 2014 http://www.electronicsweekly.com/news/business/viewpoints/ibm-fabs-sale-semiconductor-shock-2014-02/#sthash.p1E0hyzx.dpuf
111. Merritt, R., 2014, "IBM strikes historic fab deal with GlobalFoundries", *EETAsia,* October 21.
112. Waters, R., 2014, "IBM's troubles with cloud send profits tumbling.", FT, 21 October: front page. According to industry insiders, IBM management was under quite some pressure from Warren Buffett, IBM's biggest shareholder, whose stake has been drastically reduced by IBM losses.

There are still considerable regulatory hurdles, not only because of the defense-related products, but also because Global Foundries is primarily owned by the government of Abu Dhabi, and hence requires approval of the deal by CFIUS (the Committee on Foreign Investment in the U.S.). But if the deal would go through, it would not only expand Global Foundries' capacity by more than 10%, but it also would add more than 10,000 IBM semiconductor patents. IBM, after all has been one of the founding fathers of semiconductor technology. IBM's semiconductor patent portfolio thus will be quite valuable, especially those patents which cover IBM's 22nm and especially its 14nm technologies.

It is unclear to what degree the IBM'Global Foundries deal will affect China's plans to upgrade its semiconductor foundry industry. Taiwan's UMC most likely will be negatively affected. In light of the earlier speculations that China might be the recipient of IBM's foundry assets, it is worthwhile asking: Why did China not acquire the IBM semiconductor business? Were there US national security considerations involved? Or were there doubts whether SMIC would have the level of competency needed for ongoing support of IBM mainline of business?

Another important player in this transformation of the global foundry landscape is Intel. By establishing its own rapidly growing Custom Foundry group, Intel demonstrated that it intends to play an active role at the top end of the global foundry industry. Intel is actively recruiting worldwide top foundry service specialists. With locations in the US, Canada, and India, Intel's strategy is to provide "select customers strategic access to our leading edge process technology and manufacturing services…[, as well as]… turnkey services… [such as]… ASIC design services, specialty IP, wafer manufacturing, packaging and testing."[113] A first step was a 12-year agreement, signed in February 2013, with Altera, a leading US fabless chip design company. As part of recently announced strategic partnerships with two Chinese fabless companies (Rockchip and Spreadtrum), Intel is expected to add these two Chinese companies as foundry customers[114].

There are persistent rumors that Apple may select Intel to fabricate some of its most recent application processors[115]. In the end, intensifying competition in the global foundry business is all driven by wafer price negotiations – all the leading fabless companies are searching for ways to escape the high prices charged by TSMC.

From China's perspective, what matters is that the industry clearly is in turmoil, due to intensifying competition among a small band of foundries that are able to offer high-volume leading-edge foundry production over the next five years. This leading group of foundries includes TSMC, Global Foundries, UMC, Samsung and Intel, but China's SMIC is not part of this exclusive club. These five leading-edge technology foundry leaders are fierce competitors — their main goal is to put pressure on TSMC

113. See the web site of Intel's Custom Foundry Group, http://www.intel.com/content/www/us/en/jobs/campaigns/foundry-jobs.html.114.

114. For details of Intel's deals with Rockchip and Spreadtrum, see section 3.5. below.

115. Nenni, D., 2014, "The Apple Samsung TSMC Intel 14nm Mashup!", October 4, https://www.semiwiki.com/forum/content/3898-apple-samsung-tsmc-intel-14nm-mashup.html

to reduce its foundry service prices for leading-edge semiconductors. In fact, it is now expected that pricing will likely come under pressure, and that this may even be the case for leading-edge devices.

As a result, a recent forecast of growth patterns in foundry sales expects the 2014 leading-edge 28nm-and-below foundry market to be about $5.1bn, a 72% increase in size as compared to 2013[116]. The report concludes:" Not only is the vast majority of pure-play foundry growth coming from leading-edge production, most of the profits that will be realized come from the finer feature sizes as well."

For China, one possible impact of the emerging new global foundry landscape may well be to reduce the scope of its "trailing node upgrading" strategy. In the end, it is unclear at this stage whether the emerging global foundry landscape will support China's upgrading efforts in this industry, and how all of this will affect China's new push in semiconductors. This provides yet another example of the deeply entrenched uncertainty that characterizes the dynamics of semiconductor industry development.

3.5. A New Interest in Strategic Partnerships and Mergers and Acquisitions.

As described in Part Two of the paper, strategic partnerships, joint ventures, and mergers and acquisitions (M&A) are an important ingredient of China's new policy on semiconductors. Two objectives are driving these efforts: On the one hand, M&A among domestic firms are expected to create new opportunities for economies of scale and scope, and for creating synergies among firms with different specialization patterns and capabilities. A second objective is to gain access to cutting-edge technology and best-practice management techniques through strategic partnerships and joint ventures with leading global semiconductor firms.

Domestic M&A: Spreadtrum and RDA

On July 19, 2014, Tsinghua Unigroup announced that it was arrangi ng for a merger between Spreadtrum and RDA[117].The main goal is to create a credible competitor in

116. IC Insights, 2014, *Leading-Edge IC Foundry Market Forecast to Increase 72% in 2014, IC Insights Research Bulletin,* September 25.

117. The process of merging Spreadtrum and RDA was actually quite complex. On December 23, 2013, Tsinghua Unigroup announced the US$1.7 billion acqusition of Spreadtrum, "as contemplated by the previously announced agreement and plan of merger, dated as of July 12, 2013 (the "Merger Agreement"), between Tsinghua Unigroup and Spreadtrum". (http://www.spreadtrum.com/en/news/press-releases/tsinghua-unigroup-completes-acquisition-of-spreadtrum-for-us31.00-per-ads). And on July 19, 2014, Tsinghua Unigroup announced the "approximately US$907 million merger of RDA Microelectronics with an affiliate of Tsinghua Unigroup (the "Merger") as contemplated by the previously announced agreement and plan of merger, dated November 11, 2013 and amended on December 20, 2013 (the "Merger Agreement"), between Tsinghua Unigroup and RDA." http://ir.rdamicro.com/releasedetail.cfm?ReleaseID=860768 . Most likely, this complicated process was necessary to get the necessary pre-clearance from the NDRC, the responsible Chinese government agency.

the IC design market for low-end budget smart phones, not only against Taiwan's MediaTek, but also against the emerging challenge from Qualcomm[118]. Since 51 percent of Tsinghua Unigroup is owned by Tsinghua Holdings, a 100 percent state-owned limited liability corporation funded by Tsinghua University, the Spreadtrum/RDA merger is expected to deliver a new, state-owned, consolidated entity that might be able to generate sufficient economies of scale and scope.

In addition, there is the promise of significant potential synergies between these two companies that started out with very different business models[119].

RDA is proud of its local roots, initially providing low-cost RF(radio frequency) circuits, especially to Chinese Shanhzai handset vendors. RDA's strategy relies on access to cheap, well-trained local engineering talent for chip design. These engineers have graduated from Chinese universities, and RDA willingly takes on the task of providing them with real-world design experience. Through intensive use of domestic engineering talent, RDA engages in exceptionally rapid cycles of prototyping and new product development. RDA chips don't need leading-edge process technology, and hence can rely on foundries with older technology. This low-key and pragmatic business model has allowed for rapid catch-up in capabilities and a sustained growth in market share at the low end of the end market.

Spreadtrum on the other hand followed the path initially blazed by Taiwan's MediaTek, providing a turnkey platform that combines baseband and RF chips, along with the relevant associated software solutions. Dr. Leo Li, Chairman, CEO and President of Spreadtrum Communications, Inc., has more than 23 years of experience in the wireless communications industry, and has worked for instance for Broadcom, Rockwell Semiconductors and Ericcson. Since Dr. Li joined Spreadtrum in May 2008, the company has followed a remarkable strategy of technology leapfrogging into trailing-node process technology. This strategy has enabled it to offer feature-rich phones and move rapidly into low-end smartphones. A key milestone came in October 2010, when Spreadtrum engineers successfully prototyped a 2.5G integrated chip solution using 40 nm process technology, which provided the basis for a 95% increase in sales in 2011.

Spreadtrum's focus on trailing-node process technology culminated on June 23, 2014, in the introduction a quad-core smartphone platform (the "SC883XG"), designed with advanced 28nm process technology, that integrates diverse Third Generation mobile telecommunications standards, including China's TD-SCDMA standard[120]. Spreadtrum's adoption of more advanced semiconductor process technology delivers higher performance and lower power consumption, providing handset makers with a cost-effective solution for mid- to high-end handset models.

118. Bushell-Embling, D., 2014, "Qualcomm bringing LTE-A to low-cost phones". *Telecom Asia,* September 11

119. For details, see Ernst and Naughton, 2012: chapter IV.

120. Spreadtrums' SC883XG platform integrates current best practice 3G mobile standards of the 3GPP international standard development organization that draws on Europe's GSM standard and includes China's TD-SCDMA standard.

On paper at least, the merger between Spreadtrum and RDA offers significant potential synergies.

As one Chinese semiconductor industry observer explained, "Spreadtrum is weak in everything except TD-SCDMA, while RDA is strong in RF. Both are weak in application processors. … Spreadtrum's integrated circuit R&D is weak, but … [the company is] …strong in software. Meanwhile, RDA is very strong in IC R&D, but has no real software development."[121]

A similar assessment is offered by a US-based industry observer: "If you wanted to create a China-based company that could (with a lot of work and a lot of money) someday rival Qualcomm, Spreadtrum and RDA are the two companies that I would pick."[122] Whether this merger will work however remains an open question. Forcing together two companies with very different cultures has triggered raw emotions and turmoil among RDA employees who object to it. RDA's Chairman and CEO Vincent Tai, who reportedly resisted the Tsinghua Unigroup's acquisition plan, was fired by the RDA board in late 2013[123]. This apparently has created quite some bad blood in the company.

Global Partnerships and M&A

China's efforts to realize partnerships and M&A with leading global semiconductor firms are facilitated by two recent developments: First, as the cost of moving to leading-edge multi-component semiconductors (MCOs) and process technologies keeps rising, the semiconductor industry experiences a growing pressure to consolidate size and market power through partnerships and M&A[124]. At the same time, China's emerging role as a lead market for mobile devices acts as a powerful magnet to global industry leaders, both in the semiconductor and in the mobile device industry, to secure long-term access to the China market.

As a result of these two developments, the interest and willingness of foreign firms to engage with Chinese firms now seems to have substantially increased. To some degree this reflects a perception in the headquarters of global firms that the balance of power is shifting, providing China with greater bargaining power. In fact, the leading global players, and especially US firms, are all now experimenting with strategic

121. Anonymous Chinese industry observer, quoted in Yoshida, J., 2014, "Battle of Spreadtrum/RDA Merger", EETimes, March 21
122. Email to the author by Will Strauss, president of Forward Concepts (Tempe, Arizona), August 22, 2014.
123. Mr. Vincent Tai is RDA's co-founder and has been chairman of RDA's board of directors and chief executive officer since RDA's inception in 2004.
124. During the first half of 2014, a wave of mergers and acquisitions has hit the semiconductor industry, as chipmakers try to gain scale, cut operating expenses, and grow their cross-selling opportunities by consolidating. Important deals include: Qualcomm's acquisition of Cambridge Silicon Radio (CSR); Infineon's acquisition of International Rectifier; Cirrus Logic's purchase of Wolfson Electronics; the merger between RF Micro Devices and TriQuint Semiconductor; Avago's purchase of LSI Corp; and Microchip's acquisition of Bluetooth chipmaker ISSC.

partnerships and M&A with Chinese IC design companies and foundries[125]. China's technology planners believe that, if handled correctly, the new interest by global industry leaders in strategic partnerships could create new opportunities for Chinese firms to engage in global technology sourcing.

Important examples of this new round of US-Chinese partnerships in semiconductors include, but are not restricted to the following recently announced agreements.

Global Partnerships in the Foundry Industry

Qualcomm/SMIC

On July 2nd, 2014, Qualcomm and SMIC announced that they are working together on 28nm wafer production for Qualcomm's latest Snapdragon processors in China[126]. Qualcomm, the leading base band cellular processor company states that it will offer support to accelerate the development of SMIC's 28nm process technology[127].

If Qualcomm would stick to its commitment to share critical knowhow, this agreement would be a big win for SMIC, enabling China's leading foundry to implement its trailing-node upgrading strategy that depends on the advancement of its 28nm technology.

But what is in it for Qualcomm? Some observers argue that without the NDRC antitrust pressure on Qualcomm, it is debatable whether Qualcomm would have found SMIC to be its best choice.

However, it is useful to consider that a combination of the following three motivations may have been instrumental in Qualcomm's decision. The catalyst most likely has been indeed the pressure exerted by NDRC. As Qualcomm had been singled out by the Chinese antitrust authority, appeasing the Chinese government by contracting some 28nm production to SMIC might clear the air between the parties. In addition, it is also very lucrative business. Second, there is a general shortage of 28nm production capacity, so Qualcomm may not have had much of a choice but to resort to second-tier production capacity available at SMIC. But SMIC is not Qualcomm's only option. On October 14, 2014, UMC announced that it has received orders from Qualcomm 28nm chips for Fourth Generation LTE smartphones, with shipments to begin in the fourth quarter of 2014[128]. Again this indicates how unpredictable these global transformations are, and hence how precarious key assumptions are which underlie China's industrial upgrading scenario for semiconductors.

125. Very little information on these efforts is in the public domain, but rumors abound.
126. While Qualcomm refuses to provide details, the deal most likely is for Qualcomm's Snapdragon 210 processor, a low-cost chip for 4G LTE budget smart phones that features multimode 3G/LTE and LTE Dual SIM support. (Bushell-Embling, D., 2014, "Qualcomm bringing LTE-A to low-cost phones". *Telecom Asia,* September 11)
127. Yoshida, J., 2014, "Is SMIC-Qualcomm 28nm deal one-sided?", *EETimes,* July 7
128. Lien, J. and S.Shen, 2014, "UMC lands 28nm LTE chip orders from Qualcomm, say sources", *DigiTimes,* 14 October. According to industry sources, these chips are to be used for the production of iPhone 6 smart phones, which seems to indicate that UMC is expected to continue to receive more follow-up 0rders from Qualcomm.

Third, Qualcomm like other leading design companies may seek to use diversification of foundry suppliers not only to get better pricing at SMIC, but also to induce price reductions by TSMC. Fourth, as Qualcomm seeks to outmaneuver Taiwan's MediaTek and China's Spreadtrum in the low end of the smartphone market, a strategic partnership with China-based SMIC might enhance the chances to gain design-ins from Chinese smartphone vendors. This motivation has gained further urgency, as Spreadtrum has recently received a $ 1.5bn investment from Intel (further discussed below).

An additional motivation for Qualcomm's decision to link up with SMIC might reflect a more fundamental shift in the semiconductor industry. As indicated earlier in this paper, there is an intense debate within the industry whether the cost of producing leading-edge devices will decline, and if so, at what pace. The Global Five (TSMC, Global Foundries, UMC, Samsung and Intel) are betting on a speedy transition to leading-edge process technologies, starting with 20nm devices. However, another equally influential group contends that barriers to such cost reductions will remain substantial for a considerable time.

Take for instance Zvi Or-Bach, a respected industry figure[129], who argues that "dimensional scaling beyond 28nm would not provide reduction of SoC [=system-on-chip] cost and, accordingly, 28 nm could the preferred node for many years."[130] The Global Semiconductor Alliance (GSA) in fact has established a 3D-IC Packaging Working Group, reflecting the importance of this potentially disruptive move towards 3D-IC based on 28nm process technology[131].

Qualcomm apparently has decided to support this approach. At the 2014 Design Automation Conference (DAC), Qualcomm declared: ""One of the biggest problems is cost. We are very cost sensitive. Moore 's Law has been great. Now, although we are still scaling down, it's not cost-economic anymore. It's creating a big problem for us."[132]

In other words, Qualcomm needs to find production partners for monolithic 3D chips. As TSMC is not taking the lead in 3D chips, Qualcomm may bet that SMIC, after establishing a good relationship with Qualcomm in 28nm, will continue to up-

129. Zvi Or-Bach has more than 20 years of experience in the IC design industry, and holds over 100 issued patents, primarily in the field of 3D integrated circuits and semi-custom chip architectures. http://www.monolithic3d.com/zvi-bio.html

130. Or-Bach, Z., 2014, comments on Yoshida, J., 2014, "China's SMIC-Qualcomm 28-nm Deal: Why Now?", *EETimes,* July 3. On the underlying technological transformations, see also Or-Bach, Z., 2014, "Qualcomm Calls for Monolithic 3D IC", EETimes, June 17.

131. According to GSA, "…[a]s geometries continue to shrink and 2D scaling becomes increasingly difficult, 3D-IC packaging becomes a natural alternative to continued advances in ever smaller footprints; it is the convergence of performance, power, and functionality. Many of the benefits of 3D-IC packaging, such as increasing complexity while simultaneously improving performance, reducing power consumption, and decreasing footprints are proven and readily understood. Other benefits such as improving time-to-market, lowering risk, and lowering cost will be conquered as 3D-IC packaging becomes a commercially viable solution across many application domains." http://www.gsaglobal.org/working-groups/3d-ic-packaging/

132. Quoted in Or-Bach, Z., 2014, "Qualcomm Calls for Monolithic 3D IC", *EETimes,* June 17.

grade its foundry capacities into monolithic 3D chips. According to SMIC's web site, "SMIC will also extend its technology offerings on 3DIC and RF front-end wafer manufacturing in support of Qualcomm as its Snapdragon product portfolio continues to expand."[133] Or-Bach argues that, while SMIC lags behind TSMC in leading-edge nodes, this does not disqualify SMIC to use the Qualcomm deal to develop a strong position in 28nm. If it is true that the value of the more advanced nodes is diminishing, then the SMIC-Qualcomm deal might suggest that "SMIC is positioning itself to lead in the next generation technology driver - monolithic 3D, using the most effective node for years to come. If the rest of the foundries will ignore it, they may find themselves trailing behind SMIC in few years, in what by then could become THE technology driver."[134]

Global Partnerships in IC Design

Global partnerships and M&A also are gathering momentum in China's IC design industry. Among partnerships initiated by US firms, of particular interest are Intel's investments in two Chinese fabless companies, Rockchip (for tablet ICs) and Spreadtrum (for smart phone ICs).

Intel/Rockchip

In May 2014, Intel announced that it has entered a strategic agreement with Fuzhou Rockchip Electronics Co., a Chinese fabless IC design company focused on IC design for Android tablets[135], to accelerate and expand the portfolio of Intel-Based Solutions for tablets.

This deal had well calculated commercial and technological features. For Intel, it could certainly accelerate time-to-market for its tablet-related processors. There may also be a substantial public relations component, as Intel can now claim "We have a Chinese Partner".

A unique feature of the Android tablet market is that China-based IC design houses like Rockchip, Allwinner Technology and Actions Semiconductor have become the main suppliers of tablet chips. The reason for this is not technological superiority, but the simple fact that leading international smart phone chip design companies have

133. http://www.smics.com/attachment/201407181552332_en.pdf
134. Or-Bach, Z., 2014, comments on Yoshida, J., 2014, "China's SMIC-Qualcomm 28-nm Deal: Why Now?", *EETimes,* July 3.
135. Founded in 2001, Fuzhou Rockchip Electronics Co. develops System-on Chip solutions for Android Tablet, Android TV box(Smart TV), E-Book, WIFI/ Bluetooth audio solution.The company has combined its Video/Audio and Android experience to produce semiconductor (IC) solutions for leading global contract manufacturers and brand name companies. Rockchip is headquartered in Fuzhou, where most design and development is taking place, and has three additional branches in Beijing, Shanghai and Shenzhen, focusing mostly on software and marketing, www.rock-chips.com

neglected this market. For them, the tablet chip market was unattractive, because global demand for tablets is only about one-fifth of the smartphone market, and prices for tablet chips are only about one-third of those for smart phone chips[136].

The success of Chinese tablet chip designers has been a wake-up call for companies like Intel which now aims to ship 25 million tablet processors in the second half of 2014[137]. For Intel, the link with Rockchip is expected to provide it with Rockchip's ecosystem in China, including Rockchip's software support and existing back-end component and market channel relationships[138]. An important motivation for Rockchip apparently is the intensifying competition between tablet chip design based on ARM processors, which has caused Rockchip's profits to fall and narrowed its options to differentiate itself from competing design houses.

In short, the Intel/Rockchip partnership may well have positive effects on the upgrading of China's IC design industry, provided of course that both companies find ways to establish effective mechanisms for technology transfer and absorption.

Intel/Spreadtrum

On September 24, 2014, Intel announced that it will pay $1.5bn for a 20% stake in two Chinese mobile IC design companies (Spreadtrum Communications and RDA Microelectronics) through a deal with Tsinghua Unigroup, the government-affiliated private equity firm which owns the two mobile chipmakers. This deal is quite complex, and many essential data points have not yet been made public. For instance, how much for the $ 1.5 billion was paid in cash? What are the contractual arrangements for sharing intellectual property? And does this involve an IC fabrication deal for Intel's Custom Foundry group?

In principle, this deal could provide a boost to China's efforts to upgrade its IC design industry. If RDA and Spreadtrum would be able to absorb Intel's technology, this deal could empower these two companies to compete head-on against Qualcomm and Taiwan's MediaTek. At the same time, Chinese smart phone vendors might also benefit, as they now would have an alternative to costly Qualcomm chipsets.

As for Intel's motivations, the company's web site states that "..[t]he purpose of the agreements is to expand the product offerings and adoption of Intel-based mobile devices in China and worldwide."[139] Since a new CEO tool over at Intel in 2013, the company has pursued an array of deals and strategies to ensure its chip tech-

136. Chao, C. and A. Hwang, 2014, "International smartphone chip vendors enhance development of tablet chips." *Digitimes,* October 21.
137. Chen, M. and J. Tsai, 2014, "Intel aims to ship 25 million tablet processors in the second half of 2014", *Digitimes,* August 26.
138. Lin, E., 2014, "Intel, Rockchip look to expand the x86 presence in tablet AP market", *Digitimes,* 22 September.
139. http://newsroom.intel.com/community/intel_newsroom/blog/2014/09/25/intel-and-tsinghua-unigroup-collaborate-to-accelerate-development-and-adoption-of-intel-based-mobile-devices

nology gets into more smartphones and tablets[140]. Reflecting Brian Krzanich's background in semiconductor fabrication, Intel "… has opened the chipmaker's prized, cutting-edge factories to paying customers."[141]

But apart from access to the thriving China market, Intel's main motivation clearly is to overcome its persistent weakness in the smartphone chip industry, which is being dominated by ARM, Qualcomm and MediaTek. As Intel's design philosophy is shaped by the needs of the PC market, it neglected the alternative design approach in the mobile IC design industry, which is based on system-on-chip design that provides "turnkey solutions". Intel now seems to recognize that it could benefit from partnering with Spreadtrum and RDA. After all, these two Chinese companies have been early adapters of "turnkey solutions", and they have learnt to sell an integrated device template to smart phone vendors, who in turn have benefited through lower production costs and faster turnaround times.

By the same token, the partnership with Intel could help both Spreadtrum and RDA to reduce their dependence on ARM processors. As long as they remain "me-too ARM IC designers", their profit margins will be limited, as ARM captures the largest share of the value-added. According to industry observers, "…[w]ith Intel's architecture and tech support, … [Spreadtrum and RDA]…will jump to the forefront and give Qualcomm, MediaTek and [other apps processor companies] a serious run for the money."[142]

Finally, partnering with two leading Chinese mobile IC design companies, could also provide Intel with new customers for its Custom Foundry Group. At this stage, this is mere speculation, as the Intel-Tsinghua Unigroup agreement does not provide much details. Intel's300mm wafer fabrication line in Dalian, which was opened at great fanfare in 2010 to produce 65nm chipsets for PCs and servers, is significantly under-utilized. This by itself would provide a powerful motivation for Intel to include foundry services in the agreement with Tsinghua Unigroup.

Mergers and Acquisitions Initiated from the Chinese Side

Proposed Acquisition of OmniVison Technologies

In August 2014, US camera sensor-maker OmniVision Technologies,a leading developer of advanced digital imaging solutions, has received a take-over bid from Hua Capital Management Ltd (HCM), a Beijing-based investment management company[143]. As indicated in Part Two of the paper, HCM was chosen in June to

140. Intel's investment in Spreadtrum and RDA comes less than six months after Intel reached an agreement with Chinese chip maker Rockchip to make inexpensive tablet chips with Intel's architecture and branding. For details, see below.
141. Shih, G. and N. Randewich, 2014, "Intel to invest up to $1.5 billion in two Chinese mobile chipmakers", http://www.reuters.com/article/2014/09/26/us-spreadtrum-m-a-intel-idUSKCN0HK29R20140926
142. Yoshida, J., 2014, "4 Reasons for Intel's $ 1.5 Billion Bet in China", *EETimes,* September 26
143. Omnivision Announces Receipt of Non-Binding Acquisition Proposal, http://www.reuters.com/article/2014/08/14/ovti-acquire-proposal-idUSnPn63Cqkl+88+PRN20140814

manage the sub fund for chip design and testing under the Beijing government's 30 billion-yuan (HK$37.8 billion) Semiconductor Industry Development Fund. Omnivision's stock price climbed by 14 per cent to just over $28 on the news. The company's board of directors said it was evaluating HCM's proposal. And on September 19, HCM has hired Bank of America to provide funding for its US$1.7 billion bid for US camera sensor-maker OmniVision Technologies[144].

The proposed acquisition of OmniVision is the first example of how China's Guidelines are being used to acquire a foreign company, with the intention of "making that company Chinese." In fact, Omnivision has strong Chinese roots, hence the chances of success are considerable. In fact, OmniVision was co-founded by Hong Xiaoying, a Chinese immigrant and current chief executive, and the company has Chinese and Taiwanese managers among its senior ranks. The company had sales of US$1.45 billion last year, but has hardly grown from 2013. The company however has attractive technology with a wide range of applications, such as cars, mobile devices and security equipment. In 2012, Omnivision was second placed among the top-three vendors of CMOS image sensors that comprised Sony, Omnivision and Samsung with 21, 19 and 18 per cent of the $6.9 billion market, respectively. Omnivision has supplied Apple with back-side illuminated CMOS image sensors for its iPhone and has a design center and testing facility in Shanghai, China.

If that acquisition would go through, it could give a significant boost to China's plans to upgrade its IC industry. The deal also would seem to address some of the Leadership's security concerns. It is of course an open question whether this deal will receive regulatory approval in the US, from CNIFUS and other relevant agencies, as the deal may well raise security concerns in the US. According to USITO, the OmniVision deal may be less significant technologically, but it may well be an early herald of bigger more substantial foreign acquisitions down the road[145].

Acquisition of Broadcom Division?

On June 24, 2014, it was reported that the Chinese government was planning to take over Broadcom's mobile baseband unit[146]. These rumors however have not yet been confirmed. The rumors probably emerged in response to an earlier announcement by Broadcom that it is considering selling or shutting down its cellular baseband business. After that statement, industry sources reported that other companies such as Qualcomm, Intel, and Taiwan's MediaTek were not interested in acquiring the business unit because Broadcom's product lines are not complementary to their businesses.

144. "Hua Capital hires Bank of America for OmniVision deal", *South China Morning Post,* September 19, 2014, http://www.scmp.com/business/companies/article/1595559/hua-capital-hires-bank-america-omnivision-deal
145. USITO email to the author, dated October 23, 2014.
146. "China govt to bid for Broadcom cellular unit – report", June 25, 2014, http://www.telecompaper.com/news/china-govt-to-bid-for-broadcom-cellular-unit-report--1021572

From China's perspective, an acquisition of Broadcom's mobile baseband unit would carry significant promises. Broadcom's activities, which include a strong portfolio 3G and 4G chips as well as modem IP, could help Chinese handset vendors which are planning to build up their own in-house chipset platforms. China's technology planners expect that the acquisition of Broadcom's business unit by the Chinese government might enhance the semiconductor supply chain, and it may also reduce China's huge demand-supply gap of ICs.

Broadcom's main goal is to expand its sales in China by making chips that support a wider range of handsets. Of particular interest are those handsets which run on the network of the world's largest telecom carrier, China Mobile Inc., using the Chinese Standards for 3-G and 4-G mobile communications[147]. Broadcom's strategy is shaped by the assumption that demand will continue to rise for low-cost smartphones that work on China Mobile's third-generation network.

An acquisition of parts of Broadcom's mobile communications chip business thus might fit well with Broadcom's general strategy. In contrast to many US IT firms, Broadcom publicly states that it welcomes the recent spending by the Chinese government to bolster the domestic chip production and design industry. The underlying rationale is that this might help to strengthen Broadcom's already quite close cooperation with Chinese companies such as Spreadtrum and SMIC. Broadcom also acknowledges that it is in talks with Tsinghua Unigroup, the government-related fund that has acquired both Spreadtrum and RDA.

At this stage, it is unclear why China's government has not proceeded to acquire Broadcom's mobile baseband unit. Many theories are circulating in the investment community, highlighting possible constraints, in terms of timing, sharing of intellectual property, and lack of trust.

There is no doubt that, if well managed, the strategic acquisition of foreign IC design houses could help to address important weaknesses (there are aplenty!) of China's still precariously weak IC design industry. And even if strategic acquisitions would face regulatory hurdles in the US, there are arguably other opportunities for China to implement global knowledge sourcing strategies. For instance, ex- Nokia teams in Finland and around the world (including in China) could be used as sources of critically important intangible knowledge. The same may be true for engineers and engineering teams from the former RIM/Blackberry, from the down-sized IC division of Infineon, and other such once important global companies.

China also may want to consider other opportunities, such as cooperating with leading centers of excellence like IMEC (in Belgium), the Holst Center (in the Netherlands), and other centers of excellence, for instance in Nordic countries.

In the end, China's push to upgrade its IC design industry through M&A raises of course a fundamental question: Does China have the managers who could make

147. Murphy, C. and P. Mozur, 2014, "Broadcom Aims to Sell Chips Supporting All Chinese Telecom Carriers", *The Wall Street Journal,* March 20.

these extremely demanding acquisitions and cooperation agreements work? And are management approaches in place which could cope with the negative side effects of internationalizing the work force of Chinese IC design companies, as manifested for instance in the substantial gaps in remuneration between domestic and foreign engineers and managers?

China's Growing Role in Semiconductor Mergers and Acquisitions

The Thomson Reuters data base on mergers and acquisitions (M&A) in the semiconductor machinery and semiconductor and related device manufacturing industries (NAICS codes 333295 and 334413) provides some proxy indicators of China's growing role in semiconductor mergers and acquisitions[148]. The afore-mentioned illustrative examples thus may well be quite representative.

First, M&A deals in which Chinese firms were targets, display a rising trend – out of 225 such M&A deals between January 1, 2005 and September 30, 2014, almost 30% (65 deals) occurred in 2013 and the first nine months of 2014. Of those 225 M&A deals,72% (161 deals) were transactions where Chinese firms were both the target and the acquirer[149].

Second, China's importance as an acquiring nation is on the rise – of the 196 deals that involved China as the acquiring nation between 2005 and end September 2014, 30% (59 deals) were closed in 2013 and the first nine months of 2014.

China also has gained in importance both as an acquirer nation and as a target nation in the semiconductor industry. As an acquirer nation, China now is number 4 (with 198 deals), after the dominant US (901 deals), South Korea (402), and Japan (231). And as a target for semiconductor M&A, China is now number 3 (with 227 deals), following the leading US (847 deals) and South Korea (416), but ahead of Japan (210 deals).

Future research would need to deepen the analysis to include detailed case studies of deals, focusing especially on the role of top acquirers (for semiconductor firms, as well as investor groups and government agencies.) Of equal importance will be case studies of the role of Chinese firms, both as acquirers and as acquisition targets, and the impact of these deals on technology transfer, and the development of absorptive capacity and innovation capabilities of the companies involved in these deals.

148. I am grateful to Ed Pausa at PwC for sharing his analysis of the Thomson Reuter database.
149. There were 64 other transactions where the acquirer was from a different nation including the US (16), Hong Kong (10), Singapore (5), and Japan (4), et al.

3.6. How will China's push in Semiconductors Affect its Exports of Electronic Final Products?

An important challenge for China's industrial upgrading scenario in semiconductors is the possible impact on exports of China's electronics final products. Unfortunately, there is little discussion of this critical issue in the publicly available Chinese policy documents.

China's exports of electronic final products are of huge value and central to the country's trade and development. For 2013, the UN COMTRADE data base reports China's ICT (=information and communication technology) exports (not including IT services and software) as $599.7 billion, which is roughly 27% of China's total goods exports[150]. In other words, almost a third of China's total goods exports are ICT products that are powered by semiconductors[151]. China thus relies on semiconductors as an essential input of a large share of the products it exports.

As China still lacks a fully developed semiconductor industry, China depends on semiconductor imports as an enabler of its exports of electronic final products. For 2013, again according to UN COMTRADE data, China's ICT exports are reported as roughly 2.3 times the value of China's 2013 semiconductor imports ($261.3 billion).

Some observers in the U.S. suggest that China's new push to expand and upgrade its semiconductor industry may actually undermine downstream users, i.e. China-based semiconductor-consuming producers of electronic final products, and hence may erode China's export surpluses in the ICT industry[152]. It is argued that, in case China-based semiconductor consuming ICT goods vendors only had access to locally produced chips, this might severely limit the quantity, type and quality of chips they can design into their final goods, and hence might constrain performance features of those final goods, and increase their cost. If these IC consuming companies were foreign firms, this could motivate them to move to locations outside of China where they would have unrestricted access to all the chips they need.

To succeed in global competition, semiconductor-consuming ICT goods vendors based in China would need fast and unrestricted access to all chips that are available in the global market. In this scenario, China's new semiconductor policies may only be able to change buying patterns if chips designed and fabricated in China are superior in performance and price relative to competing products. The policy conclusion drawn from this argument is that China's new policies on semiconductors can only work if they allow for "free and open markets and a level competitive playing field in all markets."

150. I am grateful to Falan Yinug of the U.S. Semiconductor Industry Association (SIA), for sharing these data.
151. Other industries, like car and aircraft, are also large consumers of semiconductors. Hence, the role of semiconductors for China's total goods exports is significantly higher.
152. The following arguments are based on written comments from SIA emailed to the author, dated September 26, 2014.

Chinese technology planners view these arguments with considerable skepticism. From a Chinese perspective, these arguments neglect the needs of a country that is a latecomer to this industry. In this view, China first needs to develop gradually a more integrated local industrial value chain and firm-level capabilities, before it can fully reap the benefits of a more open, more transparent, and less discriminatory market for semiconductors. Chinese technology planner acknowledge that, in the short run, global technology sourcing (through imports of semiconductors, but also through joint ventures, strategic partnerships or M&A) is necessary to accelerate catching-up. They seem to be convinced, however, that forging ahead would require the development of a domestic semiconductor industry value chain, as well as relevant technology and management capabilities of Chinese firms.

Based on the findings of this paper, it is appropriate to highlight two caveats that should inform assessments of China's policies to upgrade its semiconductor industry. The first caveat is that China's new push in semiconductors should take into account the need of down-stream, semiconductor-consuming industries. Moving to self-sufficiency in semiconductors not only is unnecessary. It simply would not work, and it would defeat its purpose, as it would undermine the competitiveness of downstream semiconductor-consuming industries. For China's new policy on semiconductors to succeed, planners and policy makers need to step back and explore possible unintended negative consequences for downstream user industries.

The second even more important caveat is that, thus far, there is little research on possible impacts of China's new semiconductor policy on down-stream user industries. China needs in-depth empirical research on how to balance the needs of the semiconductor and its user industries. As will be argued below, the only way to collect the necessary information is to move towards a bottom-up, market-led approach to "industrial policy", and close interaction between the government and private firms through multi-level industrial dialogues and public-private partnerships. In order to do justice to the conflicting needs of stakeholders across the industrial value chain, China clearly needs a substantially enhanced capacity for flexible policy implementation.

3.7. Rising Uncertainty Requires Flexible Policy Implementation

The analysis of China's semiconductor industry upgrading scenario has shown that global transformations in the semiconductor industry may facilitate China's efforts to move from catching-up to forging-ahead in semiconductors. A second important finding however is the precarious nature of these opportunities — basic parameters that determine how China will fare may change at short notice and in unpredictable ways. Rising complexity of technology, business organization, and competitive dynamics are the root causes for such uncertainty.

Today, innovation in semiconductors depends increasingly on science and on interactions of multiple and very diverse stakeholders through geographically dispersed innovation networks that extend the boundaries of industries and nations[153]. For semiconductors, competition is centered on the increasingly demanding performance features for electronic systems. Whether one looks at laptops, smart phones, mobile base stations, medical equipment or car electronics, these electronic systems all need to become lighter, thinner, shorter, smaller, faster, and cheaper, as well as having more functions and using less power. To cope with these demanding performance requirements, engineers have pushed modular design and system integration, with the result that major building blocks of a mobile handset are now integrated on a chip.

Design teams also need to cope with the accelerating pace of technical change. Essential performance features are expected to double every two years, time to market is critical, and product life cycles are rapidly shrinking to a few months. Only those companies thrive that succeed in bringing new products to the relevant markets ahead of their competitors. Of critical importance is that a firm can build specialized capabilities quicker and at lower cost than its competitors[154].

Arguably, the most important manifestation of rising technological complexity is the convergence of ICT infrastructures for the Internet, wireless, and mobile communications, and cloud computing that culminates in ubiquitous networks (or the "Internet of Everything")[155].

The root cause for these increasingly demanding requirements for technology development is the emergence of a "winner-takes-all" competition model, described by Intel's Andy Grove[156]. In the fast moving ICT industry, success or failure is defined by return on investment and speed to market, and every business function, including R&D and standard development, is measured by these criteria.

Intensifying technology-based competition has provoked fundamental changes in business organizations. No firm, not even a global market leader like Intel or Qualcomm, can mobilize all the diverse resources, capabilities, and repositories of knowledge internally.

Corporations have responded with a progressive modularization of all stages of the value chain and its dispersion across boundaries of firms, countries, and sectors through multi-layered corporate networks of production and innovation. The complexity of these global networks is mind-boggling. According to Peter Marsh, the Financial Times' manufacturing editor, "…[e]very day 30m tones of materials valued at roughly

153. For detailed analysis, see Ernst, D., 2005, "Complexity and Internationalisation of Innovation: Why Is Chip Design Moving to Asia?" *In International Journal of Innovation Management,* special issue in honor of Keith Pavitt (Peter Augsdoerfer, Jonathan Sapsed, and James Utterback, guest editors) 9(1) (March): 47–73. See also Ernst, D., 2009, *A New Geography of Knowledge in the Electronics Industry? Asia's Role in Global Innovation Networks,* Policy Studies, no. 54 (Honolulu: East-West Center, August).

154. Kogut, B. and U.Zander (1993). "Knowledge of the Firm and the Evolutionary-Theory of the Multinational Corporation", *Journal of International Business Studies* 24 (4): 625–645.

155. For an analysis of the increasing complexity and diversity of global innovation networks, see Ernst, D., 2014, *Trade and Innovation in Global Networks* – Regional Policy Implications, East-West Center Working papers, Economics Series, No.137, May, chapter two.

156. Grove, A., 1996, *Only the Paranoid Survive,* Doubleday

$80 billion are shifted around the world in the process of creating some 1 billion types of finished products."[157]

While the proliferation of global production networks goes back to the late 1970s, a more recent development is the rapid expansion of global innovation networks (GINs), driven by the relentless slicing and dicing of engineering, product development, and research (Ernst 2009). Empirical research documents that this has further increased the complexity of global corporate networks. GINs now involve multiple actors and firms that differ substantially in size, business model, market power, and nationality of ownership, giving rise to a variety of networking strategies and network architectures.

The flagship companies that control key resources and core technologies, and hence shape these networks, are still overwhelmingly from the United States, the European Union, and Japan. However, there are also now network flagships from emerging economies, especially from Asia. Huawei, China's leading telecommunications equipment vendor, and the second largest vendor worldwide, provides an example of a Chinese GIN that can illustrate the considerable organizational complexity involved in such networks[158].

In short, rising complexity and uncertainty is the defining characteristic of today's global ssemiconductor industry. For China's policy to upgrade its semiconductor industry, flexible policy implementation is required to cope with this rising complexity and uncertainty.

Uncertainty implies that it is always preferable to have built-in redundancy and freedom to choose among alternatives rather than seeking to impose from the top the "one best way" of doing things[159]. First, rising complexity drastically reduces the time available for policy formulation and implementation, which makes it practically impossible to get solutions right the first time. There may have to be many policy iterations, based on trial and error, and an extended dialogue with all stakeholders to find out what works and what doesn't.

Second, rising complexity makes it difficult to predict possible outcomes of any particular policy measure, especially unexpected negative side effects, of which there is an almost endless variety. In fact, a small change in one policy variable can have far-reaching and often quite unexpected disruptive effects on many other policy variables and outcomes. To cope with this complexity challenge requires a capacity for flexible adjustments in policies meant for instance to strengthen the absorptive capacity and R&D investment of Chinese firms.

157. P. Marsh, "Marvel of the World Brings Both Benefit and Risk," *Financial Times,* June 11, 2010, 7. For a detailed case study of the multi-layered global production networks in Asia's ICT industry, see Ernst 2004.Yusuf OUP

158. The company has pursued a two-pronged strategy (Ernst and Naughton: 2007): it is building a variety of linkages and alliances with leading global industry players and universities, while concurrently establishing its own global innovation network of more than 25 R&D centers worldwide. Huawei's own GIN now includes, in addition to at least eight R&D centers in China, five major overseas R&D centers in the United States, and at least ten R&D centers in Europe (Ernst, 2014: chapter Two). The choice of these locations reflects Huawei's objective to be close to major global centers of excellence and to learn from incumbent industry leaders: Plano, Texas, is one of the leading U.S. telecom clusters initially centered on Motorola; Kista, Stockholm, plays the same role for Ericsson and, to some degree, Nokia; and the link to British Telecom was Huawei's entry ticket into the exclusive club of leading global telecom operators.

159. Jordan, L.S. and K. Koinis, 2014, *Flexible Implementation: A Key to Asia's Transformation, East-West Center Policy Studies series,* No.70, March.

And, third, it is next to impossible to predict the full consequence of interactions among an increasingly diverse population of both domestic and international stakeholders in China's semiconductor industry. Given the diversity of competing stakeholders, the results of a particular industrial support policy depends much more on negotiations, gaming, and compromises than on the logical clarity and technical elegance of that policy (Ernst: 2014).

Prioritization is no longer the exclusive role of the state planner. The focus of policy-making thus needs to shift from the selection of priority sectors, technologies and areas for public investment to the facilitation of "smart specialization", defined as *"an interactive process in which the private sector is discovering and producing information about new activities and the government provides … [incentives and removes regulatory constraints] ….for the search to happen, assesses potential and empowers those actors most capable of realizing the potentials."*[160]

Conclusions

To assess the findings of this study, it is useful to highlight that policies to develop the semiconductor industry in China have experienced many changes over a relatively short period of time. In the broad view of things, a progressive integration into international trade and global networks of production and innovation has transformed the industry, with private firms emerging as major sources of growth, pricing decisions and investment allocation.

At the same time however, China's policies to develop the semiconductor industry still carry the legacy burden of the old top-down policy approaches. This study documents that China's new policy to upgrade its semiconductor industry, as described in the *"Guidelines to Promote National Integrated Circuit Industry Development",* does not represent a radical break with a deeply embedded statist tradition. It retains many aspects of the "old industrial policy" doctrine, placing final control over whatever changes might occur in the hands of the government, and, in the final instance, the top leadership.

Within these boundaries, however, the study detects important changes in the direction of bottom-up, market-led approach to industrial policy. The study highlights a shift in the composition and governance of the IC Industry Support Small Leading Group. It is now more common to have experts play an active role in policy formulation and implementation who have intimate knowledge both of the international industry and the national policy circles.

160. OECD, 2013, *Innovation-driven Growth in Regions: The Role of Smart Specialisation. Preliminary Version,* OECD, Paris. For the underlying concept of "smart specialization", see Foray, D., 2014, *Smart Specialisation: Opportunities and Challenges for Regional Innovation Policy Opportunities and Challenges for Regional Innovation Policy,* Routledge.

Equally important are potentially quite important shifts in the allocation of investments funds. A closer look at the Beijing IC Industry Equity Investment Fund finds that the use of professional investment fund managers, as opposed to government subsidies or investment, signals a new approach to industrial policy that focuses on building a strong and sustainable investment environment in China. This does not imply that China's approach to investment funding will converge any time soon to a U.S.-style model of investment finance. More likely is the development of a hybrid model that seeks to combine the logic of equity investment fund management with the objectives of China's IC development strategy.

The study also highlights additional examples of at least incremental movements towards a more bottom-up, market led approach to industrial policy. For instance, China's technology planners no longer view global transformations in markets and technology merely as threats. In this more assertive view, global transformations are viewed as opportunities for China to forge ahead in semiconductors. The study has analyzed in quite some detail how China's new semiconductor strategy seeks to identify upgrading opportunities for China's semiconductor industry that could benefit from four global transformations: a) the demand pull from mobile devices; b) new opportunities for China's foundries in trailing-node semiconductor technologies; c) changes in the IC foundry industry landscape; and) a new interest in strategic partnerships and mergers and acquisitions (M&A).

An important, largely unresolved challenge for China's industrial upgrading scenario in semiconductors is the possible impact on exports of China's electronics final products. Research for this study did not find much discussion of this critical issue in the publicly available Chinese policy documents. Despite movements in the right direction, is would seem fair to state that the new Semiconductor Strategy's capacity for flexible policy adjustments remains limited, and that multi-layered industrial dialogues among key stakeholders in the industry are still at an early stage.

Finally, a defining characteristic of China's new Semiconductor Strategy is a persistent tension and frequent vacillation between more statist and more bottom-up industrial policies. To some degree this reflects China's latecomer status in this industry. But, given the tremendous progress that China has realized in this industry, it is time to shift the focus of attention to domestic impediments that are still constraining progress to a "new industrial policy" approach, which of course would need to reflect and address the specific needs of China's evolving economy.

What Could Derail the Industrial Upgrading Scenario?

Finally, it is time now to address three larger issues, which might well derail China's industrial upgrading scenario for semiconductors. A detailed analysis is beyond the scope of this paper. Instead, an attempt is made to raise some specific questions for future research.

Threat of Overcapacity

The first question addresses the ever present threat of overcapacity: Will China's push to upgrade its semiconductor foundry industry create overcapacity like in the solar PV industry and wind power? As is typical for China, the implementation of the semiconductor policy is left to the local governments. As Lieberthal demonstrates, "…[t]he last three decades of reforms…have greatly empowered the leaders… in every province, municipality, and township to act in entrepreneurial ways to grow the GDP of their locality every year."[161] Each locality is quite inward looking, and much less concerned about national issues.

This has negative consequences. Most importantly, local governments have become masters in producing over-capacity, due to misaligned incentives that are focused exclusively on the region's GDP growth. In addition, local protectionist policies reduce the scope for scale economies and economies of scope. "Even with a very large national market, many plants produce at suboptimal scale, and many investment decisions are made on the basis of political criteria." (Lieberthal (2011): p.26)

This raises the question: Why should this be different for the semiconductor foundry industry? Some observers argue that, unlike in the PV industry, technological barriers and the huge minimum investment burdens may prevent over-investment in the IC foundry industry. Future research needs to assess how realistic this argument is.

Cyber- Security

The second question asks: Will the Leadership's cyber-security objectives derail the Industrial Upgrading scenario?

China's policy on information security seeks to protect China-based information systems against perceived threats to national and public security[162]. The underlying strategic rationale provides an example of Susan Shirk's description of China as a "fragile superpower."[163]

161. Lieberthal, K, 2011, *Managing the China Challenge. How to Achieve Corporate Success in the People's Republic,* Brookings Institution Press, Washington, D.C.: page 21.
162. The following draws on chapter two in Ernst, D., 2011, Indigenous *Innovation and Globalization: The Challenge for China's Standardization Strategy,* UC Institute on Global Conflict and Cooperation; La Jolla, CA and East-West Center, Honolulu, HI., 123 pages http://www.EastWestCenter.org/pubs/3904 [Published in Chinese at the Univers ity of International Business and Economics Press in Beijing, 自主创新与全球化：中国标准化战略所面临的挑战].
163. Shirk, S.L., 2007, China: *Fragile Superpower: How China's Internal Politics Could Derail Its Peaceful Rise,* Oxford University Press, Oxford etc.

There is a widespread concern among China's leadership, especially in the military and the Ministry of Public Security (MPS), that China is exposed to nontraditional and asymmetric threats to national security. Information technology is viewed as a double-edged sword. China's resurgence both as an economic and military power challenges incumbent global and regional leaders. China's leadership believes that Western IT systems use product backdoors, system loopholes, and Trojan horses to steal China's national secrets, and to slow down China's rise as a global economic power[164].

China's leaders also fear that persistent leadership in IT provides ample opportunities for "Western powers" to use export controls, control over technical standards, and high licensing fees to stifle

China's development and force reliance on Western technology. As a latecomer to the global race in information and communications technology, China has weak capabilities in information system management, and there is a general lack of knowledge and institutions that are capable of protecting China's critical information systems.

To counter these threats, the China State Informatization Leaders Group (SILG), a high-level Chinese leadership body, developed in 2003 China's Five-Year National Cyber Security Strategy (SILG Document 27) to address threats to information systems and networks through an indigenous national assurance system under firm domestic control. Apparently this confidential document contains a comprehensive strategy, with its priorities reaching just about every aspect of information security technology.

In response to Edward Snowden disclosure of U.S. National Security Agency (NSA) global surveillance practices in China and elsewhere[165], China's concern with cyber-security receives prominent attention in the "Guidelines to Promote National Integrated Circuit Industry Development". The Guidelines argue that, in order the Security and Reliability of ICT products and services in China, it is necessary to

a. "Promote the wide use and government procurement of "safe and reliable" software and hardware, including IC.
b. Encourage telecommunications, internet and end-product companies to make procurement decisions based on safety and reliability of products

164. A *backdoor* is a secret or undocumented means of getting into a computer system. Many programs have backdoors placed by the programmer to allow them to gain access to troubleshoot or change the program. Some backdoors are placed by hackers once they gain access to allow themselves an easier way in next time or in case their original entrance is discovered. A *loophole* is a weakness or exception that allows a system, such as a law or security, to be circumvented or otherwise avoided. Loopholes are searched for and used strategically in a variety of circumstances, including taxes, elections, politics, the criminal justice system, or in breaches of security. The *Trojan horse,* in the context of computing and software, describes a class of computer threats (malware) that appears to perform a desirable function but in fact performs undisclosed malicious functions that allow unauthorized access to the host machine, giving them the ability to save their files on the user's computer or even watch the user's screen and control the computer. Trojan viruses can be easily and unwillingly downloaded.

165. A study on the damage to America's ICT industry caused by NSA global surveillance practices concludes: "The recent revelations about the extent to which the National Security Agency (NSA) and other U.S. law enforcement and national security agencies have used provisions in the Foreign Intelligence Surveillance Act (FISA) and USA PATRIOT Act to obtain electronic data from third-parties will likely have an immediate and lasting impact on the competitiveness of the U.S. cloud computing industry if foreign customers decide the risks of storing data with a U.S. company outweigh the benefits." (Castro, D., 2013, *How Much Will PRISM Cost the U.S. Cloud Computing Industry?,* http://www2.itif.org/2013-cloud-computing-costs.pdf .

c. Form industry standards system and develop safe and reliable capabilities in emerging industries (IoT, Big Data, cloud computing)"[166]

This raises the following questions for future research: Is the drumbeat on security used primarily as a tactic to mobilize support for aggressive investment funding?[167] Or is this focus on security an overriding concern for China's leadership that will cast aside many of the afore-mentioned economic considerations? How serious in fact are potentially short-term negative impacts? For instance, according to some observers, much of the Chinese government is in gridlock, as no one dares to start new initiatives in light of the renewed focus on Security (under the guise of the anti-corruption campaign). And, longer term, what would be the fate of China's semiconductor industry, if security concerns would really sideline China's commercial and industrial interests, and if China would indeed move back to creating its own self-reliant system of semiconductor and information and communication technologies?

Trade and Investment Agreements

Finally, a third question for future research would need to examine how new international and investment agreements might affect China's efforts to upgrade its semiconductor industry. A defining characteristic of today's international trading system is that plurilateral trade agreements are gaining in importance relative to the gridlocked Doha round of multilateral trade negotiations[168]. Examples are the WTO Government Procurement Agreement (GPA), the Information Technology Agreement (ITA), the Trans-Pacific Partnership Agreement (TPP) and the Transatlantic Trade and Investment Agreement (TTIA).

Of immediate interest is the Information Technology Agreement (ITA)[169]. By reducing barriers to trade that have not been adequately addressed in the gridlocked

166. Quoted from *USITO, 2014, USITO Summary and Analysis – China IC Industry Support Measures,* September 1: p.5
167. After all, security concerns as a tactic to mobilize support for investment in R&D have been used in other countries before, the US included.
168. In contrast to multilateral WTO agreements, where all WTO members are party to the agreement, a plurilateral agreement implies that WTO member countries have a choice to agree to new rules on a voluntary basis.
169. ITA went into effect in April 1997 with 29 World Trade Organization (WTO) Member countries. Unlike other plurilateral agreements, ITA provides "most favored nation" (MFN) treatment to all WTO Members, even if those countries have not joined the agreement. Today, ITA has 78 WTO Members—36 are non-Organisation for Economic Co-operation and Development (OECD) member countries, and 35 of them are developing countries. They include significant players in the electronics industry (China, Taiwan, Malaysia, Thailand, and Vietnam), and other countries, such as India, Egypt, Indonesia, Philippines, and Turkey, which have the potential to become players. In its current form, ITA provides zero tariffs for 217 electronics products. The main product groups covered are computers, semiconductors, semiconductor manufacturing and test equipment, telecommunications equipment, software, and scientific instruments. (For details, see WTO. 2012. *15 Years of the Information Technology Agreement, Trade, Innovation and Global Production Networks.* World Trade Organization, Geneva)

Doha round, the ITA is widely expected to facilitate the diffusion of innovation in the critically important information and communications technology (ICT) industry[170].

Proponents of ITA emphasize that developing countries, and especially Emerging Economies, could reap significant gains from trade for innovation from the ITA, as tariff reduction will lower import prices, improve market access for exporters, and enhance competition[171]. China benefitted substantially from the first round of ITA trade liberalization. During 2013, ITA members in Geneva were negotiating a possible substantial expansion of the list of products covered by ITA, the so-called ITA-2 round. Since November 2013, these negotiations have stalled. The real sticking point remained advanced semiconductors, the so-called MCOs (i.e. multi-component semiconductors), where China was adamant "that it will not accept tariff cuts."[172]

Throughout the 2013 ITA-2 negotiations, China has used a combination of delay tactics and a slowly evolving strategy of co-shaping the design of an expanded ITA-2. This reflects China's over-riding concern to upgrade its semiconductor industry through innovation and the development of generic technology platforms like MCOs. However, ITA-2 without China would be an oxymoron. Not only is China the world biggest smartphone market,[173] it is also by far the most important market for US semiconductor firms[174]. As John Neuffer, senior vice-president of global policy at the Information Technology Industry Council (ITIC) points out, "China has got to be part of this. They are too big a player. You can't have an outcome without the Chinese."[175]

In short, without China, ITA-2 negotiations are likely to remain stalled. Bold action is required to avoid zero-sum game or even negative-sum game outcomes and resultant trade conflicts. Thus far, progress has been incremental. China has enough resources to cope with the current stalemate of ITA-2 negotiations. But longer-term, China needs progress in ITA-2 negotiations as much as the US. Without some sort of compromise on these trade negotiations, it will be difficult for China to proceed with its strategy of upgrading its semiconductor industry. If China would remain on the sidelines of an expanded ITA-2 agreement, this could have substantial negative impacts on China's prospects in semiconductors.

170. From a global welfare perspective, trade expansion could reinforce the diffusion of innovation, as argued in Curtis, J. 2013. "Trade and Innovation: Challenges and Policy Options." Background paper for Expert Group 6 meeting, ICTSD, Geneva, 6–7 June.

171. For an optimistic scenario, see for instance Ezell, S. J. 2012. *Boosting Exports, Jobs and Economic Growth by Expanding the ITA.* Information Technology and Innovation Foundation (ITIF), Washington, DC, March, pp 8–9. For a comparative analysis of India's and China's experience with ITA, see Ernst, D., 2014, The Information Technology Agreement, Industrial Development and Innovation: India's and China's Diverse Experiences, Think piece prepared for E15 Expert Group on Trade and Innovation, http://e15initiative.org/wp-content/uploads/2014/03/Dieter-Ernst.pdf

172. "ITA Expansion Talks Suspended Again; No Timeline for Resumption Set.". *Inside US Trade.* 21 Nov, 2013. http://insidetrade.com/Inside-US-Trade/Inside-U.S.-Trade-11/22/2013/ita-expansion-talks-suspended-again-no-timeline-for-resumption-set/menu-id-172.html .

173. Ernst , D. and Naughton, B. J. 2012. "Global Technology Sourcing in China's Integrated Circuit Design Industry: A Conceptual Framework and Preliminary Findings." East-West Center Working Paper No. 131, Aug.

174. PWC. 2013. "China's Impact on the Semiconductor Industry, 2014 Update." http://www.pwc.com/gx/en/technology/chinas-impact-on-semiconductor-industry/index.jhtml.

175. Donnan, S. 2013. "Negotiators Nervously Eye China's Resistance in IT Trade Talks." *Financial Times.* 19 Nov, http://www.ft.com/intl/cms/s/0/9456096e-5112-11e3-b499-00144feabdc0.html#axzz2srbBkrjM.

In the end, there is hope that pragmatism will continue to prevail. As Brandeis University's Peter Petri observes, "China is not averse to intervening, but it has done that against the background of a lot of liberalization. It's paying off."[176]

176. Email to the author from Peter Petri, 28 Jan 2014.

Global Technology Sourcing in China's Integrated Circuit Design Industry A Conceptual Framework and Preliminary Findings[1]

Dieter Ernst and Barry Naughton

Introduction

The study of "technology transfer" has produced a rich and valuable literature, but the term "technology transfer" can also be somewhat misleading. Technology "transfer" puts the primary focus on the technology owners (or holders); the determinants of their strategies; and the impact of these on "access to technology" by the recipient country. We prefer instead to talk about "technology sourcing" strategies of technology-using companies and countries that involve search, absorption, learning, diffusion, as well as innovations—especially incremental innovations—that convert ideas, inventions, and discoveries into new products, services, processes, and business models.

We apply this framework to China's integrated circuit (IC) design industry and examine the role of global technology sourcing, its drivers and impacts. IC design is one of the priority targets of China's innovation policy, as codified especially in the SEI initiative. At the same time, however, China's IC design industry is deeply integrated into the vertically disintegrated global semiconductor industry, through markets, investment and technology. The study of global technology sourcing in China's IC design industry thus allows us to explore a fundamental challenge for China's innovation policy: To what degree is indigenous innovation compatible with globalization?

Specifically, the paper contributes to the literature in the following ways: First, we show that the process of global technology sourcing is changing in important ways as it becomes possible to "source" technological services in an increasingly fine division of the value chain, even compared to what was possible a few years ago.

1. A first draft of this paper has been presented at the international conference on China's High-Technology Trade and Investment with Major Partners, cosponsored by *SITC/University of California Institute of Conflict and Cooperation (IGCC) and the Stockholm International Peace Research Institute (SIPRI),* La Jolla, California, July 23 and 24, 2012.

Second, the paper introduces a conceptual framework for analyzing the great variety of technology sourcing arrangements that characterize a highly globalized industry like IC design.

Third, the paper examines stages of chip design where global technology sourcing is likely to be critical for Chinese fabless IC design companies. Fourth, a distinction of different types of technology sourcing arrangements, such as licensing of inventions, contractual arrangements for training, knowledge sharing (e.g. the source code for IC design, software and system platforms), as well as the development of applications allows us to make some fresh observations about the nature of intellectual property protection, standardization, global technology sourcing, and the innovation process.

The paper focuses on global technology sourcing in China's IC design industry for wireless communications. The paper proceeds from the general to the specific: we begin with global trends and conclude with a description of the business and technology strategies of three Chinese companies. Part One of the paper describes the broad patterns through which globalization has transformed the distribution of scientific and technical knowledge; explores possible effects on technology sourcing; and examines the tension between these global changes and China's indigenous innovation policy. Part Two introduces a framework for analyzing the industrial value chain of the semiconductor industry (with a focus on IC design), highlighting the role of providers of EDA tools, design IP building blocks, fab equipment, and materials, as well as foundry services and assembly and testing services.

Part Three identifies possible drivers of global technology sourcing. We focus on IC design for wireless communications, one of the most dynamic industries in the world, and arguably the most dynamic part of China's country's IC design industry. We examine how changes in markets and technology create new strategic opportunities for Chinese IC design companies. We then explore multiple challenges that Chinese IC design firms are facing when they attempt to upgrade and scale up their operations in order to penetrate new markets for higher-end products and processes. In Part Four, we describe diverse approaches to global technology sourcing by one Chinese smart phone vendor and two Chinese wireless IC design firms.

Part One - Globalization Transforms Technology Sourcing and this has Implications for China's Innovation Policy

Reflecting the globalization of markets and production, technology transfer increasingly cuts across national borders and links technology owners and users in countries that differ in their stage of development and in their economic institutions, and hence in their capacity to absorb and develop technology. International technology transfer has long been characterized by two basic facts: First, despite an increase in the geographic dispersion of R&D, scientific and technological knowledge remains highly concentrated. Second, the commercialization of technology typically imposes restrictions - legal and other - on the free communication of knowledge.

Yet the conditions of international technology transfer are also changing fast: the process of global technology sourcing is changing in important ways as it becomes possible to "source" technological services in an increasingly fine division of the value chain, even compared to what was possible a few years ago. (We discuss these transformations further below.)

The changes in the global sourcing environment pose significant challenges to China's innovation policy. On the one hand, Chinese innovation policy since 2005 has strongly stressed the importance of "indigenous innovation." While indigenous innovation does not imply a closed-door approach to innovation, it lays heavy stress on increasing domestic inputs into the R&D process and on developing locally-owned intellectual property. Indigenous innovation was adopted as a policy in the Medium and Long-term Plan for Science and Technology Development (2006-2020) [hereafter, MLP], which explicitly states that "experience shows that developed countries are unwilling to transfer core technologies to China." Thus, indigenous innovation was promoted as a domestically controlled alternative for developing core technologies that are (asserted to be) unavailable on the international marketplace.

On the other hand, Chinese industry is deeply integrated into global industry. In 2011, foreign-invested enterprises produced 52.4% of China's exports. 44% of exports were produced under so-called "processing trade" arrangements, in which imported inputs are assembled into exports, which is an index of China's high degree of insertion into global production networks[2]. But China's integration goes far beyond this, since Chinese industry is linked to multinational corporations by investment and cross-national research networks as well. Today, China is the largest 'net importer' of R&D, and it is the third most important offshore R&D location for the 300 top R&D spending multinationals, after the United States and the United Kingdom[3]. As a result, the share of China's high tech exports by foreign-invested enterprises (FIEs) rose from 79% in 2002 to 82% in 2010[4].

It is true that through the present, China has typically participated in global production networks by providing low-value assembly services that intensively use low-cost labor. From garments to assembly of laptop computers, relatively low-wage Chinese workers earn a small portion of the value of export products. Case studies of particular products—strikingly including the iPhone—confirm that China earns a small proportion of the value of sophisticated exports, often less than 5%[5]. Thus, conclusions based on data about the share of high-technology exports among China's

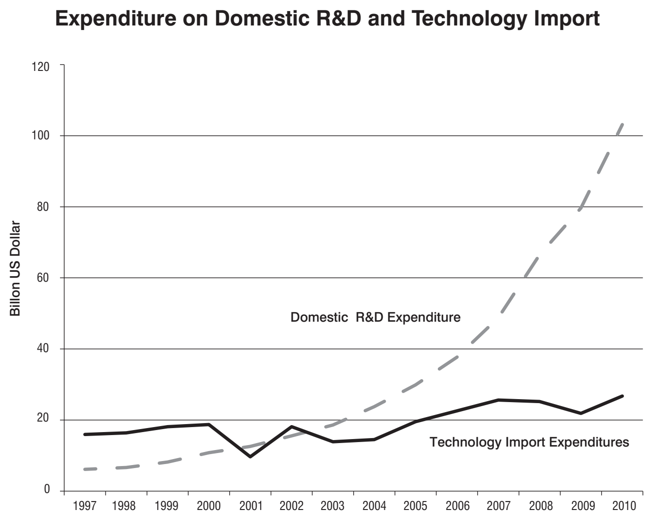
2. General Administration of Customs, PRC, "2011 Trade by Trade Regime," accessed at http://www.customs.gov.cn/publish/portal0/tab44604/module109000/info353199.htm
3. Ernst, D., 2011,Testimony To the U.S.-China Economic and Security Review Commission Hearing on China's Five Year Plan, Indigenous Innovation and Technology Transfers, and Outsourcing June 15, 2011, page 6
4. Congressional Research Service, China's *Economic Condition, June 2012, page 11*
5. See, for instance, Ali-Yrkko, J. et al, 2011, *Who Captures Value in Global Supply China? Case Nokia N95 Smartphone,* ETLA Discussion Papers No. 1240, 28 February, The Research Institute of the Finnish Economy, Helsinki

exports are highly misleading (or even more so, about China's total high technology exports in comparison to the high technology exports of the US)[6].

Whether China's initial concentration in low-tech assembly and export processing means that upgrading is difficult or impossible is a question for empirical research, and much depends on conditions in individual industrial sectors. The close ties with multinational firms and global markets suggests a path of technological upgrading that would rely on close partnering with multinationals, development of sub-contracting networks, and gradual "learning by doing." To a certain extent, indigenous innovation represents a rejection of this technology development path, and an assertion that only a stronger domestic effort can really succeed in developing core technological capabilities. The fact that China's technology planners are willing to risk policies that may weaken the strong existing international links displays their deep conviction that China is locked into a low-technology position in global value chains that is difficult to break out of, and that global firms will not willingly share core technologies. Thus, a fundamental challenge for China's innovation policy is: To what degree is indigenous innovation compatible with globalization?

It should be stressed that, intellectually at least, "indigenous innovation" policies do not advocate closed-door innovation or technological autarchy. Global technology sourcing and the integration of acquired technologies into new technological solutions are explicitly mentioned in the MLP as types of indigenous innovation. However, the plan also sets as a target the increase in domestic R&D expenditures relative to expenditure on technology import, which is unlikely to be compatible with a pure cost minimization strategy. Moreover, the strong stress on indigenous innovation undoubtedly discourages firms in practice from deep partnership strategies. In any case, the actual outcome, as Figure 1 shows, is that China has dramatically increased domestic outlays for R&D, while expenditures for technology import have grown much more slowly. Between 2000 and 2010, domestic R&D increased by nearly a factor of ten (in dollar terms, converted at exchange rates), while technology import expenditures increased by about 40%.

6. For an analysis of the impact of fragmentation on trade statistics, see Stehrer, R., N. Foster and G. de Vries, V*alue Added and Factors in Trade. A Comprehensive Approach,* World Input-Output Dababase Working Paper # 7, April, pages 1-22



The IC design industry exemplifies the dilemma that China faces. IC design is one of the priority targets of China's innovation policy, as codified most recently in the Strategic Emerging Industries (SEI) plan just published[7]. Moreover, Chinese technology planners have studied value chains enough to decide that the key to successful planning is to nurture the development of every stage of the value chain. They believe that the creation of an alternative Chinese 3G telecom standard, TD-SCDMA was a success made possible by their decision to nurture base station producers, handset manufacturers, telecom operators, and chip manufacturers simultaneously. Their development strategy, then, assumes the need to support domestic development at every stage of the value chain, and this is explicit in the IC sector in the SEI plan[8].

At the same time, however, China's IC design industry is deeply integrated into the global semiconductor industry, through markets, investment and technology. China's integration into the global industry depends precisely on the vertical dis-integration of the global IC industry, including the IC design industry. The process of dis-integration started decades ago, as the semiconductor industry re-organized around so-called "fabless IC design companies" who sent their designs to be made into silicon-based products at "pure play fabs" (IC factories). While a few of the largest integrated device manufacturers, such as Intel and Samsung, continued to combine

7. 国务院关于印发“十二五”国家战略性新兴产业发展规划的通知 [The State Council Notification on the Long-term Development Plan for Strategic Emerging Industries during the 12th Five Year Plan], 国发〔2012〕28号. July 7, 2012.

8. For semiconductors, the initial goal was to "…significantly increase the self-sufficiency ratio to over 70 percent for integrated circuits used for information and national defense security, and to over 30 percent for integrated circuits used in communications and digital household appliances…. We should basically achieve self-sufficiency in the supply of key products". Ministry of Information Industry, August 29, 2006.

IC design and manufacture (and thrive), most firms moved to the disaggregated model. This dis-integration was also associated with a shift of the industry toward Asia, as the most important pure-play fabs were in Asia, and especially in Taiwan[9].This long-term dis-integration of the industry has recently accelerated, as we show later.

Recently, the whole value chain related to mobile phone handsets has been transformed, with the center of gravity moving to Asia, and especially China. For instance, there are three times as many mobile handset subscribers in China as in the US (more than 1 billion relative to 331.6 million)[10]. China now accounts for more than one sixth of the world's mobile subscribers[11]. Most significantly, China has recently emerged as the largest market for smart phones – with 22% of global smart phone shipments in Q4 2011, China has now overtaken the US which accounts for 16%[12].

The recent further dis-integration in the semiconductor value chain has substantially reduced entry barriers for newcomers like Chinese IC design firms. As the CEO of one of the most important Chinese IC design companies recently told us, "the availability of IC design tools, semiconductor fab services, and open-source smartphone software [Android] allows Chinese firms to circumvent their weak spots and develop their strengths in hardware, IC design, and integration."[13]

In other words, fundamental changes in global end user markets for wireless communication chips, combined with recent advances in the organization of the global semiconductor industry have opened up new possibilities of an increasingly fine division of the IC design value chain. One of these possibilities is the space for Chinese firms to introduce new innovative and disruptive business models that foster and reward significant innovation in IC design and system integration. This raises a number of important questions that need to be addressed head on in current debates on China's innovation policy: Will intensifying competition during the second half of 2012 generate a wave of such innovations to break into the Chinese telecom market? What forces could drive this emerging innovation push in China's IC design industry for wireless communications? Is this innovation push sustainable? How important a source for those innovations is global technology sourcing relative to home-made inventions? And what are the implications for global issues relating to intellectual property rights, standardization, and economic development?

To explore these issues we need to describe in greater depth how globalization is changing technology sourcing in the IC design industry in general, and in IC design for wireless communications in particular. This paper is a first attempt to develop such a research agenda.

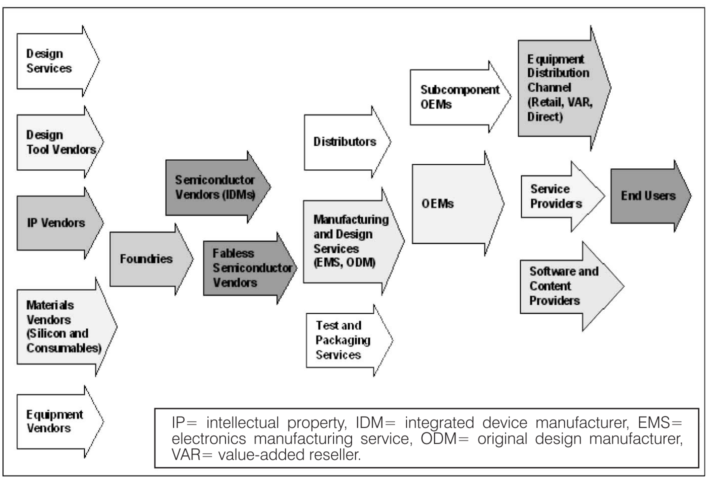
9. For the economics of global vertical disintegration in IC design, see Ernst, D., 2005, "Complexity and Internationalization of Innovation: Why is Chip Design Moving to Asia?", *International Journal of Innovation Management:* and Ernst, D., 2005, "Limits to Modularity - Reflections on Recent Developments in Chip Design", *Industry and Innovation.*
10. CTIA, November 2011
11. ITU, 2012.
12. Canalys, Q1 2012
13. Authors' interviews in China's IC design industry, June 21 to July 2, 2012.

II. A Framework for Analyzing Technology Sourcing in the Semiconductor Value Chain, with a Focus on IC design

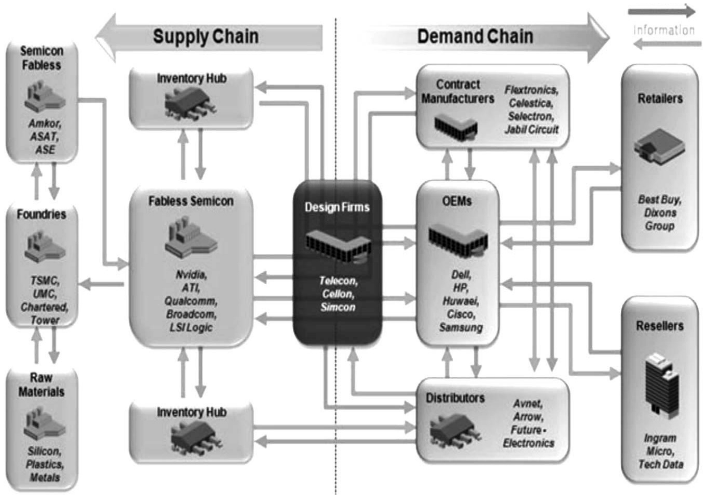
This part describes the participants in the semiconductor value chain, and their specific role as technology holders and technology users. [See slide 1] Of the almost 20 participants in the semiconductor value chain, the paper highlights the role of providers of EDA tools, design IP building blocks, fab equipment, and materials, as well as foundry services and assembly and testing services. Drawing on our first round interview notes, a few illustrative examples are described of technology sourcing arrangements of Chinese IC design companies.

In a second step, we look at information flows across the Semiconductor value chain, and distinguish between information flows within the supply chain, and information flows within the demand chain. This distinction allows us to bring into our analysis as well OEMs and contract manufacturers, and possibly also distributors. [See slide 2]

Participants in the Semiconductor Value Chain

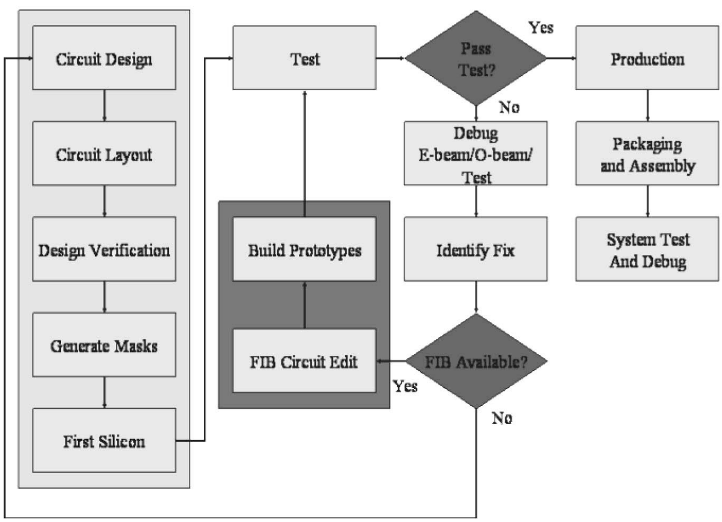


Gartner, 2005.



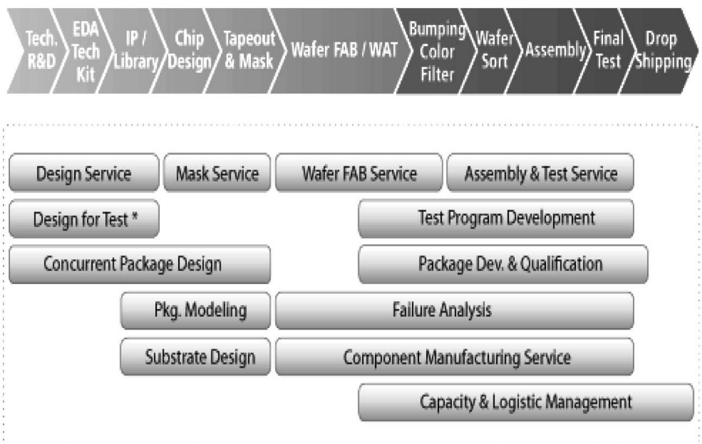
EDI (Electronic Data Interchange)

We then shift the focus of our analysis to IC design. The following slide 4 presents a typical chip design flow chart to distinguish stages of chip design all the way from circuit design to fabrication, packaging and assembly and final system test and debugging. We can use this flow chart to identify areas where Chinese IC design companies need to engage in technology sourcing. [slide 4].



Slide 5 demonstrates how significant the scope is for technology sourcing across all stages of the development cycle of an integrated circuit. The slide identifies 13 different types of IC design support services that Chinese IC design companies in principle can contract out to external suppliers. These services can be provided by individual specialized service providers, many of them located in Taiwan. Or, as indicated in slide 5, these services can all be consolidated in one IC design service package provided for instance by a foundry like TSMC. The analysis will have to establish the pros and cons of fragmented versus integrated provision of these IC design services.

IC Development Cycle Stages



TSMC, 2012

Part Three IC design for Wireless Communications –Changes in Markets and Technology as Drivers of Global Technology Sourcing by Chinese firms

In order to identify possible drivers of global technology sourcing, part three provides an analysis of the evolution of IC design for wireless communications in China, the most dynamic part of the country's IC design industry. Not only is China the biggest market for mobile handsets, with China Mobile being the world's biggest carrier by a margin. Since 2011, China has also emerged as the biggest market for smart phones, ahead of the US, and third generation (3G) mobile telecommunications is finally taking hold. In addition, massive investments are underway to accelerate the build-up of China's 4G network infrastructure.

Together, these changes in markets and technology have created new strategic opportunities for Chinese IC design firms to upgrade their product portfolios, process technologies and business models. To utilize this potential, and to develop effective upgrading strategies will not be easy for Chinese firms, given their so far limited management and innovation capabilities.

The analysis reviews the current status of China's IC industry and discusses changes in markets and technology that are providing strategic opportunities for Chinese IC design companies to expand their role in mobile handsets and especially smart phones. We then explore multiple challenges that Chinese IC design firms are facing when they attempt to upgrade and scale up their operations in order to penetrate new markets for higher-end products and processes.

We argue that, in order to cope with those 'upgrading challenges', Chinese IC design companies are forced to rely on global technology sourcing across the semiconductor value chain. Our first found of interviews show that leading Chinese IC design firms are all relying quite extensively on global technology sourcing. But we also find very different approaches to global sourcing. To some degree, this reflects the current state of experimentation – after all, these developments are very new. However, the diversity of approaches may also indicate that there is no one-best way of organizing global technology sourcing. This raises an important question for future research: Do Chinese IC design firms in the wireless communications industry have discretion to develop their own idiosyncratic forms of technology sourcing?

1. Current status of China's IC Design Industry

IC design has been one of the favorite poster childs of China's indigenous innovation policy. And it certainly fared better than most of China's semiconductor industry. Growing from $178M in 2001 to $5.4B in 2010, IC design experienced a CAGR of more than 46%. In fact, IC design was the fastest growing segment of China's semiconductor industry[14]. In 2010, China's IC design dollar revenues grew by 36%, exceeding the worldwide market growth rate of 32%. In the same year, China's fabless IC design companies had a share of 7% in the $74B worldwide fabless IC design industry — up from a 1% share in 2001 and a 4% share in 2004.

Despite this rapid growth, Chinese IC design firms continue to play second fiddle. Insufficient size is an important weakness. In fact, the combined revenues of the top ten Chinese IC design companies of $ 1.57 B is much lower than the individual results posted by each of the top five global fabless companies[15].

Key weaknesses that constrain the growth of China's IC design industry include a narrow focus on consumer products, especially low- and middle-end products such as color TVs, sound systems, clocks, electronic toys, small home appliances and remote controls. As long as China depends on these mature and relatively standardized products, this will constrain China's R&D and capability development in IC design.

14. PwC 2011, China's impact on the semiconductor industry…
15. China's Fablessss Profile, *EE Times Confidential Special Report 2011*

In addition, while China's IC design industry has improved its design capabilities, it still lags substantially behind the US, Japan, Taiwan and Korea, in terms of process technology and design line width. Furthermore, China lacks strong domestic suppliers of EDA tools and software and domestic licensors of IC design-related intellectual property.

China's patent applications for semiconductors show that its innovative capacity is improving, but China still has a long way to go to catch up with the US. China's share of worldwide semiconductor technology-focused patents published each year increased from 13.4% in 2005 to 21.6% in 2009 - and was forecast to reach 33% in 2011. More significantly, China's share of semiconductor patents that are being first issued in China has grown from zero in 2005 and 2006 to 24.1% in 2009[16].

Among leading Chinese IC design companies are affiliates of China's leading telecom equipment vendors Huawei (HiSilicon Technologies) and ZTE (Shenzhen ZTE Microelectronics); an affiliate of the Haier Group (Haier Beijing IC Design Company); and Shanghai Belling (which until March 2010 was a joint venture with Alcatel as the second largest share holder with a 25.64% share). Of particular interest are independent fablesss design companies like RDA (with a focus on RF ICs), Spreadtrum Communications (a supplier of chipsets of China's TD-SCDMA 3G handsets), Nationz Technologies (SOC and RF design for information security telecommunication and consumer devices), and Availink (focus on digital TV, multimedia and communications).

But even these Chinese industry leaders are well behind the global IC design industry leaders. Take productivity. Of the five Chinese IC design companies that were reported in the Global Semiconductor Alliance (GSA) Global Financials Report in 2009, only one, Spreadtrum Communications with 674 employees, had a sales per employee productivity level that was more than one-third that of the GSA's worldwide 183 fablesss company 2009 average of US$475,000 per employee[17]. The company achieved sales per employee of only US$156,000 in 2009, up from US$141,000 in 2008.

In short, China's IC design industry still has a long way to go to catch up with the leading IC design industries in the US, Japan, the EU, Taiwan and Korea. There is no Chinese IC design company in sight that might be able to challenge current global industry leaders. China's persistent innovation gap in IC design implies that Chinese firms continue to need access to foreign technology. Hence, global technology sourcing across the semiconductor value chain is of critical importance for reaping the strategic opportunities that current changes in markets and technology are creating in wireless communications.

16. *Derwent Worldwide Patent* data quoted in Ernst, D., 2012, *China's Position in the Global Semiconductor Value Chain – Still Playing Second Fiddle?,* manuscript, East-West Center, Honolulu
17. Global Semiconductor Alliance (GSA), 2010, *Global Semiconductor Financial TRACKER* http://www.gsaglobal.org/login_special.asp?redirect=/publications/financials/0904/index.asp

2. Strategic Opportunities in the Wireless Communications Market

Since the bursting of the Internet bubble at the turn of the century, wireless communications is an industry in turmoil, with tectonic shifts in markets and technology.

Here are a few proxy indicators that demonstrate the tsunami-like character of these changes[18]. In 2012, Total Global Mobile Revenues have reached $1.5 Trillion, over 2% of Global GDP. Mobile Operator Profits have more than doubled over the last 10 years. However, the wealth is not divided evenly, with Asia's share having tripled at the expense of Europe whose profit share has declined by 50%.

By the end of 2011, the global mobile subscriptions exceeded 6 Billion. The first 1 billion took over 20 years and this last one took only 15 months. The primary growth drivers are India and China which are cumulatively adding 75M new subscribers every quarter. China became the first country to eclipse the 1 billion mark in March 2012. India is likely to arrive at the milestone by early 2013.

However, while mobile subscriber growth is fastest in Asia, revenue growth still remains focused on the US. In 2011, the US accounted for only six % of worldwide new mobile subscriptions. Yet, in the same year, the US reported 21% of the global service revenues, 26% of the mobile data revenues, and 27% of the global capital expenditures. Despite the growing importance of Asian markets, the US market continues to matter, especially for the higher-end and more profitable market segments.

Of particular importance for IC design is that mobile devices are now exceeding traditional computers in unit sales and revenues. In 2011, for instance, 1,551.4 M handsets were sold worldwide (compared to 355.2M computers), up 14% compared with 2010. And the share of smart phones in global handset sales has increased now to 32%, up from 19.3 % in 2010. Most importantly, China is now the largest market for smart phones – with 22% of global smart phone shipments in Q4 2011, China has overtaken the US which accounts for 16%[19]. With global smart phone shipments of 146 million, this means that 32 million smart phones have been sold in China during Q4 2011. As a result, the size of the Chinese smart phone market is now large enough to enable minimum economies of scale and scope for leading Chinese IC design firms.

In addition, entry barriers to IC design for wireless communications are drastically declining, as vertical specialization has penetrated deeper and deeper into the global semiconductor value chain. As shown in part Two, fablesss IC design companies in China can now source technology and management support services from multiple sources, but especially from providers of IC design building blocks, EDA and testing tools, and foundry services. For instance, the availability of design IP building blocks through ARM and many other companies like for instance Tensilica, enables Chinese IC design firms companies to reduce their R&D investments which allows for a substantial reduction in their overheads. Chinese fabless IC design companies

18. Sources include author's interviews; Mobithinking.com; Portico Research Mobile Factbook 2012; ITU; Canalys; Strategy Analytics; iSuppli; McKinsey; PwC; and Gartner Dataquest.
19. Canalys, Q1 2012

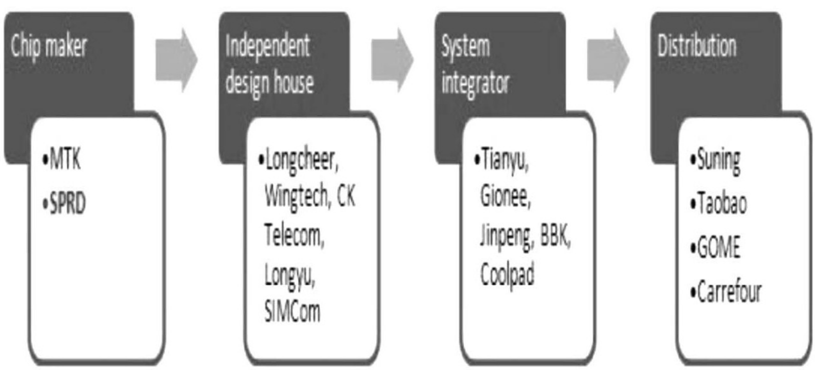
can now better focus on speed-to-market and reduce R&D cycles, enabling them to respond faster to the required yearly changes in IC design.

Furthermore, China-based fablesss IC design companies can source complementary intellectual property and management capabilities through the acquisition of competitors. Prominent recent examples that we observed during our June 2012 China interviews, include RDA's acquisition of Coolsand, and, most importantly, Mediatek's acquisition of M-Star[20].

A particular important enabling factor for the entry of Chinese IC design firms has been the emergence of open-source smart phone software. This enables Chinese IC design firms to concentrate on hardware design first, before developing and catching-up in software design capabilities.In the first quarter of 2012, Google's Android mobile operating system took almost 77% of China's smart phone sales[21]. At the same time, the availability of mature and inexpensive chip set solutions provided by Taiwan's Mediatek has furthered lowered the entry barriers, enabling China's whitebox ("Shanzhai") makers to penetrate into China's thriving budget smart phone market. This has given rise to a renaissance of China's Shanzhai sector, but this time the focus is on incremental innovations in low-cost smart phones.

As a result, a local ecosystem for budget smart phones is emerging that links IC designers, OEMs and Chinese customers (see slide 6). The primary focus is on the China market, and but increasingly other Asian emerging economies are becoming important targets.

Grey Market Mobile Phone Supply Chain



Source: Siang Zhang

20. While both MediaTek and M-Star are Taiwanese companies, their prirmary focus is the China market. The authors' future research will examine possible implications of these acquisitions for global technology sourcing.
21. Android's rapid rise has been at the expense of Nokia's Symbian operating system which in the first quarter of 2011 still accounted for almost 43% of China's smart phone sales, but fell to less than 12 % in Q1 2012. A further sign of Nokia's decline in the China market is that it reduced its China workforce by 50% in June 2012.

In short, fundamental transformations in the wireless communications industry have had important implications for the geographic location of fablesss wireless IC design. Following the pull of Asian markets, especially in China, there has been a move of such activities to Asia, and this has changed quite dramatically the global competitive landscape in this industry. Until only a few years ago, fablesss wireless IC design was dominated by around 20 companies, 10 from the US, 6 from Europe and and 4 from Japan[22]. Today, four leading companies in the US[23] compete against a growing number of new contenders from Asia (outside of Japan), with one European company (ST-Ericsson) and one Japanese company (MegaChips[24]) left in the top global 25 list. As shown in slide 7, 8 of the top 25 fablesss IC suppliers in 2011 were from emerging Asia (with two from China). And ranked by growth, 10 companies from emerging Asia were among the top 25, with one Chinese company, Spreadtrum, displaying by far the fastest growth rate during 2011 (slide 8).

2011 Top 25 Fabless IC Suppliers (SM)

2011 Rank	2010 Rank	2009 Rank	Company	Headquarters	2009 ($M)	2010 ($M)	% Change	2011 ($M)	% Change
1	1	1	Qualcomm	U.S.	6,409	7,204	12%	9,910	38%
2	2	3	Broadcom	U.S.	4,271	6,589	54%	7,160	9%
3	3	2	AMD	U.S.	5,403	6,494	20%	6,568	1%
4	6	5	Nvidia	U.S.	3,151	3,575	13%	3,939	10%
5	4	6	Marvell	U.S.	2,690	3,592	34%	3,445	-4%
6	5	4	MediaTek	Taiwan	3,500	3,590	3%	2,969	-17%
7	7	7	Xilinx	U.S.	1,699	2,311	36%	2,269	-2%
8	8	10	Altera	U.S.	1,196	1,954	63%	2,064	6%
9	9	8	LSI Corp.	U.S.	1,422	1,616	14%	2,042	26%
10	10	11	Avago	Singapore	858	1,187	38%	1,341	13%
11	13	12	MStar	Taiwan	838	1,065	27%	1,220	15%
12	11	13	Novatek	Taiwan	819	1,149	40%	1,198	4%
13	15	16	CSR	Europe	601	801	33%	845	5%
14	12	9	ST-Ericsson*	Europe	1,263	1,146	-9%	825	-28%
15	16	15	Realtek	Taiwan	615	706	15%	742	5%
16	17	17	HiSilicon	China	572	652	14%	710	9%
17	27	67	Spreadtrum	China	105	346	230%	674	95%
18	19	19	PMC-Sierra	U.S.	496	635	28%	654	3%
19	18	14	Himax	Taiwan	693	643	-7%	633	-2%
20	21	—	Lantiq	Europe	0	550	N/A	540	-2%
21	33	30	Dialog	Europe	218	297	36%	527	77%
22	22	21	Silicon Labs	U.S.	441	494	12%	492	0%
23	29	20	MegaChips	Japan	445	337	-24%	456	35%
24	23	24	Semtech	U.S.	254	403	59%	438	9%
25	24	23	SMSC	U.S.	283	397	40%	415	5%
Top 25 Total			—	—	38,242	47,733	25%	52,076	9%
Non-Top 25 Fabless			—	—	11,091	14,781	33%	12,811	-13%
Total Fabless			—	—	49,333	62,514	27%	64,887	4%

*Represents the 50% share not accounted for by ST.

Source: Company reports, IC Insights *Strategic Reviews Database*

22. US: Qualcomm, Broadcom, Skyworks, TI, Freescale (ex-Motorola), Silicon labs, Agere. LSI. ADI, Intel.; Europe: NXP (ex Philips), STM, Infineon, Wavecom, TTPcom, Ericsson; Japan: NEC, Matsushita, Fujitsu, Renesas
23. Qualcomm, Broadcom, Marvel, Intel (through acquisition of Infineon's wireless fablesss IC design division)
24. Mega Chips is part of the Kawasaki Microelectronics, Inc. group.

2011 Top 25 Fabless IC Suppliers Ranked by Growth Rate (SM)

2011 Rank	Company	Headquarters	2010 ($M)	2011 ($M)	% Change
1	Spreadtrum	China	346	674	95%
2	Dialog	Europe	297	527	77%
3	Qualcomm	U.S.	7,204	9,910	38%
4	MegaChips	Japan	337	456	35%
5	LSI Corp.	U.S.	1,616	2,042	26%
6	MStar	Taiwan	1,065	1,220	15%
7	Avago	Singapore	1,187	1,341	13%
8	Nvidia	U.S.	3,575	3,939	10%
9	HiSilicon	China	652	710	9%
10	Semtech	U.S.	403	438	9%
11	Broadcom	U.S.	6,589	7,160	9%
12	Altera	U.S.	1,954	2,064	6%
13	CSR	Europe	801	845	5%
14	Realtek	Taiwan	706	742	5%
15	SMSC	U.S.	397	415	5%
16	Novatek	Taiwan	1,149	1,198	4%
17	PMC-Sierra	U.S.	635	654	3%
18	AMD	U.S.	6,494	6,568	1%
19	Silicon Labs	U.S.	494	492	0%
20	Himax	Taiwan	643	633	-2%
21	Xilinx	U.S.	2,311	2,269	-2%
22	Lantiq	Europe	550	540	-2%
23	Marvell	U.S.	3,592	3,445	-4%
24	MediaTek	Taiwan	3,590	2,969	-17%
25	ST-Ericsson*	Europe	1,146	825	-28%
Top 25 Total			47,733	52,076	9%
Non-Top 25 Fabless			14,781	12,811	-13%
Total Fabless			62,514	64,887	4%

*Represents the 50% share not accounted for by ST.

Source: Company reports, IC Insights *Strategic Reviews Database*

2. Upgrading Challenges and Emerging Strategies

Chinese IC design firms are facing multiple challenges in their attempts to scale up, and to broaden and upgrade their IC design portfolio. It is useful to distinguish external and internal upgrading challenges. The former reflect fundamental transformations in the global wireless communications industry while the latter indicate limited technological and management capabilities of Chinese IC design companies.

Today, carriers and OEMs everywhere are requiring system-level integration on a chip in order to cope with the increasingly demanding *performance requirements* for electronic systems. At the same time, carriers and OEMs require drastic cost reduction of chips, and substantial improvements in the efficiency of their energy consumption. While these requirements are not new, the intensity of these requirements for chip design have substantially increased.

Over the last few years, the convergence of digital computing, communication and consumer devices has produced electronic systems that all strive to become lighter, thinner, shorter, smaller, faster and cheaper, as well as more multi-functional and less power-consuming. Essential performance features of mobile devices are expected to double every year or so, time-to-market is critical, and product-life-cycles are rapidly shrinking to a few months. Hence, time compression is essential in designing chips for such systems - chip design cycles of months or years are no longer acceptable.

At the same time, there is growing pressure to improve design productivity. A widening *productivity gap* between design and fabrication has been a primary driver behind these changes in design methodology. While the productivity of semiconductor fabrication has seen a 58% compounded annual growth since the 1980s, the productivity of chip design has lagged behind, with only a 21% compounded annual rate. There is also an important time dimension to this gap, as rapid technology change shortens product-life-cycles. Manufacturing cycle times are measured in weeks, with low uncertainty. However, design and verification cycle times are measured in months or years, with high uncertainty. In the end, the design productivity gap reflects a growing mismatch between process and design technology -- the number of available transistors has grown faster than the ability to design them meaningfully. Miniaturization has resulted in chips of nano-meter feature size – with the current best practice process technology moving below 22nm. As a result, it is now possible to fabricate millions of transistors on a single chip. The resultant increase in design complexity must be matched by a dramatic improvement in design productivity, which requires significant changes in design methodology and organization.

Scaling-up is of the essence, in order to reap both economies of scale and economies of scope. Economies of scale are necessary to reduce the unit cost of each chip design. Economies of scope are at least equally important, as Chinese IC design firms now must address multiple market segments simultaneously. In wireless communications, Chinese IC design firms must sustain leadership in the lower-end feature phone markets which provide them with an important cash cow. At the same time, Chinese IC design firms must also penetrate new markets for higher-end products and processes. Economies of scale and scope are also necessary, as Chinese IC design firms must respond to integrated solutions "bundling" strategies of global market leaders with their own integrated "bundling" solutions.

Adding further to these upgrading challenges, Chinese IC design firms must adjust their strategy and organization in a competitive environment that is characterized by market consolidation through M&A and strategic partnerships. An equally important challenge results from shrinking margins due to unanticipated disruptive technical change which reflects the rising complexity of wireless communication technology and its markets and its industry structure.

Arguably the most important challenge for upgrading and innovation strategies of Chinese IC design firms in wireless communications is that intellectual property has become a critical determinant of competitive success — 21% of all patents granted in the US in 2011 are related to wireless communications[25]. What matters in particular is the persistent concentration of patent ownership, with China still being a marginal actor.The top 20 global patent leaders in mobile communications control one third of the overall mobile patent pool. China's leading telecom equipment vendors have increased their international patent applications – in 2010, ZTE was No.2 in WIPO's

25. *Derwent Worldwide Patent Data Base 2012*

Patent Cooperation Treaty (PCT) Applications, and Huawei was No.4[26]. However, no other Chinese company is among the top 100 applicants, and China keeps lagging way behind the US in terms of the overall volume of wireless communications patent applications.

The gap is even larger for patents that are essential for the new 4G LTE wireless communications standard. A recent study shows that Nokia, Qualcomm, Samsung and Ericsson have built the strongest LTE patent portfolios while also taking a leadership position in future LTE technologies[27]. In addition, the recent acquisitions of the patent portfolios of Nortel and Motorola Mobility at $ 4.5B and $12.5B respectively have given Apple, Microsoft, Google and RIM a strong position in patent ownership of LTE technology.

China's position in LTE essential patents is still very weak. Of the 3,107 patents and pending patents declared as essential for the LTE standard by the ETSI in September 2011, Huawei had 116 (i.e. 3.73 % of the total)and ZTE 84 (2.7 %) such patents - hardly enough to compete on an equal footing.

To cope with the above upgrading barriers, Chinese IC design companies need to introduce in a timely manner new product and process technologies. But Chinese IC design companies are facing fundamental challenges in their attempts to expand their in-house R&D. The low margins that Chinese IC design companies can reap in their cash cow markets for feature phone handsets are limiting the funds available for in-house R&D. While smart phone markets are now increasing in importance, much of that market in China will be for low-cost budget smart phones, which again may lead to low and sometimes even razor-thin profit margins. In addition, IC design companies are under tremendous pressure to respond quickly to new technologies and abruptly changing demand patterns. This implies that in-house R&D is not a very practical option, as it would take too much time.

Finally, as newcomers to the wireless IC design field, Chinese IC design firms face serious problems in gaining "design-ins". First-tier handset makers typically prefer proven designs by leading IC design companies, like Qualcom, rather risking the success of their handsets with largely unproven designs from Chinese firms. In short, global technology sourcing is a must for Chinese IC design firms if they want to scale up and upgrade quickly into more profitable higher-end products and processes. Our interviews show that leading Chinese IC design companies are heavily relying on global technology sourcing.

26. WIPO Patent Data Base. WIPO's Patent Cooperation Treaty (PCT) provides a unified procedure for filing patent applications to protect inventions in each of its contracting states.
27. Article One Partners, 2012, *LTE Standard Essential Patents Now and in the Future,* http://newsletters.articleonepartners.com/news_4296e045-efdc-f819-c332-f181a6d2e012LTE%20Standard%20Essential%20Patents%20Now%20and%20in%20the%20Future_AOP.pdf

IV. Diverse Approaches to Global Technology Sourcing – Preliminary Findings from Interviews with one Chinese Smart Phone Vendor, and two Fabless Chinese IC Design Companies.

It is most striking that the leading Chinese designers of ICs for handsets have responded to this opportunity with dramatically different business and technology strategies. Each of these business strategies depends on a particular approach to global technology sourcing, which in turn is tailored to that business strategy[28]. While the business strategies are very different, they imply that the companies will be in intensified competition with each other as the market for smart phones in China explodes; as low-cost smart phones hit the market; and as feature phones with smartphone like features are developed. Differences in strategy, combined with a huge and rapidly growing market, may make it possible for many of these firms to thrive simultaneously by occupying slightly different market niches. However, the firms are very aware that they are coming into increasingly direct competition with each other, and that it is very likely that only a few of these companies will survive, and the others will be washed away by the force of competition.

A simplified breakdown of business strategies of three of the leading firms is as follows:

Xiaomi ["Millet"]. Xiaomi is sometimes called the "Apple of China" because of its stylish, multi-colored, powerful smart phones. The title is not precise, but it gives a flavor of Xiaomi's strategy. Xiaomi's business strategy relies on being first to market with a fast, high quality smartphone that is affordable. Selling smartphones for RMB 1,999—a price which, given discounts and various other pressures is being forced down toward 1,499—the company has quickly established a market presence among consumers in big cities[29].

Global sourcing: Uniquely among our respondents, Xiaomi uses top quality components from global firms, including Qualcomm processors, memory from Samsung, and Sharp screens. Then, Xiaomi's engineers do everything else in house, including integration of these components, hardware design and software design and integration. In addition, Xiaomi's strategy, like many firms in China, is founded on availability of the open-source Android OS from Google. Xiaomi is the most reliant on global technology sourcing of all the companies we visited.

28. Future research will explore, for a larger sample of Chinese IC design companies, the possible implications of their heavy use of design tools and design IP.
29. Recall that in China, unlike in the US, phone carriers do not generally subsidize handset prices by bundling them with long-term service contracts. Most Chinese consumers are used to paying full price for handsets, meaning that a new model iPhone sells for about 5,000 RMB. At the current exchange rate of 6.3 RMB to the dollar, this means an iPhone sells for almost $800, while the Xiaomi was introduced at $317, and is now available for $238. To be able to buy a good quality smartphone for $200 and plug it into cheap, flexible networks (including choice of different payment arrangements) is something American consumers can only dream of.

Discussion: Xiaomi's strategy is centered around the conviction that control of the software interface provides the greatest long-run profit opportunity. Thus, their strategy is to forgo hardware profits in order to establish a dominant position as provider of internet services through software superiority, which can be monetized later. Xiaomi has some very innovative practices, including posting weekly software updates online, and soliciting user comment, enabling super-fast tweaking and optimization.

RDA. RDA is following a strategy that is in some sense the most "traditional" late-comers catch-up strategy. RDA produces chips that are cheaper, and while not as advanced as the cutting-edge producers, they provide excellent features and functionality for price. Moreover, they are able to work with customers to provide a high level of integration among components and customized solutions. RDA has a large market share in China with inexpensive handset producers, including so-called shanzhai producers, and those that export inexpensive phones to developing Asia and Africa. RDA first established itself with a good quality, cheap Bluetooth chip, and developed capabilities from there. The formal acquisition of Coolsand in February 2012, completed the process of RDA developing its own baseband chips, which in turn enables them to offer packaged solutions[30]. RDA with Coolsand shipped their first baseband chips in 2011 and are now number 3 in the GSM baseband chip market after Mediatek and Spreadtrum. They will have a 3G baseband chip in the first half of 2013, allowing them to support the smartphone market, but later than Mediatek or Spreadtrum.

Global sourcing: RDA's strategy of cost minimization requires an exceptionally careful and focused global technology sourcing strategy. The price of global technology matters to RDA a great deal, as they must minimize total non-recurring costs. RDA licenses a great deal of IP, including prominently ARM cores and the core IP for wifi. They work closely with ED suppliers such as Synopsis. However, these are far from "turn-key" operations. RDA licenses blocks of IP and then encourages their engineers to invest substantial time and effort to understand that IP. Engineers are encouraged to prototype early, producing a chip which the company then debugs itself. Faster prototyping leads to quicker learning. The cost of sending tape-outs (prototypes) to the fab is considered good value for the rapid learning it produces. RDA is not dependent on global foundries, since it is currently designing at 60 nm (and has products using from 110 to 55 nm), so they are able to use a range of foundries, predominantly within China.

30. From Wikipedia: "A baseband processor (BP) is a device (a chip or part of a chip) in a network interface that manages all the radio functions (all functions that require an antenna). This may not include wi-fi and/or bluetooth. It typically uses its own RAM and firmware. The rationale of separating the baseband processor from the main processor (known as the AP or Application Processor) is threefold: (1) radio control functions are highly timing dependant, and require a real time Operating System; (2) legal: some authorities require that the entire communications software stack be certified. Separating the BP into a different component allows reusing them without having to certify the full AP; (3) radio reliability: Separating the BP into a different component ensures proper radio operation while allowing application and OS changes. Baseband processors typically run a real time operating system written in firmware.

Discussion: RDA's strategy relies on access to cheap, well-trained engineering talent. These engineers have graduated from Chinese universities, and RDA willingly takes on the task of providing them with real-world experience. Through intensive use of domestic engineering talent, RDA engages in exceptionally rapid cycles of prototyping and new product development. This has allows rapid catch-up in capabilities and a sustained growth in market share at the low end of the end market.

Spreadtrum (zhanxun). Spreadtrum is a rapidly-growing mid-size firm that has a large share of the TD-SCDMA market in China. Following a path initially blazed by Taiwan firm Mediatek, Spreadtrum aims to provide a turnkey platform that combines baseband and RF (radio frequency) chips, along with all the relevant associated software solutions (including protocol stack, SW platform, and multimedia and internet interfaces). Beginning as a low-cost copycat of Mediatek's comprehensive solutions for low-end feature phones, Spreadtrum has followed a remarkable process of technology leapfrogging, moving rapidly to implement near leading-edge process technology, which has enabled it to offer feature-rich phones and move rapidly into the smartphone era. A key milestone came in October 2010, when Spreadtrum engineers successfully prototyped a 2.5G integrated chip solution using 40 nm process technology, which provided the basis for a 95% increase in sales in 2011. The company is now planning for a transition to 28 nm process technology during 2012.

Global sourcing: Spreadtrum is a major user of global technology resources. Spreadtrum has greater resources than RDA to spend in acquiring IP cores and design blocks from global suppliers such as Synopsis. The ability of Spreadtrum to efficiently access and utilize these resources is a key part of its success. Even more striking, though, in Spreadtrum's case, is the close cooperation with Taiwan Semiconductor (TSMC) which has enabled Spreadtrum to shrink the gap with the process technology global frontier. According to Spreadtrum's own account, TSMC prioritizes cooperation with two fablesss IC design companies in telecom, and these are Qualcomm and Spreadtrum. TSMC cooperation is alleged by competitors to have been a key enabling factor in Spreadtrum's astonishing success in skipping a generation and successfully prototyping—on the first try—a 40 nm integrated solution (baseband +) in 2010. Subsequently, this sustained relative advantage in process technology has given Spreadtrum the ability to move to new performance levels as it can producer smaller more efficient chips with a greater range of capabilities.

Discussion: Spreadtrum's strategy places it squarely in the center of the emerging Chinese market for smartphones, and particularly those based on TS-SCDMA, in which it is dominant. In current market conditions, Spreadtrum has been able to consolidate and expand its presence in a wide range of market segments, extending from mid-tier feature phones, through the new smart phone market, and up to current development of phones that will provide multi-mode functions in the future 4G LTE markets. During the second half of 2012, Spreadtrum is ramping up sales of true 3G smartphone chips, and expects to sell 15-20 million.

Conclusions

This paper highlights a fundamental challenge for China's innovation strategy: How can China reconcile its primary objective of strengthening indigenous innovation with the benefits that it could reap from its deep integration into international trade and into global networks of production and innovation?

As vertical specialization disintegrates the global semiconductor value chain, latecomers like China can now "source" technological knowledge and services from a growing variety of sources. We demonstrate that global technology sourcing is necessary for the success of the upgrading strategies of Chinese wireless IC design firms. We also highlight stages of IC design where global technology sourcing is of critical importance, and describe the great variety of technology sourcing arrangements that are emerging in this industry.

The paper explores how tectonic shifts in the global telecommunications industry provide new entry possibilities for Chinese IC design firms. An important finding is that disruptive changes in the global semiconductor value chain that started with seemingly small discrete steps can completely upset the existing competitive order. We show how entry barriers were driven down when Mediatek of Taiwan introduced inexpensive system-on-chip solutions, enabling China's whitebox ("Shanzhai") makers to penetrate into China's thriving budget smart phone market. This disruption is about to happen again, as China belatedly enters third generation (3G) mobile telecommunications, and prepares its foray into fourth generation (4G) technologies. The result is intensifying competition, with domestic and global players rushing to bring out new chips, and pushing the envelope on process technology. This process culminates in the development of new hybrid business models that rely heavily on global technology sourcing.

These findings have important policy implications. They support our argument, advanced a few years ago, that innovation in China progresses in areas that escape the attention of both pessimists (who emphasize China's weak innovation capacity) and proponents of an emerging new technology superpower[31]. This paper shows an innovative China that is deeply integrated into global production and innovation networks; uses sophisticated global technology sourcing strategies; and quickly responds to changes in the global division of labor. And Taiwan plays an important role in many of those technology-sourcing links.

Global technology sourcing describes a small but important segment of China's innovation system that is very different from the government-sponsored innovation of the strategic emerging industries and "indigenous innovation." These two faces

31. Ernst, D. and B. Naughton, 2008, "China's Emerging Industrial Economy – Insights from the IT Industry", in C. McNally, editor, China's Emergent Political Economy – Capitalism in the Dragon's Lair, Routledge, Milton Park and New York; and Ernst, D., 2008, "Can Chinese IT Firms Develop Innovative capabilities within Global Knowledge Networks?", in H.S. Rowen, M.G. Hancock, and W.F. Miller, 2008, China's Quest for Independent Innovation, Shorenstein Asia Pacific Research Center and Brookings Institution Press

of “innovative China” coexist, but so far with little interaction. This raises an important question for China’s innovation strategy: Is China adequately accounting for the unintended costs of “indigenous innovation”, and can China combine the benefits of both innovation strategies?

Toward Greater Pragmatism? China's Approach to Innovation and Standardization[1]

Dieter Ernst

Why China's Approach Matters

Only a few years ago, China's approach to innovation and standardization barely played a role in international economic diplomacy. With its economic power on the rise, that assessment has changed dramatically. Today, China's innovation policy and its perceived threat to American innovation and competitiveness is a hot topic in U.S.–China economic relations, adding to contentious disputes about exchange rates, trade, and foreign direct investment. Standardization, as well as intellectual property rights and government procurement, are at the center of this conflict.

As the United States and China display fundamental differences in their levels of development and in their economic institutions, they pursue different approaches to standards and innovation policy. The U.S. consensus is that market forces and the private sector should play a primary role in innovation and standardization. China, on the other hand, relies much more on the government to define strategic objectives and key parameters.

Limited Convergence

In the United States, there is a widespread expectation that further reforms of China's standards system will "naturally" converge to (almost) full compliance with a U.S.–style, market-led, voluntary standards system. That expectation can be found, for example, in

1 This article was originally published as Dieter Ernst, "Toward Greater Pragmatism? China's Approach to Innovation and Standardization, SITC Policy Brief 18 (La Jolla, CA: IGCC, August 2011). The Study of Innovation and Technology in China (SITC) is a project of the University of California Institute on Global Conflict and Cooperation. The material is based upon work supported by, or in part by, the U.S. Army Research Laboratory and the U.S. Army Research Office through the Minerva Initiative under grant #W911NF-09-1-0081. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the U.S. Army Research Laboratory and the U.S. Army Research Office.

the American National Standards Institute's "United States Standards Strategy," which proposes a "universal application of the globally accepted principles for development of global standards" based on the U.S. voluntary standards system[1].

China's evolving system provides little evidence that convergence to the American system is likely to materialize. When Chinese reformers argue for a transition to a more market-driven standards system, they emphasize that the government will continue to play an important role as a promoter, enabler, and coordinator of an integrated standards and innovation policy.

China's leaders are committed to indigenous innovation as the key to ending poverty and to accelerating China's catching up with the United States, European Union, and Japan. Indigenous innovation is considered essential not just for moving beyond China's precarious export-oriented growth model. At stake is the survival of the system. Chinese leaders understand that export-led growth can no longer guarantee rapid gains, hence they place all their bets on indigenous innovation as a catalyst for industrial upgrading.

Conflicting Perceptions

China's indigenous innovation policy and its entry into the global standards game as a contender has raised concerns in the United States that this may erode American leadership and hasten the decline of the U.S. economy. The U.S. government considers China's innovation policy to be "discriminatory," implying that this policy is used as a trade-distorting ploy to challenge American supremacy in the global knowledge economy[2]. The U.S. Chamber of Commerce claims that China's innovation policy "… restricts the ability of American companies to access the market and compete in China and around the world by creating advantages for China's SOEs and state-influenced champions, … [and has] … the potential to undermine significantly the innovative capacity of the American economy in key sectors ..."[3]

China's standardization strategy is viewed in the United States as a critical weapon of China's neo-mercantilist policies to keep American companies at bay. The U.S. Information Technology Office (USITO), which represents the U.S. information and communications technology industry in China, observes "a clear trend to promote indigenous technology which is developed outside the international standards development system."[4] And for the chair of the National Academies Committee on

1. American National Standards Institute, United States Standards Strategy (New York: ANSI, 2005).
2. Commerce Secretary Gary Locke, as quoted in "U.S., China Begin Talks on Innovation Trade Dispute," at http://www.reuters.com/assets/print?aid=USTRE66J6SO20100720.
3. Testimony by Jeremi Waterman before the U.S. International Trade Commission Hearing on "China: Intellectual Property Infringement, Indigenous Innovation Policies, and Frameworks for Measuring the Effects on the U.S. Economy" (Investigations 332-514 and 332-519), June 15, 2010.
4. USITO, "Written Comments to the U.S. Government Interagency Trade Policy Staff Committee regarding China's Compliance with its Accession Commitments to the World Trade Organization (WTO)," 2009.

Comparative Innovation Policies, China's standardization strategy "raises serious questions of WTO compliance," as it promotes "[t]he creation and application of a large number of national standards in China, as opposed to the use of existing international standards."[5]

Perceptions in China are very different: "Among Chinese industries and scholars, there is deep frustration with the U.S.–China standards discussions and distrust in the sermon-style arguments propagated by the United States … the disputes between the United States and China on ICT standards and the overarching issue of IPRs in standardization still remain unsolved. The situation may actually be worse in the sense that both sides have noticed the difference but continue to head in their own directions."[6] China's leadership considers the American critique of its innovation policy to be unfair and hypocritical, and suspects that the United States is trying to contain China's rise.

China's Strategy

In response, according to the Standards Administration of China (SAC), China seeks to upgrade its standards system to i) lessen the "control of foreign advanced countries over the PRC," especially "in the area of high and new technology"; and ii) increase the effectiveness of Chinese technical standards as important protective measures or barriers to "relieve the adverse impact of foreign products on the China market."[7] SAC adds that China's standardization strategy needs to fill a policy vacuum, as its accession commitments to the WTO have substantially reduced the use of most other trade restrictions such as tariffs, import quotas, and licensing requirements.

China's efforts to develop a unified standardization strategy are focused on these priorities:

Fostering economic development remains critical, with the result that the state will continue to play an important role as a promoter and coordinator of an integrated standards and innovation policy.

Standardization should help to reduce the cost of licensing essential patents for both Chinese manufacturers and consumers. Access of foreign companies to Chinese standards development organizations should create a quid pro quo: Foreign companies can participate in technical committees in exchange for technical contributions, including disclosure of essential patents and acceptance of fair, reasonable, and non-discriminatory (FRAND) licensing conditions.

5. 4. A. W. Wolff, "The Direction of China's Trade and Industrial Policies," testimony before the House Ways and Means
6. Baisheng An, "Intellectual Property Rights in Information and Communications Technology Standardization: High-Profile Disputes and Potential for Collaboration Between the United States and China," Texas International Law Journal 45 (2009): 195.
7. SAC, "Study on the Construction of National Technology Standards System," Sept. 2004, preface and part I, sect. IV.

A defining characteristic of China's standardization strategy is to use standardization as a platform for indigenous innovation.

"Enterprises" are encouraged to be the "main players in formulating standards."[8] This leaves open the question of what role, if any, foreign enterprises are to play. An important objective, however, is to use homegrown standards to develop innovative "national leaders" and to protect domestic industry.

Standardization should focus on priority sectors and should reflect sector specific requirements[9].

Effective standardization requires a complementary set of certification and conformity assessment regulations, such as the Compulsory Certification scheme (administered by the China National Certification and Accreditation Administration) and the regulations for telecommunications (administered by the Ministry of Industry and Information Technology) on Network Access Licensing and on Network Access Identification.These conformity assessment regulations are essential for controlling access to the Chinese market.

Standardization should take a decentralized approach, in order to reduce the urban–rural gap and to encourage dispersed local industrial development.

As a latecomer to standardization, China should pursue a dual-track strategy that combines the adoption of international standards with the insertion of indigenous innovations into domestic and international standards.

The role of the voluntary standards should substantially increase, "where the need for standards comes from the market, enterprises are the main drafters of standards, and the implementation of standards relies on the market mechanism."[10]

Outward Chinese foreign direct investment should be facilitated through the promotion of Chinese standards practices and processes in overseas markets.

China's role in international and regional standards development organizations and consortia should substantially increase, enabling Chinese enterprises and research institutes to move from being standards takers to become standards co-shapers and ultimately standards setters in some areas.

Diversity of Stakeholders and Fragmentation

In principle, a unified national standardization strategy has important advantages. It facilitates the quick mobilization of resources for massive investments in standardization infrastructure. Clear and uncontested objectives can facilitate rapid learning.

8. Ping Wang, Yiyi Wang, and John Hill, "Standardization Strategy of China: Achievements and Challenges," East-West Center Working Paper, Economics Series No. 107, January 2010, 8.
9. Note, however, that the list of the "eight key areas for standardization" is quite comprehensive, and covers most sectors of the Chinese economy. This comprehensiveness indicates the daunting challenge faced by China's standardization strategy, as it still lacks a highly diversified production and innovation system.
10. Wang, Wang, and Hill, "Standardization Strategy of China," 5.

In addition, a unified strategy makes it easier to create nation-wide markets based on a single mandated standard.

However, implementing this demanding strategy in China will not be easy. From the outside, China's innovation policy presents a homogenous picture of a top-down "model of neo-mercantilist state developmental capitalism."[11] Hence, implementation constraints should be limited, once the leadership has given the go-ahead. But that picture fails to capture the surprisingly fragmented Chinese innovation system, which involves diverse stakeholders with conflicting interests. Like most latecomers, China's innovation system is constrained by multiple disconnects: between research institutes and universities and industry; between civilian and defense industries; between central government and regional governments; and between different models of innovation strategy[12]. In fact, standardization in China today is a hybrid system. The government remains in charge as the main driver and final arbiter of China's standardization strategy, yet the diversity of stakeholders have increased.

This has resulted in a fair amount of diversity in the definition and implementation of strategic goals. However, this diversity of approaches is overwhelmingly restricted to central and local government agencies. Industry and especially private firms and final users continue to play a limited role. China's government documents on standardization all emphasize "openness, transparency, and impartiality." But as China has no tradition of an independent "civil society," standards-making bodies, industry associations, research institutes, and consumer organizations all remain dependent on the government.

Instead, local governments act as pace setters for a more decentralized approach, establishing local standards as a constituent building block of the overall standards system. Pioneered by the Shenzhen government in 2007, the governments of Shanghai, Beijing, Jiangsu, Zhejiang, Shandong, Henan, and Shaanxi have all issued their own local standardization strategies. On the positive side, these strategies are presumably better customized to the specific requirements and capabilities of the industrial sectors in their respective localities, and to the regions' level of economic development and the needs of their citizens. The potential advantages of decentralized self-government are well-established in theories of innovation and organization.

There is, however, a negative side to Chinese-style diversity. China's standards system is overly complex and displays signs of fragmentation. Ambiguity is a fundamental source of such fragmentation. Key concepts are loosely defined and often differ from the definition of these concepts in other countries. Even China's definition of "standards" deviates from the definition used in the United States, which focuses on voluntary consensus standards.

11. A. W. Wolff, China's Indigenous Innovation Policy, testimony before the U.S. China Economic and Security Review Commission Hearing on China's Intellectual Property Rights and Indigenous Innovation Policy, Washington, D.C., May 4, 2011, 3.
12. Creating university–industry linkages has been the focus of many Chinese attempts to reform its innovation system. More recently, attempts are under way to address the other disconnects, but so far with mixed results.

There is also typically a lack of clarity about the boundaries and the division of labor between competing national, industry, ministry, and provincial standards. Equally important sources of fragmentation are inter-agency rivalries and turf battles among different ministries and their respective stakeholders. These inter-agency rivalries reflect the conflicting interests of major Chinese stakeholders in innovation and standardization.

Stakeholders

There are four main groups of stakeholders who seek to impose somewhat conflicting objectives on China's standardization strategy and, more broadly, on the country's innovation policy.

China's export industry is a strong supporter of compliance with WTO commitments. This position reflects China's deep integration into global corporate networks of production and innovation[13]. Support for greater compliance with international standards also comes from leading Chinese ICT firms that have accumulated a critical mass of intellectual property rights, like Huawei, ZTE, Lenovo, and Haier. Huawei, China's leading telecommunications equipment vendor, is now the third largest global player in this industry. A broad portfolio of essential patents in important technologies (such as next-generation mobile communications and convergence of fixed and mobile networks) has established this company as a serious player in the development of architectural and radical innovations[14].

A second group of stakeholders emphasizes the need to improve China's absorptive capacity in order to benefit from foreign technology through strengthened domestic capabilities. Equally important objectives are to reduce the cost of patent licensing fees paid on foreign technology and to reduce China's dependence on foreign technology overall. Strong support for developing China's indigenous innovation capabilities can be found in public research institutes, in SOEs in China's priority industries (such as the *Strategic Emerging Industries* initiative), in parts of the domestic high-tech industry that seek to take domestic market share away from multinational corporations, and in parts of the defense and space industry. This coalition of domestic stakeholders supports, for example, policies on patent licensing for standards that seek to reduce the costs of licensing foreign patents.

A third group of stakeholders are "copy-cats" that seek to retain space for low-cost reverse engineering, unauthorized copying, and opportunistic incremental innovations. Typical of this type of successful low-cost innovation are no-name shanzhai (unlicensed) handsets that are estimated to have at least a 40 percent share of the

13. A good proxy indicator for China's integration into global production networks is that foreign-invested enterprises dominate China's manufactured exports. They account for 58 percent of China's total exports, and more than 88 percent of its high-technology exports.
14. Essential patents are frequently quoted in other patent filings, and hence shape technology trajectories. Patents are also called essential when it is not possible to comply with an international standard without infringing those patents.

Chinese handset market. The main thrust of these stakeholders is to prevent a modernization of China's laws and regulations on IPR, including any reform of China's patent law that would reduce the role of utility model patents.

Fourth, China's defense industry and top planning institutions like the National Development and Reform Commission seek to broaden the space for developing mission-oriented, complex technology systems (space, military, energy, environment, climate). These stakeholders view information security and certification regulations as a critically important policy tool of China's innovation strategy. They fear that China's critical information networks provide an easy "target of attack, sabotage, and terrorism by hostile forces and elements."[15] A strategic assumption is that control over standards and a strong Chinese information security industry are necessary to protect China's information networks[16].

Toward Greater Pragmatism?

It is difficult for outsiders to assess which of these four stakeholder coalitions has most leverage in shaping decisions on China's innovation policies. A detailed analysis of recent developments of China's innovation policies finds a fairly consistent pattern of response to foreign complaints[17]. In the first round, government regulations start out with requirements that exceed established international norms. This typically gives rise to a wave of criticism from foreign enterprises and business organizations, and also from Chinese companies that have established a significant position in the international market and that have begun to accumulate a broad portfolio of intellectual property rights. In response to this criticism, the second round then leads to adjustments in government regulations that combine a selective relaxation of contested requirements with persistent ambiguity.

This raises the question of what will happen in further rounds of negotiation. In the run-up to the 18th Party Congress, there are signs that Chinese policymakers are moving toward more dogmatic positions on economic policies, political ideology, internal control policies, and geostrategic and foreign policy positions. It is unclear whether the shift toward greater dogmatism is a temporary tactical move dictated by internal power struggles. Some observers see a growing role for security considerations in China's innovation policy.

15. Comments by Vice Minister Lou Qingjian, Ministry of Information Industry, at the 2006 BOAO Forum, at http://www.boaoforum.org/AC2006/yjgE.asp, accessed July 6, 2010.
16. For a detailed analysis of China's policy on information security standards and certification, see Dieter Ernst, *Indigenous Innovation and Globalization: The Challenge for China's Standardization Strategy* (La Jolla, CA: UC Institute on Global Conflict and Cooperation and East-West Center, 2011), chap 2.
17. Ibid., chap. 4. This is true for China's definition of products that contribute to indigenous innovation, the revision of government procurement regulations, and new regulations for patents included in standards.

Or can we expect, once the Congress is over, a gradual strategic shift to greater openness and transparency to meet China's needs for foreign technology and the requirements of its deep integration into the global economy? There is reason for cautious optimism that China's innovation and standards policies will gradually move towards greater pragmatism. As a specialist on Chinese law puts it: "As China pursues the upgrading of its economy, there will be more debate over policies on technology development. The very tentativeness with which indigenous innovation has been pursued may be a hopeful sign that continued dialogue may bring about adjustments of measures that are deemed protectionist."[18] Another expert's assessment is that, when push comes to shove on implementation of China's innovation policy, "the most mercantilist elements are regularly rebuffed, and given the array of interests in favor of a more open innovation strategy, that pattern is unlikely to change."[19]

Policy Implications

To conclude, both China and the United States have much to learn from each other as they each face their own innovation imperatives. While they compete in global markets, both would benefit from cooperation on science, technology, and innovation to solve the challenges of economic growth, better and lower-cost health systems, and a greener environment. Given the importance of both countries in the global economy and for geopolitics, it is striking to see that such cooperation remains as yet quite limited.

There is ample scope to extend such cooperation beyond the exchange of scientific knowledge and to include the exchange of ideas on how to develop and upgrade the innovation and standardization systems of both countries. While China's innovation policy has been a success, at least in quantitative terms, the United States is still far ahead in overall innovation capacity. China's persistent innovation gap implies that Chinese firms continue to need access to American technology, whether in terms of equipment, core components, software, or system integration. This implies that China's innovation push will create new markets for American firms, provided they stay ahead on the innovation curve.

Implementing such cooperation faces many hurdles. These partnerships need to be on an equal footing, with reciprocity of rights and obligations on contentious issues such the right balance between the protection of intellectual property rights and China's interest in technology diffusion.

18. Stanley Lubman, "Changes to China's 'Indigenous Innovation' Policy: Don't Get Too Excited," *China RealTime Report,* July 22, 2011, 3.
19. Scott Kennedy, "Indigenous Innovation: Not as Scary as It Sounds," *China Economic Quarterly* (Sept. 2010), 19, 20.

Establishing such reciprocity between countries at different stages of development will not be easy. While incumbent industry leaders seek to retain the status quo, latecomers like China seek to adjust the old rules to reflect their interests. Progress toward adjusted rules of reciprocity should be possible, once the United States and China accept that while their economic and innovation systems are different, they are deeply interdependent.

China, for example, ought to acknowledge that the United States needs safeguards against forced technology transfer through policies such as compulsory licensing, information security standards and certification, and restrictive government procurement policies. The United States, in turn, needs to acknowledge that Chinese firms feel disadvantaged by restrictions on Chinese foreign direct investment and on the export of so-called dual-purpose technologies to China. The United States also needs to engage more actively with Chinese concerns about issues such as the unequal distribution of benefits that result from the current rules of patent licensing and the role of essential patents in critical interoperability standards.

To move toward greater reciprocity, it is necessary to increase the level of trust. While this is not easy, given deeply entrenched fears in both countries, creative incrementalism through "learning-by-doing" can help to move things forward.

Further Reading

- Battelle. 2009. "2010 Global R&D Funding Forecast." *R&D Magazine* (December): 23. Available at http://www.battelle.org/aboutus/rd/2010.pdf.
- Ernst, Dieter. 2006. *Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks.* East-West Center Special Reports, No. 10 (Honolulu, HI: East-West Center).
- _____. 2009. *A New Geography of Knowledge in the Electronics Industry? Asia's Role in Global Innovation Networks.* Policy Studies No. 54, August (Honolulu, HI: East-West Center).
- McGregor, J. 2010. "China's Drive for 'Indigenous Innovation': A Web of Industrial Policies," report commissioned by the U.S. Chamber of Commerce. Available at https://www.uschamber.com/reports/chinas-drive-indigenous-innovation-web-industrial-policies.
- Shanghai Municipal Government. 2007. "Outline of the Standardization Development Strategy of Shanghai (2007–2020)," April, 上海市标准化发展战略纲要(2007–2020). Available at http://www.shanghai.gov.cn/shanghai/node2314/node2319/node10800/node11408/node16796/userobject26ai10444.html.
- Shenzhen Municipal Government. 2007."Notice on the Implementation of Shenzhen Standardizations Strategy (2006–2010) from Shenzhen Municipal Government," May 18, 深圳市人民 政府关于印发深圳市标准化战略实施纲要(2006–2010)的通. Available at http://www.34law.com/lawfg/law/1797/3122/law_258909093846.shtml.
- Standards Administration of China. 2004. "Study on the Construction of National Technology Standards System," Beijing, September.
- U.S. Office of Budget Management. 1998. OMB Circular A-119. Available at http://www.whitehouse.gov/omb/circulars_a119.

Trade and Innovation in Global Networks – Regional Policy Implications

Dieter Ernst

Overview of topic and why it is important

This Think Piece explores how integration into international trade through global networks of production (GPNs) and innovation (GINs) might affect a region's innovation capacity.

Policy debates typically focus on three specific channels through which trade could strengthen a region's innovation capacity: i) imports, FDI and technology licensing, and ii) learning-by-exporting would both expose the region to foreign technology and intangible knowledge as a source of product and process innovation. In addition, iii) competition may reduce monopoly rents from innovation and create pressure to increase productivity[1]. It is argued that, for these gains from trade to materialize, the following policies must be in place:

- Trade *liberalization* through tariff reduction would lower import prices, improve market access for exporters, and enhance competition.
- A business *environment* that encourages private investment through the provision of "political and macroeconomic stability, quality of regulation", and the provision of infrastructure, R&D capacity and a skilled workforce[2].
- Effective *intellectual property legislation and enforcement* is necessary to enable knowledge diffusion and external knowledge sourcing.

These policy prescriptions continue to shape debates about trade and innovation. A fundamental assumption is the existence of certain preconditions and capacities that are not always present in every region. In fact, recent research has convincingly demonstrated that the success or failure of trade liberalization is determined by the *economic structure* of a country or a region (i.e. its institutions and policies, its market size and sophistication, and the managerial and technological capabilities of its

1. Kiriyama, N., 2012, *Trade and Innovation: Synthesis Report,* OECD Trade Policy Papers, No.135, OECD, Paris, and Onodera, O., 2008, *Trade and Innovation: a Synthesis Paper,* OECD Trade Policy Working Paper No.72, August 7.
2. Somewhat confusingly, Kiriyama (2012: p.5) uses the term "absorptive capacity" to describe the key features of an investment-friendly business environment. For a precise definition of "absorptive capacity", see below.

firms)[3]. In addition, integration into geographically dispersed global networks of production (GPNs) and innovation (GINs) may also significantly affect a country's or a region's approach to and its experience with trade liberalization. These two parameters — a region's *economic structure* and its global network integration — encompass what might be called *domestic determinants of gains from trade for innovation.*

As regions across the globe are progressively integrated into those global networks — some certainly more than others — these regions are all faced with a fundamental challenge: How might progressive integration of its firms into GPNs and GINs affect learning, capability development and innovation? Will network integration unlock new sources of industrial innovation? Or will it act as a poisoned chalice that will sap and erode the region's accumulated capabilities?

There is nothing automatic about these processes, and they cannot be left to market forces alone. To cope with market failures identified many years ago by Kenneth J. Arrow[4], appropriate policies need to be in place to develop absorptive capacity and innovative capabilities, both at the firm level and across the industry.

Support policies for local firms will be required. And, as emphasized by Greg Tassey substantial investments are needed in "human science and engineering capital" and "innovation infrastructure."[5] An important objective is to improve the efficiency of a nation's innovation systems and to reduce the risks of innovation through "more comprehensive growth policies implemented with considerable more resources and based on substantive policy analysis capabilities"[6]. Aimed at upgrading a country's or region's innovation system, such generic support continues to matter.

There is however a growing consensus that effective innovation policy in a world of ubiquitous globalization has to move, as Rob Atkinson puts it, "beyond simply supporting factor conditions that all firms can use; it has to go inside the "black box" of the firm to help firms and key industries thrive."[7]

Part One of the paper lays out the Policy Challenge that ubiquitous globalization imposes on a region's innovation capacity. Part Two presents illustrative examples of how "ubiquitous globalization" increases the diversity and complexity of GPNs and GINs, and briefly discusses the underlying systemic pressures and enabling forces. In order to capture the gains for innovation that a region might reap from global network integration, Part Three suggests moving from a one-way analysis of the external

3. See Acemoglu, D., P. Aghion and F. Zilibotti (2006), " Distance to Frontier, Selection, and Economic Growth", Journal of the European Economic Association, 4(1), pp. 37-74, March; Aghion, P., R. Burgess, S. Redding, F. Zilibotti, 2006, *The Unequal Effects of Liberalization: Evidence from Dismantling the License Raj in India,* NBER Working Paper No. 12031, February: 31 pages; and Chandra,V., I.Osrioa-Rodarte and C.A. Primo Barga, "Korea and the BICs (Brazil, India and China): catching-up experiences", chapter 3 in Chandra, V., D. Erocal, P.C. Padoan, and C. A. Primo Barga 2009, editors, *Innovation and Growth. Chasing A Moving Frontier,* OECD and World Bank, Paris and Washington, D.C..
4. Arrow, K. J. 1962. "The Economic Implications of Learning by Doing" *Review of Economic Studies,* June, 153–73.
5. Tassey, G. 2007. *The Technology Imperative.* Cheltenham: Edward Elgar.
6. Tassey, G., 2008. "Globalization of Technology-Based Growth: The Policy Imperative." *Journal for Technology Transfer,* December: p.2
7. Atkinson, R., 2014, "Two Cheers for Martin Baily's "U.S. Manufacturing", *ITIF Innovation Files,* February 14, http://www.innovationfiles.org/two-cheers-for-martin-bailys-u-s-manufacturing/

impacts on a region's innovation capacity to an analysis of two-way interactions. The paper concludes with Policy Implications and highlights Unresolved Issues for Future Research, including the critically important issues of spillover employment effects and inequality.

Part One – The Policy Challenge

Rising complexity and increasing uncertainty are two defining characteristics of the new world of international economics. "Ubiquitous globalization" now reaches beyond markets for goods and finance into markets for business services, technology, intellectual property rights, and knowledge workers[8]. The result is an increase in the organizational and geographical mobility of knowledge[9]. However, the new geography of knowledge is not a flatter world where technical change and liberalization rapidly spread the benefits of globalization. Instead, the industrial heartlands in the US, Europe and Japan are intensely competing with a handful of new— yet very diverse— manufacturing and R&D hubs that are emerging in Asia.

Regions differ in their capacity to address this challenge. To understand why, it might be useful to examine first the following three questions: What do we know about how regions differ? What types of innovation are necessary for upgrading a region's growth prospects and prosperity? And how does one measure industrial upgrading?

What do we Know About how Regions Differ?

Research on the geography of production and innovation has long struggled with a simple question: *Why is it that some regions achieve significantly higher growth rates than others?* For instance, Anthony Venable's 2006 Jackson Hole symposium lecture poses three specific questions[10]:

- Why are economic activity and prosperity spread so unevenly?
- Does increasing trade—or spatial interaction more generally – necessarily narrow these differences?
- How should we think about future developments, both for developed and for developing regions?

8. Ernst, D., 2009, A New Geography of Knowledge in the Electronics Industry? Asia's Role in Global Innovation Networks, Policy Studies, no. 54 (Honolulu: East-West Center, August).
9. Ernst, D., 2005, "The New Mobility of Knowledge: Digital Information Systems and Global Flagship Networks." In Latham, R., and S. Sassen, eds. 2005. *Digital Formations: IT and New Architectures in the Global Realm.* Princeton, NJ, and Oxford: Princeton University Press for the U.S. Social Science Research Council.
10. Venables, A., 2006, "Shifts in Economic Geography and Their Causes", Paper prepared for 2006 Jackson Hole Symposium, http://www.rrojasdatabank.info/venables.paper.0821.pdf

Regions differ widely across many dimensions. Significant variation exists for instance in industry composition (such as the size of firms and plants), the industry structure (e.g. large OEM with many SME suppliers versus a fragmented industry structure with many SMEs), and the region's degree of specialization versus its diversity. At the same time, wide disparities exist across regions in wages, labor markets and work conditions, and, most importantly, in the spatial distribution of high-growth clusters, jobs, and income levels. Furthermore, regions differ widely in their technology levels and capabilities, in their skill portfolios, and the quality of their Vocational Training and Higher Education systems. Last, but not least, regions may also differ in their R&D capacity, and in their institutional arrangements for intellectual property development and protection, and for standardization and certification.

Research on the causes of regional diversity focuses on the role of initial conditions, the potential for innovation and knowledge spillovers, and the composition of economic activity[11]. Maryann Feldman emphasizes the impact of science-based related industries on innovation performance[12]. Venables' great insight is that we need a model of the location of economic activity as the outcome of tension between concentration forces and dispersion forces. As he puts it in the revised version of his Jackson Hole lecture, published by the *Federal Reserve Bank of Kansas,* "globalization causes dispersion of activity, so economic development will be in sequence, not in parallel; some countries will experience rapid growth while others will be left behind."[13] Once we substitute "Regions" for "Countries", we are getting closer to the question at hand[14].

A more recent interesting conceptualization can be found in a 2012 NBER paper by Delgado, Porter, and Stern (DPS) which focuses on differences in cluster composition to explain variation in regional economic performance[15]. "Regional clusters" are defined as "groups of closely related and complementary industries operating within a particular region. A key finding is that industries participating in a strong cluster register higher employment growth as well as higher growth of wages, number of establishments, and patenting. An important objective is to ensure that "…the positive impact of clusters on employment growth does not come at the expense of wages, investment, or innovation."[16]

To get to the root causes of differentiated cluster performance, DPS suggest taking a fresh look at two fundamental determinants of cluster performance:

11. See, among others, Porter, M.E., 1990, *The Competitive Advantage of Nations,* Free Press, New York; Barro, R.J. and X. Sala-i-Martin, 1995, *Economic Growth,* Cambridge,MA: MIT Press; and Fujita, M.P., P. Krugman, and A.J. Venables, 1999, *The Spatial Economy,* MIT Press, Cambridge, Massachusetts.
12. Feldman, M. P. 1999, "The New Economics of Innovation, Spillovers and Agglomeration: A Review of Empirical Studies", *Economics of Innovation and New Technology* 8: 5–25.
13. Venables, A.J., 2006, "Shifts in Economic Geography and Their Causes", *Economic Review – Fourth Quarter,* Federal Reserve Bank of Kansas City.
14. For an empirical analysis based on Venables' approach, see Ernst, D., 2009, A New Geography of Knowledge in the Electronics Industry? Asia's Role in Global Innovation Networks, Policy Studies, no. 54 (Honolulu: East-West Center, August).
15. Delgado, M., M.E. Porter, and S.Stern, 2012, Clusters, Convergence, and Economic Performance, NBER Working Paper 18250, July, http://www.nber.org/papers/w18250.
16. Ibid:6.

- *Convergence,* i.e. the potential for growth is declining in the level of economic activity as a result of diminishing returns.
- *Agglomeration* which arises from interdependencies across complementary economic activities that give rise to increasing returns. Agglomeration can increase inequality across regions over time[17].

DPS find that convergence and agglomeration typically coexist, but they occur on different levels[18]: "While convergence is likely to be most salient at the industry level (or at relatively narrow levels of industry aggregation), strong agglomeration forces operate across industries within a cluster (or across closely related clusters)." The analysis focuses on complementarities, and examines "the agglomeration forces arising among closely related and complementary industries. By sharing common technologies, knowledge, inputs and cluster-specific institutions, industries within a cluster benefit from complementarities."

In short, what really matters for successful regional clusters are "complementarities across related industries."[19]. "Such policies appear to be more effective than those that seek to attract a particular type of investment, offer incentives to benefit a small number of firms, or favor particular high-technology fields such as biotechnology or software if the region has little strength in those areas."[20]

What Types of Innovation are Necessary for Upgrading a Region's Growth Prospects and Prosperity?

Some basic definitions are in order to establish what *types of innovation* are necessary to upgrade a region's growth prospects and prosperity[21]. *Innovations* convert ideas, inventions, and discoveries into new products, services, processes, and business models. Radical breakthrough discoveries and inventions through scientific research are only the tip of the iceberg. Of critical importance are policies that would enable local firms (especially SMEs) to scale-up quickly new ideas, discoveries and inventions in order to be first at the right market at the right time.

In other words, effective innovation policies would first and foremost seek to reduce or remove barriers that may prevent a firm to move from "knowledge generation" (research) via "technology development", "scale-up" (pilot line & prototypes), and "globally competitive domestic manufacturing", all the way up to effective commercialization of new products and services.

17. The literature distinguishes two types of agglomerating forces: localization (increasing returns to activities within a single industry) and urbanization (increasing returns to diversity at the overall regional level). See for instance Dumais, G., G. Ellison, E.L. Glaeser, 2002, "Geographic Concentration as a Dynamic Process,"*Review of Economics and Statistics,* 84 (2), pp. 193-204.
18. Ibid: 3..
19. Delgado. Porter. Stern, 2012: 6.
20. Ibid: 35.
21. This section draws on Chapter 2 - Conceptual Framework: Innovation and Innovative Capabilities, in Ernst (2009)

Both in the US and in Europe, there is a growing recognition that innovation and manufacturing are closely intertwined, and that the focus should be on a set of enabling technologies (called "Advanced Manufacturing Technologies" in the US, and "Key Enabling Technologies" in Europe). According to recent MIT research[22], these enabling technologies encompass for instance

- Synthesized new materials (e.g., nano-engineering), as weall as custom-designed and recycled materials
- Continuous manufacturing of pharmaceuticals and bio-manufacturing
- Green sustainable manufacturing
- Mass customization, for instance through Additive Manufacturing (3DP) and reconfigurable robotics which might enable Continuous Manufacturing in small batch sizes and break down the boundaries between fabrication and assembly.
- Integrated solutions through bundling of physical products with services and software.

Innovations in these Advanced Manufacturing technologies are expected to act as enablers of new products and services that might create new niches and new industries. In addition, programmable manufacturing which needs less capital-intensive tooling and fixtures may facilitate manufacturing in smaller, agile and flexible production facilities, closer to end-users.

In turn, this may enhance productivity and flexibility in large-scale manufacturing and supply and distribution chains (for instance through RFID tracking and Human-Robot-interaction). Furthermore, Advanced Manufacturing technologies are expected to enhance coordination and flexibility in global production and innovation networks.

What is Success? Measuring Industrial Upgrading[23]

In general terms, industrial upgrading is about linking improvements in specialization, local value-added, and forward and backward linkages[24] with improvements in learning, absorptive capacity and innovative capabilities.

Two aspects of industrial upgrading are of greatest policy relevance: "firm-level upgrading" from low-end to higher-end products and value chain stages, and "industry-level linkages" with support industries, universities and research institutes.

For upgrading a region's growth prospects, the challenge is to enable firm-level and industry-level upgrading to interact in a mutually reinforcing way, so that both ty-

22. Berger, S., 2013, *Making in America. From Innovation to Market* (Cambridge, MA: The MIT Press).
23. For an economic analysis of "Industrial Upgrading", see Ernst, D., 2010, "Upgrading through innovation in a small network economy: insights from Taiwan's IT industry", *Economics of Innovation and New Technology,* Vol.19, No.4, June: pages 295-324.
24. As defined in Hirschman, A.O., 1958. *Strategy of Economic Development,* New Haven: Yale, University Press. chapter 6.

pes of upgrading will give rise to a "virtuous circle". "Firm-level upgrading" is the key dimension - without it, there is little hope that a region can benefit from global network integration. In other words, local firms must develop the capabilities, business models and organization that will allow them to strengthen their absorptive capacity and innovative capabilities. This requires important adjustments in corporate strategy.

But for firm-level upgrading to succeed, upgrading must take place simultaneously at the level of "industry linkages". As Powell and Grodal observe, "collaboration across multiple boundaries and institutional forms" is the norm today, and innovation networks "… are now core components of corporate strategy."[25] This reflects the growing geographic mobility of knowledge and the emergence of IT-enabled governance mechanisms to orchestrate distributed knowledge. To broaden the pool of firms that are fit for sustained firm-level upgrading, regional governments need to foster strong support industries and dense linkages with universities and research institutes.

Finding the right balance between firm-level and industry-level upgrading poses a continuous challenge for policy makers and corporate planners —the "right balance" is a moving target, it is context-specific and requires permanent adjustments to changes in markets and technology. A strategy that neglects one element at the detriment of the others is unlikely to create sustainable gains. The stronger the links between those two elements, and the better they fit, the greater are the chances that local firms can shape markets, prices and technology road maps.

In addition, three other forms of "industrial upgrading" may help to guide regional policies: (i) inter-industry upgrading proceeding from low value-added industries (e.g. light industries) to higher value-added industries (e.g. heavy and higher-tech industries); (ii) inter-factor upgrading proceeding from endowed assets (i.e., natural resources and unskilled labor) to created assets (physical capital, skilled labor, social capital); and (iii) upgrading of demand within a hierarchy of consumption, proceeding from necessities to conveniences to luxury goods[26].

Most research has focused on a combination of (i) and (ii), based on a distinction between low-wage, low-skill "sun-set" industries and high-wage, high-skill "sunrise" industries. Such simple dichotomies however have failed to produce convincing results, for two reasons: First, there are low-wage, low-skill value stages in even the most high-tech industry, and high-wage, high-skill activities exist even in so-called traditional industries like textiles. And second, both the capability requirements and the boundaries of a particular "industry" keep changing over time. An example is the transformation of the computer industry from an R&D-intensive high tech industry to a commodity producer that depends on the optimization of supply chain management.

25. Powell, W.W. and S. Grodal, "Networks of Innovators", chapter 3 in: Fagerberg, J., D.C. Mowery and R.R. Nelson (eds.), 2004, *The Oxford Handbook of Innovation,* Oxford University Press, p. 57,58.
26. For a discussion of upgrading taxonomies, see Ozawa, T. 2000. "The 'Flying-Geese Paradigm: Toward a Co-evolutionary Theory of MNC-Assisted Growth", in: K. Fatemi (ed.), *The New World Order: Internationalism, Regionalism and the Multinational Corporations,* Amsterdam and New York: Pergamon.

Part Two – Increasing Diversity – the Dynamics of Global Innovation Networks

We now turn to the dynamics of global innovation networks that shape the opportunities and challenges for regional policies. The root cause for "ubiquitous globalization" is the emergence of a "winner-takes-all" competition model, described by Intel's Andy Grove[27]. In the fast moving ICT industry, success or failure is defined by return on investment and speed to market, and every business function, including R&D, is measured by these criteria. Technology-based competition is intensifying, provoking fundamental changes in business organizations. No firm, not even a global market leader like IBM, can mobilize all the diverse resources, capabilities, and repositories of knowledge internally. This indicates how much the world has changed since Edith Penrose argued in her path-breaking study *The Theory of the Growth of the Firm* that " ... a firm's rate of growth is limited by the growth of knowledge within it" ([1959] 1995: xvi, xvii).

Corporations have responded with a progressive modularization of all stages of the value chain and its dispersion across boundaries of firms, countries, and sectors through multi-layered corporate networks of production and innovation[28]. The complexity of these global networks is mind-boggling. According to Peter Marsh, the *Financial Times*' manufacturing editor,"…[e]very day 30m tones of materials valued at roughly $80 billion are shifted around the world in the process of creating some 1 billion types of finished products."[29] While the proliferation of global production networks goes back to the late 1970s, a more recent development is the rapid expansion of global innovation networks (GINs), driven by the relentless slicing and dicing of engineering, product development, and researc[30].

A defining characteristic of the new geography of knowledge is that both learning and innovation are fragmented ("modularized") and geographically dispersed through multilayered global corporate networks that integrate engineering, product

27. Grove, A. S. 1996. Only the Paranoid Survive: How to Exploit the Crisis Points that Challenge, Every Company and Career. New York and London: Harper Collins Business.
28. On the proliferation of global production networks (GPNs) and global innovation networks, see Ernst, D., 1997, *From Partial to Systemic Globalization. International Production Networks in the Electronics Industry,* report prepared for the Sloan Foundation, jointly published as The Data Storage Industry Globalization Project Report 97-02, Graduate School of International Relations and Pacific Studies, University of California at San Diego, and as BRIE Working Paper #98, Berkeley Roundtable on the International Economy, University of California at Berkeley, http://brie.berkeley.edu/publications/WP%2098.pdf ; and Ernst, D., 2007, "Innovation Offshoring: - Root Causes of Asia's Rise and Policy Implications." , chapter 3 in : In Palacios, Juan J., ed. (Ed.), 2007., *Multinational Corporations and the Emerging Network Economy in the Pacific Rim.* London: Routledge, co-published with the Pacific Trade and Development Conference (PAFTAD), London: Routledge. For an important recent contribution by trade economists, see Baldwin, Richard and J. López González (2013) "Supply-Chain Trade: A Portrait of Global Patterns and several testable hypotheses" NBER Working Paper 18957 http://www.nber.org/papers/w18957.pdf
29. P. Marsh, "Marvel of the World Brings Both Benefit and Risk," *Financial Times*, June 11, 2010, 7. For a detailed case study of the multi-layered global production networks in Asia's ICT industry, see Ernst 2004.Yusuf OUP
30. Ernst, 2007, PAFTAD

development, and research activities across firm boundaries and geographic borders. It took some time for economic theory to adjust to this important transformation.

Only a decade ago, research on the geographical distribution of patents concluded that innovative activities of the world's largest firms were among the least internationalized of their functions[31]. This finding gave rise to the proposition that innovation, in contrast to most other stages of the value chain, is highly immobile: it remains tied to specific locations, despite a rapid geographic dispersion of markets, finance, and productionv[32]. Attempts to explain such spatial stickiness of innovation have highlighted the dense exchange of knowledge (much of it tacit) between the users and producers of the resultant new technologies.

Yet, even as this research was in progress, the world was changing, with the emergence of GINs since the 1990s which carry out design and product development as well as applied and basic research. GINs share important characteristics with the GPNs that preceded them[33]:

- *Asymmetry* is a fundamental characteristic. Multinational corporations (MNCs) dominate as network flagships and define network organization and strategy. Control over network resources as well as coordination of information flows and decision making enables the flagship to directly affect the growth, strategic direction, and network position of lower-end participants (e.g., specialized suppliers and subcontractors).
- A great variety of *governance* structures is possible. These networks range from loose linkages that are formed to implement a particular project and that are dissolved after the project is finished—so-called "virtual enterprises"—to highly formalized networks, "extended enterprises," with clearly defined rules, common business processes, and shared information infrastructures. What matters is that formalized networks do not require common ownership; these arrangements may, or may not, involve control of equity stakes.

Increasing Diversity and Complexity

An important recent development however is the *increasing diversity and complexity* of these knowledge-sharing network arrangements. GINs now involve multiple actors and firms that differ substantially in size, business model, market power, and

31 Patel, P., and K. Pavitt. 1991. "Large Firms in the Production of the World's Technology: An Important Case of Non-Globalisation." *Journal of International Business Studies* 22(1): 1–21

32. Archibugi, D., and J. Michie. 1995. "The Globalization of Technology: A New Taxonomy." *Cambridge Journal of Economics* 19(1): 121–40.

33. See Ernst, D., 2006. *Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks,* Special Study prepared for the East-West Center and the U.S.-Asia-Pacific Council, East-West Center, Honolulu, July:48 pages; and Ernst, D., "Innovation Offshoring: Root Causes of Asia's Rise and Policy Implications." In Palacios, Juan J., ed. 2007. *Multinational Corporations and the Emerging Network Economy in the Pacific Rim*. London: Routledge, co-published with the Pacific Trade and Development Conference (PAFTAD).

nationality of ownership, giving rise to a variety of networking strategies and network architectures (Table 1).

The flagship companies that control key resources and core technologies, and hence shape the hierarchical intra-firm and inter-firm networks, are still overwhelmingly from the United States, the European Union, and Japan. However, there are also now network flagships from emerging economies, especially from Asia, which construct their own GINs. Huawei, China's leading telecommunications equipment vendor, and the second largest vendor worldwide, provides an example of a Chinese GIN that illustrates the considerable organizational complexity of such networks (Fig.1) The company has pursued a two-pronged strategy[34]: it is building a variety of linkages and alliances with leading global industry players and universities, while concurrently establishing its own global innovation network of more than 25 R&D centers worldwide. In the European Union, Huawei has more than 800 R&D specialists across 14 R&D sites in eight countries[35].

Table 1

2. Global innovation networks—increasing diversity

© Dieter Ernst

Hierarchical

- **Intra-firm networks -** Global companies "offshore" stages of innovation to Asian affiliates
- **Inter-firm networks -** Global firms "outsource" stages of innovation to specialized Asian suppliers
- **Asian firms** construct their own GINs (**Huawei**)

International public-private R&D consortia

- **ITRI** – global knowledge sourcing from the erstwhile periphery

From hierarchical to splintered GINs

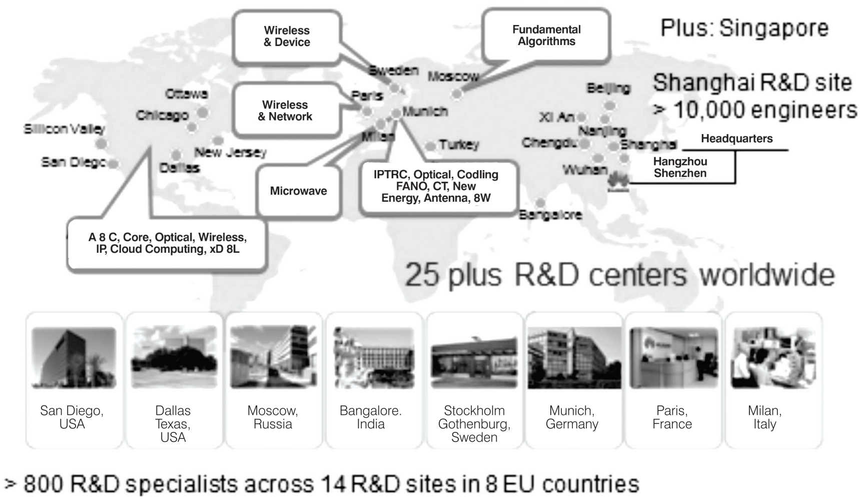
- **Foxconn** – contractors can shape strategic direction as junior network flagships

Plus: Informal social networks (students, knowledge workers)

Adapted from Ernst, D. 2009, A new Geography of knowledge

34. Ernst, D., and B. Naughton. 2007. "China's Emerging Industrial Economy: Insights from the IT Industry." In McNally, C., ed. 2007. *China's Emergent Political Economy: Capitalism in the Dragon's Lair.* London: Routledge.
35. This compares with more than 10,000 engineers in Huawei's Shanghai R&D site.

Figure 1
Huawei's Global Innovation Network



Sources: company webside and iterviews

In fact, Huawei has developed a web of project-specific collaboration arrangements with major suppliers of core components, such as Siemens (as part of China's TD-SCDMA third-generation mobile communications standard) and Alcatel-Lucent (with a focus on 4G TD-LTE development), as well as Intel and Qualcomm. And Huawei's own GIN now includes, in addition to at least eight R&D centers in China, five major overseas R&D centers in the United States, and at least ten R&D centers in Europe. The choice of these locations reflects Huawei's objective to be close to major global centers of excellence and to learn from incumbent industry leaders: Plano, Texas, is one of the leading U.S. telecom clusters initially centered on Motorola; Kista, Stockholm, plays the same role for Ericsson and, to some degree, Nokia; and the link to British Telecom was Huawei's entry ticket into the exclusive club of leading global telecom operators.

Recent Transformations

What matters most for a region like Brabant are three recent transformations in the dynamics of global innovation networks. First, international public-private R&D consortia are no longer exclusively originating from the US, the EU and Japan. Asian countries are also quite active now in global sourcing through such cross-border public-private partnerships. Taiwan's ITRI provides a telling example of such global knowledge sourcing from the erstwhile periphery (Tables 2 and 3).

Table 2

ITRI'S global knowledge network - Europe (select examples)

Germany: Brandenburg University of Applied Science; Degussa; Fraunhofer (IPA, IPK); German Aerospace Center; Karl Storz Endoscopy; MANZ AG (display); Physikalisch-Technische Bundesanstalt; Siemens

TUBerlin; University Duisburg-Essen

Netherlands: Aeon Astron Europe B.V.; Centraalbureau voor Schimmelcultures (CBS); Dutch Polymer; Eindhoven University of Technology; KEMA International; Philips Design; TNO; to-BBB Technologies; VU University Medical Center

Russia:Moscow State University; Academy of Sciences (IOFFE, ICPC, PTI···;St. Petersburg State Polytechnical University

ITRI webside & interviews

Table 3

ITRI'S global knowledge network - Europe (select examples

Universities: Carnegie Mellon; Case Western Reserve; Columbia; Cornell; Georgia Tech; Harvard; Johns Hopkins Kent State; Lawrence Berkeley National Laboratory; MIT Media Lab; MIT-CSAIL; MIT-Harvard Clinical Consortium; National Renewable Energy Laboratory; Ohio State University; Purdue University; Rensselaer Polytechnic; Texas Tech University; UC Berkeley; UCLA; UC San Diego; UC Santa Barbara; University of Central Florida; University of Cincinnati; University of Illinois; University of Missouri; University of Washington, Seattle; Virginia Polytechnic

Companies: Corning; DuPont; e-Meter Corporation; Eastman Kodak; Exactech; IBM; InVisage; Johnson & Johnson; Qualcomm MEMS Technologies; Texas Instruments; etc

- ITRI's network interacts with & complements Taiwanese corporate GINs (e.g., TSMC)

ITRI webside & interviews

Within Europe, ITRI's global knowledge network concentrates on Germany, the Netherlands, France, where it covers a broad array of science disciplines and technologies. By contrast, ITRI's presence in Russia is heavily focused on the country's leading research institutes for advanced mathematics and physical sciences. It is also noteworthy that ITRI has a much larger and widely diversified presence in the US, both with leading universities and with global industry leaders. Finally, ITRI's knowledge network closely interacts with private GINs established by leading Taiwanese companies[36].

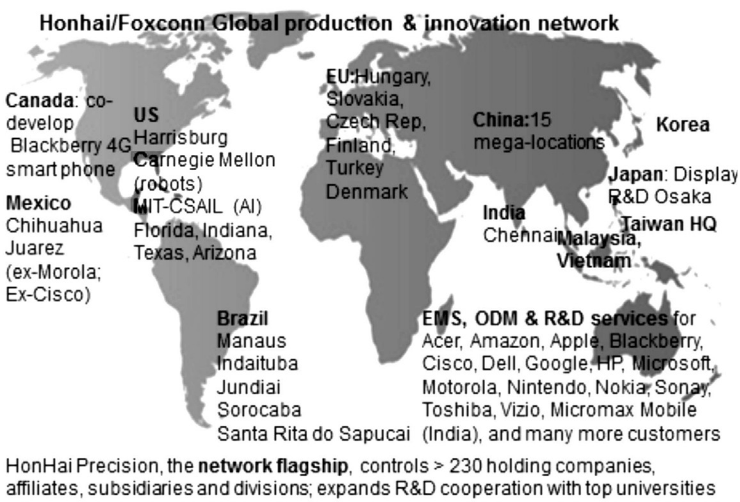
A second recent transformation are splintered GINs with diverse network flagships which increasingly complement the erstwhile dominant hierarchical networks. This indicates that

vertical specialization within global networks continues unabated. Three different types of splintered GINs are emerging[37]:

- core component suppliers (Intel, MS; ARM; QCM; TSMC) control technology platforms
- Mega-contractors (Foxconn) can co-shape strategic direction and provide integrated solutions
- Mega- distributors (e.g., Arrow Electronics; Avnet) can provide integrated solutions

Figure 2 presents a glimpse at Foxconn's expanding global production and innovation network which illustrates how contractors from the erstwhile periphery of the world economy are now *co-shaping* the strategic direction of GINs as junior partners. HonHai Precision, the network flagship, controls more than 230 holding companies, affiliates, subsidiaries and divisions worldwide, and keeps rapidly expanding R&D cooperation with top universities and research institutes in the US, Japan and Europe.

Figure 2

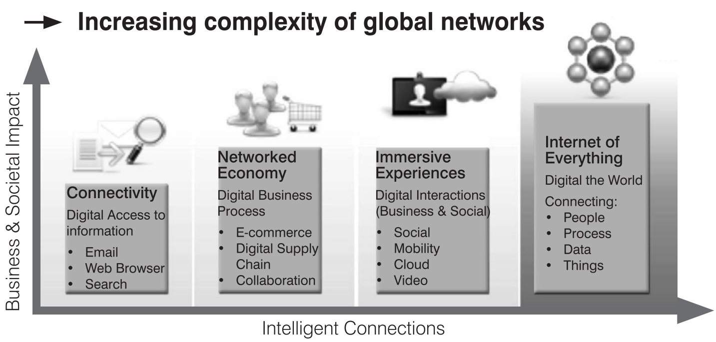


Sources: company webside and iterviews

36. TSMC for instance has a strong presence in UC Berkeley and at Stanford University, with a heavy focus on leading-edge IC development for advanced computing.
37. Ernst, 2014, *Power Shift? From hierarchical to splintered Global Innovation Networks,* manuscript, East-West Center, Honolulu

A third recent transformation is the increasing complexity of global networks, due to rapid and disruptive technical change. Arguably, the most important manifestation of rising network complexity is the convergence of ICT infrastructure for the Internet, wireless and mobile communications, and cloud computing that culminates in "The Internet of Everything". According to Cisco, the "Internet-of-Everything is expected to bring "… together people, process, data and things to make networked connections more relevant and valuable than ever before — turning information into actions that create new capabilities, richer experiences and unprecedented economic opportunity for businesses, individuals and countries."[38]. Figure 3 highlights the evolution of network connectivity, from digital access to information through email, web browser and search engines through a progressive digitization of business processes and interactions.

Figure 3
Increasing compexity: multiple levels of interconnectivity

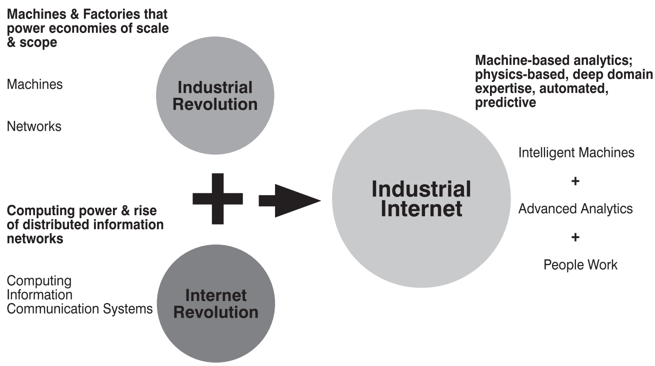


"The Internet of Everything brings together people, process, data and things to make networked connections more relevant and valuable than ever before - turning information into actions that create new capabilities, richer experiences and unprecedented economic opportunity for businesses, individuals and countries."

Cisco

38. http://www.cisco.com/web/about/ac79/innov/IoE.html

Figure 4
GE - The industrial Internet (2012)



While the vision of an "Internet-of-Everything" certainly exaggerates what will be possible over the next decades, concepts like GE's "Industrial Internet" are already being implemented to increase productivity gains across all stages of the industrial value chain (see Figures 4 and 5). And the concept of "Connected Manufacturing" highlights how global manufacturers are implementing"… bidirectional information-sharing through the global manufacturing value chain—from research and development (R&D) to the customer and back; from suppliers to plants to sales-channel partners, and conversely."[39] Of critical importance are interoperability standards that are necessary to transfer and render useful data and other information across geographically dispersed systems, organizations, applications of components[40].

39. Hartman, C., R. Kuppens, D. Schlesinger, *Connected Manufacturing,* 2006, http://www.cisco.com/web/CA/pdf/Cisco_Connected_Manufacturing.pdf
40. Palfrey, J. and U. Gasser, 2012, *Interop. The Promise and Perils of Highly Interconnected Systems,* Basic Books, New York

Figure 5
Exemple: Networks in Manufacturing

Factory 2.0: GE's advanced battery plant "Industrial Internet"

GE Factory in New York

- 170 millon plant, July 2012
- Produces sodium-nickel batteries
- 180,000 aquare feet
- 10,000 sansors connected on Ethernet
- Sansors measure
  - catch number
  - baking temperature
  - energy required to make each bettery
  - local pressure
- Plantion employ as pick up data on Wi-Fi iPads
- $1.5 millons of fine tune machines & connection
- enterprises SW-Internet

Worker productivity increased by 1.5%

$100 m investment; 350 jobs

Drivers and Enabling Forces

Global corporations construct GINs to cope with increasing pressures to internationalize innovation. Ernst (2009) documents the systemic nature of *driving forces.* Specifically, these networks are expected to:

- enable global corporations to increase the return-on-investment for R&D, despite the rising cost, complexity, and uncertainty of R&D;
- facilitate penetration of high-growth emerging markets in compensation for the slow demand growth in core OECD countries;
- accelerate speed to market in line with shorter product life cycles;
- gain access to lower-cost pools of knowledge workers;
- tap into the resources and innovative capabilities of new competitors and emerging new innovation hubs;
- bypass regulations that seek to protect society (especially the losers of globalization) and the environment; and
- perform "regulatory arbitrage", by exploit differences in IPR regimes, incentives, tax laws [especially for transfer pricing], regulations [finance; environment; health].

At the same time, a powerful mix of *enabling factors* facilitates the construction of GINs by reducing uncertainty, as well as transaction and coordination costs. The result has been a rebalancing of the centripetal forces that keep innovation tied to specific locations and the centrifugal forces that place a premium on geographical dispersion. The latter have become more powerful, although the former have hardly disappeared.

There are two root causes of this rebalancing and the resultant increase in the mobility of knowledge: 1) the improvement of the information and communication infrastructure and its extension around the world, and 2) the liberalization of international economic policies that allows this technological change to be exploited more fully by firms and organizational networks. Recent research identifies the following formidable *enabling forces* behind the proliferation of GINs and their increasing diversity[41]:

- Modular design enables vertical specialization, i.e. the progressive slicing and dicing of the innovation value chain
- Liberalization and privatization has created 'deregulated' markets, playing an important role in reducing constraints to the organizational and geographical mobility of knowledge[42]
- ICT-enabled information management has also considerably increased the mobility of knowledge
- Globalizing markets for technology, knowledge workers and innovation finance
- Growing innovative capabilities in emerging economies

Additional powerful *enabling factors* are the progressive globalization of IP protection and standards, as well as new Trade Rules and Dispute Settlement Mechanisms which are currently being negotiated as part of plurilateral and mega-regional trade agreements (TRIPS-Plus; ITA; TISA; TPP; TTIP).

Part Three – Capturing the Gains for Innovation from Global Network Integration

Economic theory still has a long way to go to catch up with the new world of *Ubiquitous Globalization.* As indicated, current policy documents (OECD, WTO, etc) focus primarily on the impact of exports and imports on innovation. This is important, but it only captures one segment of the external impacts on a country's innovation capacity.

41. Ernst, D., 2005, "Complexity and Internationalisation of Innovation: Why Is Chip Design Moving to Asia?" In *International Journal of Innovation Management,* special issue in honor of Keith Pavitt (Peter Augsdoerfer, Jonathan Sapsed, and James Utterback, guest editors) 9(1) (March): 47–73. See also Ernst (2009).
42. Ernst, D., 2005, "The New Mobility of Knowledge: *Digital Information Systems and Global Flagship Networks." In Latham,* R., and S. Sassen, eds. 2005. Digital Formations: IT and New Architectures in the Global Realm. Princeton, NJ, and Oxford: Princeton University Press for the U.S. Social Science Research Council.

New Approaches

However, new approaches are beginning to emerge that help to extend the analysis beyond trade. The E-15 *Initiative* for instance, established in cooperation with the *World Economic Forum* and supported among others by the *Dutch Government,* explores options for strengthening the governance and functioning of the multilateral trade system. Specifically on Trade and Innovation, E-15 has published widely circulated *Policy Think Pieces* that move the debate well beyond the narrow confines of established trade theory[43].

In addition, new research agendas pursued by trade economists can help to address the impact of ubiquitous globalization. Important contributions are Robert Feenstra's analysis of Integration of Trade and Disintegration of Production in the Global Economy[44], and Lee Branstetter's pioneering work on the role of FDI as a channel of knowledge spillovers[45]. More recently, Richard Baldwin and colleagues have broadened the analysis to include the "Trade-investment-service-IP nexus"[46] – a long overdue breakthrough! For Baldwin, "

> *"Trade in today's world is radically more complex. The information and communications technology revolution has internationalized supply chains, which has created a tight supply-side linkage between trade and FDI: the "trade–investment–service– IP nexus". Today's international commerce comprises complex, two-way flows of goods, services, people, ideas and investments in physical, human and knowledge capital – in addition to trade in raw materials and final goods. These connections make it almost irrelevant to talk about trade without also talking about FDI – at least for many products and markets….As a result, … trade and investment are neither complements nor substitutes – they are simply two facets of a single economic activity: international production sharing."*[47]

Research on GPNs and GINs can benefit from these new insights in policy-related trade theory. Some of the analytical tools provided by Feenstra, Branstetter, Baldwin

43. Examples include Karachalios, K. and K. McCabee, 2013, *Standards, Innovation and their Role in the Context of the World Trade Organization;* and Ernst, D., 2014, *The Information Technology Agreement, Industrial Development and Innovation - India's and China's Diverse Experiences.*
44. Feenstra, R., 1998, "Integration of Trade and Disintegration of Production in the Global Economy", *Journal of Economic Perspectives,* 12(4): 31-50; and Feenstra, R., 2008, *Offshoring in the Global Economy,* Ohlin Lectures, presented at the Stockholm School of Economics, September.
45. Branstetter, L., 2006, "Is Foreign Direct Investment a Channel of Knowledge Spillovers: Evidence from Japan's FDI in the United States," *Journal of International Economics,* vol. 68, February 2006, pp. 325-344.
46. Baldwin, R., 2013, "Global supply chains: why they emerged, why they matter, and where they are going", chapter 1 in: D.K. Elms and P. Low, eds.,2013, *Global value chains in a changing world,* WTO, Geneva: pages 13 -60; Baldwin, Richard and J. López González (2013) "Supply-Chain Trade: A Portrait of Global Patterns and several testable hypotheses" NBER Working Paper 18957 http://www.nber.org/papers/w18957.pdf;
47. Baldwin, R. 2013, "The New Relevance of FDI: The GVC Perspective", in World Economic Forum, *Foreign Direct Investment as a Key Driver for Trade, Growth and Prosperity. The Case for a Multilateral Agreement on Investment*, Geneva: p.13.

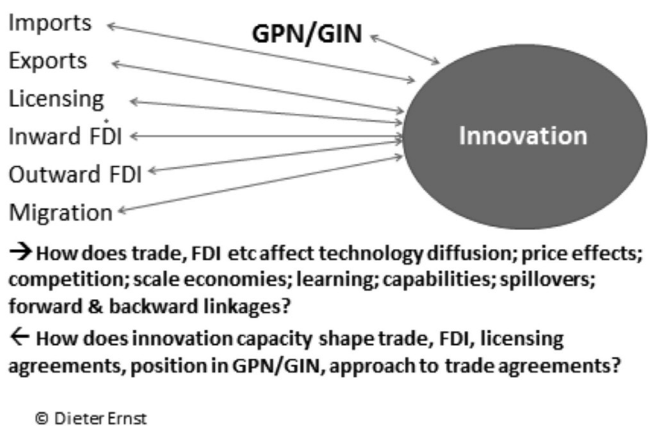
and others, should make it easier to measure the scope and depth of these global networks, and their increasing diversity. These analytical tools might also provide better insights into differences in network structure across industries, and crucially between manufacturing, professional services and natural resources.

Drawing on these new analytical tools, research on GPNs and GINs can shed new light on the impact of these networks on the geographic distribution of innovation. It is possible to conceptualize GPNs and GINs as institutional innovations that seek to bundle, coordinate and rationalize the multiple linkages and impacts of Baldwin's "Trade-investment-service-IP nexus".

As illustrated in Figure 6, it is time to examine the other side of the Trade, FDI and Innovation link. In order to capture the gains for innovation that regions like Brabant might reap from global network integration, research should move from a *one-way analysis of the external impacts* on a region's innovation to an analysis of two-way interactions.

Figure 6

Trade, FDI and innovation—linkages and impact



A central proposition of this paper is that future research should provide guidance for regional policy on two broad *strategic challenges:*

- *How does a region's innovation capacity in a particular industry affect the type of exports and imports it can realize, the licensing agreements it can negotiate, and the volume and sophistication of inward and outward FDI?*
- *And how does a region's innovation capacity in a particular industry affect its approach and position in multilateral and plurilateral trade agreements?*

To provide policy-relevant insights on the above strategic challenges, it is necessary, first, to open the black box of "innovation" in order to understand precisely what type of innovation strategy might be required. Second, future research should revisit in quite some detail what we know about the distribution of gains for innovation from global network integration.

Opening the "Black Box" – Innovations Differ

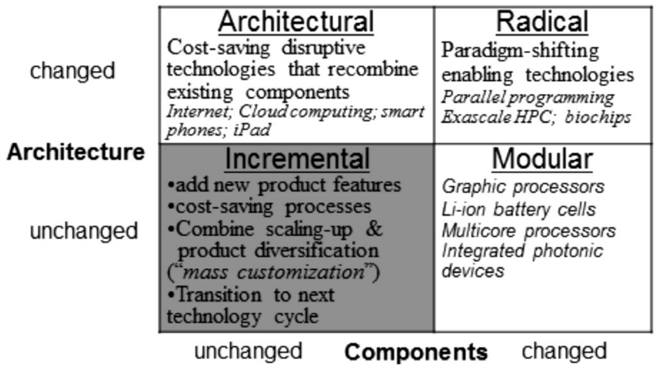
A fundamental insight of innovation theory is that learning and innovation are "the two faces of R&D" (Cohen and Levinthal 1989: 569). Learning by doing establishes routines: "The firm becomes more practiced, and, hence, more efficient, at doing what it is already doing" (ibid.: 570). But a firm's growth depends on a second type of learning ("absorptive capacity"), by which a firm acquires external knowledge "that will permit it to do something quite different."

For an effective conversion of knowledge to productive learning, two important elements are required: an existing knowledge base or competence and an intensity of effort or commitment[48]. In fact, a critical prerequisite for absorptive capacity is that a firm conducts basic research in-house. This differs from the current fashion of "open innovation"[49], which downplays the importance of a decline in corporate basic research. Cohen and Levinthal (1989) demonstrate that a firm needs to sustain a critical mass of internal basic research "to be able to identify and exploit potentially useful scientific and technological knowledge generated by universities or government laboratories, and thereby gain a first-mover advantage in exploiting new technologies."[50] The same is true for "spill-overs from a competitor's innovation."

In short, R&D is critical to strengthen the absorptive capacity of a region or a firm. However, the requirements for absorptive capacity evolve over time, as a country, a region or a firm moves up from catching-up to upgrading and leadership strategies of innovation. This raises the question: Precisely what type of innovation strategy is needed when and where?

48. Ernst, D., and Linsu Kim. 2002. "Global Production Networks, Knowledge Diffusion and Local Capability Formation." *Research Policy,* special issue in honor of Richard Nelson and Sydney Winter, 31(8/9): p.1425
49. See Chesbrough, H. W. 2003. *Open Innovation. The New Imperative for Creating and Profiting from Technology.* Cambridge, MA: Harvard Business School Press.
50. Cohen, W. M., and D. A. Levinthal. 1989. "Innovation and Learning: The Two Faces of R&D." *The Economic Journal* 99 (September): p. 593.

Figure 7
Innovation differ—complexity & capability



Henderson and Clarck, 1990; Ernst, 2009 & 2014

Innovations differ with regard to opportunities and barriers to learning; they also differ in the capabilities that a firm needs to implement a particular type of innovation. It is useful to distinguish between *incremental, modular, architectural,* and radical innovations (Figure 7)[51].

Incremental Innovations

Incremental innovations take both the dominant component design and architecture for granted, but improve on cost, time-to-market, and performance. Their purpose is to exploit to the greatest extent possible the potential of a given design by introducing relatively minor changes to an existing product or process[52]. These innovations do not require substantial inputs from science, but they do require considerable skill and ingenuity, especially complementary "soft" entrepreneurial and management capabilities[53].

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51. For the original taxonomy, see Henderson, R. M., and K. B. Clark. 1990. "Architectural Innovation: The Reconfiguration of Existing Systems and the Failure of Established Firms." *Administrative Science Quarterly,* March: 9–30. For an adaptation of the taxonomy to highlight differences in capability requirements, see Ernst, D., 2008, "Can Chinese IT Firms Develop Innovative Capabilities Within Global Knowledge Networks?", in Hancock, Marguerite Gong, Henry S. Rowen, and William F. Miller, eds.. *China's Quest for Independent Innovation.* Shorenstein Asia Pacific Research Center and Brookings Institution Press, Baltimore, MD. The boundaries between these four types of innovation are fluid. For instance, incremental and radical innovations are about the extent of changes caused by innovation, while modular and architectural innovations are about where the change is happening. They could therefore overlap.
52. Nelson, R. R., and S. G. Winter. 1982. *An Evolutionary Theory of Economic Change.* Cambridge, MA: The Belknap Press.
53. As defined in Ernst, D., 2007, "Beyond the 'Global Factory' Model: Innovative Capabilities for Upgrading China's IT Industry." *International Journal of Technology and Globalization* 3(4): 437–60; and Ernst (2009): chapter Two.

Examples of incremental innovations are improvements of products (adding new product features); cost-saving processes; design changes that allow for "mass customization" by combining scaling-up and product diversification; and organizational adjustments that facilitate the transition to the next technology cycle. Barriers to incremental innovations are relatively low, as tools and methodologies are familiar and investments tend to be limited and predictable. Most importantly, incremental innovations build on existing operational and engineering skills as well as the management of supply chains, customer relations, and information systems.

Modular innovations

Modular innovations introduce new component technology and plug it into a fundamentally unchanged system architecture. They have been made possible by a division of labor in product development: "Modularity is a particular design structure, in which parameters and tasks are interdependent within units (modules) and independent across them"[54].

Examples of modular innovations include the development of graphic processors, Li-ion battery cells, multicore processors, and integrated photonic devices. The barriers to producing such modular innovations are substantial. High technological complexity requires top scientists and experienced engineers in various fields. In addition, investment requirements can be very substantial (more than U.S.$ 5 billion for a state-of-the-art semiconductor fabrication plant), as are risks of failure.

Architectural innovations

Architectural innovations use existing component technologies but change the way they work together. Examples include cost-saving disruptive technologies that recombine existing components, such as the Internet, smart phones, tablets, and cloud computing (which however might also be subsumed under radical innovations).

A defining characteristic of *architectural innovations* is a capacity to leverage a deep understanding of market and user requirements in order to break new ground in product development. This implies that architectural innovations require strong system integration and strategic marketing capabilities, but they are much less demanding than modular and especially radical innovations in terms of their needs of science inputs and investment thresholds.

54. Baldwin, C. W., and K. B. Clark. 2000. *Design Rules: The Power of Modularity.* Cambridge, MA: MIT Press: p. 88

At the same time, however, architectural innovations tend to have far-reaching implications for the market share and the profitability of innovating firms. As highlighted by Henderson and Clark (1990: 9), architectural innovations can threaten incumbent market leaders; they "destroy the usefulness of the architectural knowledge of established firms, and since architectural knowledge tends to become embedded in the structure and information-processing procedures of established organizations, this destruction is difficult for firms to recognize and hard to correct."[55]

Radical innovations

Finally, radical innovations involve both new component technology and changes in architectural design. Examples include paradigm-shifting enabling technologies, such as *Parallel programming, Exascale High-Performance Computing, and biochips*[56]*.*

The great attraction of radical innovations is that once they have generated intellectual property rights for a blockbuster technology, the innovating firm may become a market leader in a short period of time. The flip side, however, is that "radical innovations require breakthroughs in both architectural and component technology. Radical innovations require dense interaction with leading-edge science, requiring top scientists and engineers who work at the frontier of basic and applied research in a broad range of disciplines. In addition, implementing radical innovations requires a broad set of complementary assets[57], and investment thresholds tend to be extreme.

In short, radical innovations are costly and risky, and failure can destroy even large, well-endowed companies. They are beyond the reach of most companies, but they may well be the subject of public-private consortia coordinated by a regional government in coordination with the central government[58].

Distribution of Gains for Innovation from Global Network Integration

Research on Asia's innovation offshoring hubs finds ample opportunities for knowledge diffusion and learning through global network integration. That research shows that foreign R&D centers can act as important catalysts for accelerated learning and capability development. Interviews with foreign affiliates of global corporations as well as with independent Asian network suppliers indicate that integration into global

55. Henderson and Clark (1990) use the decline of Xerox and RCA to illustrative the destructive power of architectural innovations.
56. National Research Council, 2012, *The New Global Ecosystem in Advanced Computing: Implications for U.S. Competitiveness and National Security,* The National Academies Press, Washington, D.C.
57. As defined by Teece, D. 1986. "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy." *Research Policy* 15(6) (December): 285–305.
58. For further discussion, see Part Four – Policy Implications

innovation networks can improve access to state-of-the-art innovation management practices, tools, ideas, and opportunities for innovation[59].

A look at earlier research on knowledge diffusion through global production networks explains why this is so. Ernst and Kim (2002) find that global corporations that act as "network flagships" "transfer both explicit and tacit knowledge to local suppliers through formal and informal mechanisms[60]. This is necessary to upgrade the local suppliers' technical and managerial skills so that they can meet the flagships' specifications." Furthermore, "once a network supplier successfully upgrades its capabilities, this creates an incentive for flagships to transfer more sophisticated knowledge, including engineering, product and process development" (ibid.: 1422).

This reflects the increasingly demanding competitive requirements, especially in R&D-intensive sectors of the electronics industry, which are exposed to intense price competition from a very early stage in their product life cycle[61]. Competition in these industries is driven by the speed of new product introduction, with the result that product life cycles become shorter and shorter. Only those companies that succeed in bringing new products to the relevant markets ahead of their competitors will thrive. Of critical importance for competitive success is that a firm can build specialized capabilities quicker and at a lower cost than its competitors[62].

No firm, not even a global market leader like IBM, can mobilize internally all the diverse resources, capabilities, and bodies of knowledge that are necessary to fulfill this task. As a consequence, global firms increasingly "externalize" both the sources of knowledge and its use. They outsource knowledge needed to complement their internally generated knowledge, and they license their technology to enhance the rents from innovation.

For many high-tech companies, competing for scarce global talent thus has become a major strategic concern. Global sourcing for knowledge workers now is as important as global manufacturing and supply chain strategies. The goal is to diversify and optimize a company's human capital portfolio through aggressive recruitment, especially in emerging Asia's lower-cost-labor markets. Over time, global firms realize that, in order to retain these knowledge workers, it is necessary to

59. For instance, Chang, Shih, and Wei (2006) find that exposure to state-of-the-art innovation management practices of global R&D operations can improve innovation management in Taiwan firms and force them to be "more innovative." And Shin-Horng Chen (2006: 15) shows that the R&D intensity of foreign-owned affiliates in Taiwan's manufacturing industry has increased from 1.5 percent in 2002 to 1.9 percent in 2003. Chen argues that foreign-owned subsidiaries with high export intensity and which rely on Taiwanese original equipment manufacturing/original design manufacturing suppliers "may need to devote more effort to R&D in order to effectively interact with their local suppliers" (ibid: 16). In turn, this requires that domestic R&D has reached a critical threshold so that it can "serve as a complement to, rather than a substitute for, the R&D activities of foreign affiliates."

60. Ernst, D., and Linsu Kim. 2002. "Global Production Networks, Knowledge Diffusion and Local Capability Formation." *Research Policy,* special issue in honor of Richard Nelson and Sydney Winter, 31(8/9): page 1417.

61. Ernst, D., 2002, "The Economics of Electronics Industry: Competitive Dynamics and Industrial Organization", In Lazonick, William, ed. , *The International Encyclopedia of Business and Management* (IEBM), *Handbook of Economics.* London: International Thomson Business Press.

62. Kogut, B., and U. Zander. 1993. "Knowledge of the Firm and the Evolutionary Theory of the Multinational Corporation." *Journal of International Business Studies* 24(4): 625.

transfer exciting projects to the new locations in Asia that provide opportunities for learning and knowledge sharing.

All of this implies that innovation systems of global corporations are being opened to outsiders, at least in a few select areas. There are concerns however that integration into global innovation networks may be a *poisoned chalice*. It is feared that, apart from a few prestige projects that might provide limited short-term benefits, R&D by global corporations may not provide the means for upgrading the host country's industry to higher value-added and more knowledge-intensive activities.

Foreign R&D centers often intensify competition for the limited domestic talent pool, leaving domestic companies at the sidelines. Inward R&D by global industry leaders may also give rise to a reverse "boomerang effect," providing global firms with precious insights into business models and technologies developed by domestic firms. Furthermore, foreign R&D centers typically show limited interest in sharing knowledge with domestic firms and R&D labs. In addition, as global competition is centered increasingly on the development of superior knowledge, "intellectual property" (the commercial embodiment of knowledge) will become more and more intensely guarded[63].

On a more fundamental level, recent research has raised doubts that participation in modular global networks will automatically enhance the innovation capacity of global network participants[64]. For instance, Chesbrough's dynamic theory of modularity demonstrates that, if a firm fails to adjust its organization and innovation management to the requirements of the new architecture, it risks being caught in a ''modularity trap''. In other words, if a firm focuses too much on developing products within given interface standards, this may erode the firm's system integration capabilities. A ''modularity trap'' exists, when flagships fail to retain those system integration capabilities that are necessary to incorporate new (interdependent) component technologies effectively into their systems[65]. Chesbrough's ''modularity traps'' quite often reflect fundamental conflicts of interest that separate for instance a global system player and its modular suppliers of manufacturing and design services. The dilemma facing a system player is that the more system technology he gives away to his suppliers, he may get better and cheaper products. But, at the same time, he may experience a substantial loss in the control that he can exercise over his suppliers.

In a study on the limits to modularity in chip design, Ernst (2005) finds that "…[i]t is …difficult to sustain the assumption, implicit in much of the modularity literature, that modularity is the stable end state of industry evolution, and that this is true across industries and technologies. While modular design has acted as a powerful catalyst for changes in business organization and industry structure, limits to mo-

63. Chen, Tain-jy. 2004. "The Challenges of the Knowledge-Based Economy." In Chen, Tain-jy, and Joseph S. Lee, eds. 2004, The New Knowledge Economy of Taiwan. Cheltenham: Edward Elgar.
64. The following draws heavily on Ernst, 2005, "Limits to Modularity: Reflections on Recent Developments in Chip Design." *Industry and Innovation* 12(3): 303–35.
65. Chesbrough, H. W. (2003b) Towards a dynamics of modularity. A cyclical model of technical advance, in: A. Pren-

dularity are aplenty, and constrain the convergence of technical, organizational and market modularity."[66] Specifically, two limits to knowledge sharing within modular networks are identified: (a) demanding coordination requirements; and (b) constraints to interface standardization.

(a) Demanding Coordination Requirements of GINs

As Pavitt (1999) has convincingly argued, activities that require complex knowledge pose very demanding coordination requirements[67]. There are cognitive limits to the process of modularization. Important differences exist between the coordination requirements of ''project execution'' (to design and produce an artifact, e.g. a chip) and of ''technology development'' (to produce the underlying knowledge bases)[68].

Baldwin and Clark (2000: ch. 3) correctly emphasize that modularity in design has created opportunities for vertical specialization (combining disintegration and geographic dispersion) in project execution. Their analysis however neglects the increased knowledge exchange that is necessary to develop design and manufacturing technologies. This, in turn, requires ex ante coordination through integration in technology development. Modular product design thus needs knowledge-integrating firms to coordinate specialized bodies of knowledge and increasingly distributed learning processes. It does not reduce the need for system integration.

In other words, modular product design may well increase complexity and hence the need for system integration. Large global network flagships retain diversified technology bases precisely to cope with the demanding coordination requirements of disintegrated and geographically dispersed technology development.

(b) Constraints to Interface Standardization

A surprising feature of modular systems is their considerable rigidity. Once deployed, interface standards are difficult to adjust. When performance gains from a particular design architecture approach a limit, it becomes necessary to establish a new architecture. But a defining characteristic of modular systems is that any transition to a new generation of design architecture requires fundamental changes in system components, which consequently will break down established interface standards[69].

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66. Ernst, D., 2005, "Limits to Modularity: Reflections on Recent Developments in Chip Design." *Industry and Innovation* 12(3): 303–35.
67. Pavitt, K., 1999, *Technology, Management and Systems of Innovation,* Edward Elgar, Cheltenham: p.XX
68. See for instance Brusoni, S., 2003, "Authority in the Age of Modularity", SPRU *Electronic Working Paper Series,* No. 101, The Freeman Centre, University of Sussex, June; and Tokumaru, Norio, 2004, "Codification of Technological Knowledge, Technological Complexity, and Division of Innovative Labour", in J.H. Finch and M. Orrillard, eds., *Complexity and the Economy: Implications for Economic Policy,* Edward Elgar.
69. Chesbrough,. H.W., 2003, "Towards a Dynamics of Modularity. A Cyclical Model of Technical Advance", in: Prencipe, A., A. Davies and M. Hobday, eds, The Business of Systems Integration, Oxford: Oxford University Press.

Chip design provides an important example of the tight limits to interface standardization. Based on standard interfaces and design rules, the division of labor used to be reasonably simple during much of the 1990s. The resulting separation of chip design and fabrication has been one of the favorite examples of modularization proponents. Engineers designed chips and handed the definition to the mask makers, who then sent the masks to the wafer manufacturers (the silicon foundries). And (most of the time, at least) the result of having this modular division of labor was a chip that could be manufactured at an acceptable yield.

However, this easy phase of modularization of the semiconductor industry has vanished for good. As process technology has dramatically increased in complexity, intense interactions are required across all stages of the semiconductor value chain, and it is no longer possible to work with entrenched standard interfaces and design rules. All participants in the semiconductor industry know that they need to find a way to organize collective and integrated solutions. They also know that uncertainty makes this extremely difficult, as does the fact that the industry is now vertically specialized[70].

Why Modular Global Networks may Impede Innovation

The Taiwanese PC industry provides an example where participation in GPNs and GINs has impeded rather than fostered their innovation capacity. In a recent still unpublished paper, Tain-Jy Chen and Ying-Hua Ku highlight two *pitfalls of modular production* in global networks: an u*nequal power structure and fragile inter-firm relations*[71].

Power Structure

According to Chen and Ku, network flagships seek to incorporate new technologies in such a way that the power structure of the system is maintained. In the PC industry, "the architecture is controlled by two dominant component suppliers rather than branded companies or manufacturers. Intel and Microsoft reap most of the rents of the modular system, which, in turn, allow them to invest in new technologies to maintain the system. They continuously invent new components to upgrade the power of the architecture. However, their inventions mostly belong to cumulative innovations rather than disruptive innovations. The architecture itself is a barrier to disruptive innovations as such innovations may lead to a loss of coordination power embedded within the architecture." (Chen and Ku: p.6)

70. Recently, however, attempts to avoid being trapped by prematurely frozen design parameters have led to new approaches to improve the flexibility of SoC design, for instance, through reconfigurable processors. But it remains to be seen how viable these new approaches will be.

71. Chen, Tain-Jy and Ying-Hua Ku, "Pitfalls of Modular Production: The case of Taiwan's PC industry, unpublished paper, Department of Economics, National Taiwan University, Taipei: 36 pages.

Inter-firm Relations

Because of the openness and low entry barriers of modular networks, Chen and Ku argue that relational assets embedded in a modular system are very fragile. According to Dyer and Singh (1998), when components can be designed in isolation, information sharing becomes unnecessary and, therefore, the value of relational assets evaporates[72]. In a modular system, there is thus little relation-specific knowledge to be accumulated. As a result, "it may even be more advantageous to collaborate with non-network members in making innovations because such innovations are not subject to the constraints of the architecture. Furthermore, the extra-network innovations may be more valuable to network members because they are free from rent-extraction by flagship companies. Expressed metaphorically, a modular system is conducive to 'extra-marital' affairs." (Chen and Ku: pages 6 and 7)

In short, limits to modularity provide powerful arguments for skepticism that participation in modular global networks will automatically enhance the innovation capacity of global network participants. An important insight of the above research is that the deeper a region is integrated into global networks, the more important are policies to strengthen local networks. Public policies are required in order to enhance the capacity of companies within a region to reap the hidden potential gains for innovation from global network integration. Some of the policy issues raised by this analysis are addressed in the last part of the paper.

Part Four - Policy Implications

Based on the paper's analysis of the dynamics of global innovation networks and the gains for innovation from trade and global network integration, what policy options are available for upgrading a region's innovation capacity?

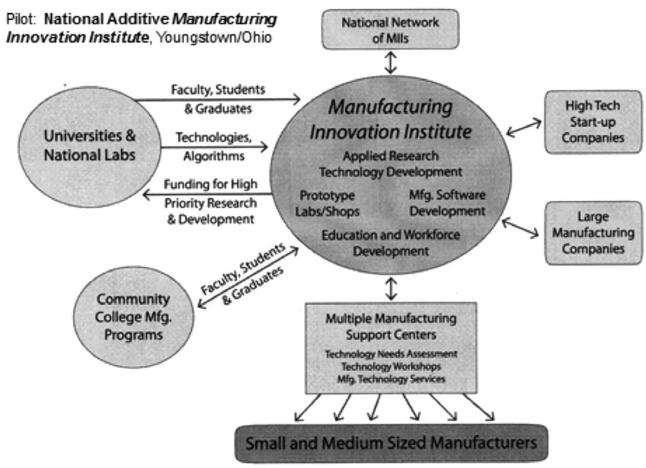
First and foremost, it is necessary to acknowledge that, while integration into GINs can accelerate the development of the region's innovation capabilities, it can also act as a *Poisoned Chalice.* In order to avoid being marginalized in these global networks, policies need to be in place to address *unintended negative consequences of global network integration.* For instance, foreign affiliates may succeed in recruiting the best talent, leaving domestic companies at the sidelines. In addition, foreign affiliates may be interested primarily in "tapping into the local knowledge base" when they invest in R&D labs in the region, which may erode the region's "Industrial Commons"[73]. Furthermore, policies need to be in place to counter significant challenges to Privacy and Cyber-Security.

72. Dyer, J.H. and H. Singh, 1998, "The Relational View: Cooperative Strategy and Sources of Inter-organizational Competitive Advantage", *Academy of Management Review,* 23(4): 660-679.
73. As analyzed in Pisano, G. and W. Shih, 2012, *Producing Prosperity: Why America Needs a Manufacturing Renaissance.* Boston, MA: Harvard Business Review Press.

Second, it is important to emphasize the systemic nature of policy responses. In order to strengthen a region's *Absorptive Capacity,* it is necessary to coordinate regional policies with trade, FDI and innovation policies. These policies need to be broad-based, and should encompass regulations; investment promotion; R&D tax credits; industrial support policies to foster firm-level managerial and technological capabilities; patient innovation finance; standard development and certification; industrial collective research consortia; industrial associations and research centers; university-industry collaborations; and trade diplomacy.

Systemic policy responses are particularly important if the objective is to foster *radical innovations*. As described in Part Three, radical innovation are beyond the reach of most companies. Radical innovations thus require public-private consortia coordinated by a regional government in coordination with the central government. Figure 8 highlights an example of a private-public consortium that originated from the US Advanced Manufacturing Partnership program (AMP), the National Additive Manufacturing Innovation Institute in Youngstown/Ohio, established as part of a planned US National Network of Manufacturing Innovation Institutes (NNMIIs)[74].

Figure 8



Source: AMP Steerina Commitee

Third, *flexible policy implementation* is critical. A broad portfolio of diverse policy approaches is required to enable regions to increase the gains from global network integration. The mix of policies will differ across sectors, sub-sectors and sub- regions. And the appropriate policy mix will have to evolve over time.

74. Hart, D. M., S.J. Ezell, R.D. Atkinson, 2012, "Why America Needs A National Network for Manufacturing Innovation", http://www2.itif.org/2012-national-network-manufacturing-innovation.pdf

Europe's current eighth Framework Program, the so-called Horizon 2020 program , provides a new policy approach, called *"Smart Specialization"* that may provide guidance for greater flexibility in policy implementation. In essence, the concept of *"Smart Specialization"* seeks to develop a more *bottom-up* approach to industrial policy that focuses on 'entrepreneurial discovery' - an interactive process in which market forces and the private sector are expected to discover and produce information about new activities and the government assesses the outcomes and empowers those actors most capable of realizing the potential[75].

In essence, the concept of "smart specialization" seeks to transform industrial policy into an "interactive process": *"Prioritisation is no longer the exclusive role of the state planner (top down) but involves an interactive process in which the private sector is discovering and producing information about new activities and the government provides conditions for the search to happen, assesses potential and empowers those actors most capable of realizing the potentials. But entrepreneurship in the knowledge economy recognises that value added is also generated outside sole ownership, in spillovers, in networks of complementarity and comparative advantage."* (OECD, 2013:p.18)

In short, the focus of public policy shifts from the selection of priority sectors and areas for public investment to the *facilitation of the joint process of discovery* ("e.g., by providing incentives, removing regulatory constraints" (OECD, 2013: p. 20).

Fourth, it is important to find ways to neutralize the constraints for regional innovation policy that result from reduced national budgetary support due to austerity policies. As emphasized in the TNO paper on *Brainport Eindhoven* by Frans A.van der Zee, "… [a]n important challenge is to overcome existing barriers to really innovate… [by]… increasing public investment in the Brainport region. This especially applies to boosting public R&D expenditure."[76]

In a situation characterized by low demand, falling tax revenue, and fiscal pressures to reduce budget deficits and the national debt, the concept of "Smart Specialization" claims to provide "…a novel avenue to pursue the dual objectives of fiscal constraint and investment in longer-term growth … through innovation."(OECD, 2013: p.23) Yet, there is reason to be skeptical whether such expectations are more than just pipedreams.

In fact, the afore-mentioned Brainport report by TNO demonstrates negative effects of budget cuts at the national level: "The decision at national level to stop re-

75. OECD, 2013, *Innovation-driven Growth in Regions: The Role of Smart Specialisation. Preliminary Version,* OECD, Paris. It is interesting to note a certain similarity of the *Smart Specialization* idea with concepts used by the U.S. Defense Advanced Research Projects Agency (DARPA). See Jordan, L.S. and K. Koinis, 2014, *Flexible Implementation: A Key to Asia's Transformation, East-West Center Policy Studies series,* No.70, March. In addition, much of the underlying philosophy seems to draw quite extensively on Albert O. Hirschman's early attempt to place private business owners at the center of information gathering and strategy design. (See Hirschman, A .O., 1958, *The Strategy of Economic Development, New Haven, Conn.: Yale University Press.)*

76. van der Zee, F.A., no date, Case 4.- *Netherlands, Brainport Eindhoven: 'Top Technology region Spreading its Wings'*, TNO : page 3.

gional development support by abolishing the 'Peaks in the Delta' (PiD)-programme brings important challenges for the funding (matching) and the scope of future activities, which not only affect regional development programmes, but also the regional development agencies such as the BOM in North-Brabant and LIOF in Limburg." (van der Zee, n.d.: page 3)

Fifth, an important unresolved policy issue is that the Advanced Manufacturing technologies described in Part One of the paper, provide much less *direct* employment effects than the current manufacturing model. Empirical research demonstrates that ICT and other enabling and emerging technologies reduce direct labor requirements of manufacturing[77]. For the US, Pisano and Shih find:" Manufacturing now accounts for only about one in ten American jobs. With increasing productivity,…it is hard to imagine how manufacturing could ever return to the days when it employed about a quarter of the US workforce."[78]

In the US, recent research has identified the following mechanisms for creating *quality spillover employment effects* of advanced manufacturing:

a. by integrating manufacturing, services and innovation[79]. Manufacturing services proliferate and are an important source for quality jobs. Successful firms thus can use transformative technologies to provide packaged solutions.
b. in downstream and upstream industries
c. in smart digital infrastructure platforms[80].

Sixth, in Europe like in the US the debate about inequalities is heating up, at two levels: geographical (rich versus poor regions) and individual (those included in prosperous developments and those being marginalized). Especially the rich – poor regions issue is important in view of how best to spend a significant amount of regional investment money in less developed regions. In short, regional policy is confronted again with the perennial question raised in the earlier debate between Ragnar Nurkse and Albert O. Hirschman about the trade-offs between balanced and unbalanced growth[81].

Hirschman's concept of "Development as a Chain of Disequilibria" highlights the importance of s strategy that seeks to create a "success breeds success" scenario. In addition, a simple Stylized Model demonstrates why regions may differ in their capacity to reap the gains from trade for innovation.

77. Shipp, S.S. et al, 2012, *Report on Emerging Global Trends in Advanced Manufacturing,* Institute for Defense Analyses-Science Technology Policy Institute (IDA-STPI), Washington, D.C.
78. Pisano, G. and W. Shih, 2012, *Producing Prosperity.Why America Needs a Manufacturing Renaissance,* Harvard Business School Press
79. National Academy of Engineering, 2012, *Making Value: Integrating Manufacturing, Design and Innovation,* The national Academies Press, Washington, D.C.
80. Smart industrial infrastructure platforms which create quality jobs may include for instance: broadband enabled new applications (e.g., cloud computing); 4G wireless communications; integrated health information systems; Smart electric grids; Low carbon energy information systems; Intelligent transportation systems; Mobile payments systems; and Mobile Collaborative Learning Systems. Atkinson, R. and S. Ezell, 2012, *Innovation Economics.The Race for Global Advantage,* Yale University Press.
81. Nurkse, Ragnar (1961). *Problems of Capital Formation in Underdeveloped Countries.* New York: Oxford University

Suppose Region A (the "innovator") possesses all the necessary prerequisites for reaping the gains from trade for innovation, as described in this paper. Region B, on the other hand is a relative latecomer. Region B thus lags behind Region A in the strength of its institutions and policies, its market size and sophistication, and the managerial and technological capabilities of its firms. As a result, Region B will also occupy a lower-tier position in global networks, and hence will be in a much weaker position than Region A to reap the gains from trade for innovation.

For policy-making, this raises two questions:

- Under these conditions, what would need to happen so that Region B can gradually catch up with Region A?
- What kind of linkage effects between Region A and Region B would need to be in place so that conditions are ripe for a "success breeds success" scenario where productivity-enhancing innovation in Region A produces positive spill-over effects in region B?

Seventh, another unresolved policy issue relates to important changes in International Trade rules. Regions face a fundamental dilemma: In order to reap the benefits of GPN/GIN integration, both the central government and the regional governments need to put in place robust and increasingly sophisticated innovation and industrial policies. In the future, these policies need to address the following issues:

- Is the scope for such policies being enhanced or constrained by increasingly strict trade rules as part of plurilateral and mega-regional trade agreements? [TTIP;TPP; ITA; TISA]
- The spread of GPNs/GINs has increased the role of business services. There is increasing pressure to move beyond GATS and to develop a much more demanding Trade in Services Agreement (TISA) that would impose much greater discipline on national and regional industrial and innovation policies.
- Will TTIP establish "Investor-State Dispute Settlement" to replace the WTO State-to-State Dispute Settlement Mechanism, and how will this affect the scope for national and regional industrial and innovation policies?[82]
-

Eighth, a final thought: As emphasized in the above TNO Brainport report, upgrading and scaling up in a region "… implies looking beyond borders" (van der Zee, n.d.: p.5). The TNO report focuses on inter-regional collaboration, "especially in R&D and innovation, with IMEC and Holst Centre as best practice examples."

But, as we have seen, regions around the globe are progressively integrated across national borders into global networks of production and innovation. Brabant is no different, and thus might find it useful to ask: Are there lessons to be learnt from the contrasting experiences in other countries?

82. Some observers claim for instance that, as part of TTIP, businesses might now be in a position to sue governments in special Arbitration Panels (e.g. the International Centre for Settlement of Investment Disputes [ICSID]) for legislation that businesses considers not to be "fair and equitable treatment".

- The US innovation system is strong for start-ups that are in their early stages of development. But it fails to provide incentives & support for scaling-up innovation ("The American company stands alone"[83])
- Taiwan (Low-cost & fast innovation in manufacturing services; Multi-layered industrial dialogues)
- China (Massive investments in the country's R&D infrastructure and Higher Education have been fast-tracking the speed of learning and capability development; low-cost up-scaling of manufacturing).

83. Berger, S., 2013, ."Lessons in Scaling from Abroad: Germany and China", in S. Berger, *Making in America. From Innovation to Market* (Cambridge, MA: The MIT Press).

About Dieter Ernst

Dieter Ernst, an East-West Center senior fellow, is an authority on global production networks and the internationalization of research and development in high-tech industries, with a focus on standards and intellectual property rights. Dr. Ernst is the co-founder, together with Michael G. Plummer (Johns Hopkins University SIAS, Bologna) of the agenda-setting East-West Center New Challenges for Trade and Innovation Workshop series focusing on the impact of trade agreements on trade and innovation in Asia. His research examines corporate innovation strategies and innovation policies in the United States and in China, India, and other emerging economies. The author has served as a member of the United States National Academies "Committee on Global Approaches to Advanced Computing"; senior advisor to the Organisation for Economic Co-operation and Development (OECD), Paris; research director of the Berkeley Roundtable on the International Economy at the University of California at Berkeley; professor of international business at the Copenhagen Business School; and scientific advisor to governments, private companies, and international institutions.

Dr. Ernst's recent public talks include "Standardization, International Trade and Government Policies, IEEE-SIIT 9th International Conference on Standardization and Innovation In Information Technology, San Jose, California, October 6 and 7, 2015; Keynote address: Innovation in Global Networks – The Challenge for Technical Standards and Related Policies, Department of Commerce- NIST workshop Supply Chain Operations, Strategy, and Infrastructure Development in a Global Economy, Georgetown University, May 18-19; and "Global Strategic Patenting and Innovation – Policy and Research Implications", Six Countries Program conference "40 Years of Innovation Policy: What's Next?", House of Research, Vienna, March 24-25, 2015, available as East-West Center Working Papers: Innovation and Economic Growth Series, No. 2.

His publications include Standards, Innovation, and Latecomer Economic Development: Conceptual issues and policy challenges" (2014); Trade and Innovation in Global Networks – Regional Policy Implications (2014); The Information Technology Agreement, Industrial Development and Innovation - India's and China's Diverse Experiences (2014); Upgrading India's Electronics Industry – Regulatory Reform and Industrial Policy (2014); Industrial Upgrading through Low-Cost and Fast Innovation—Taiwan's Experience (2013); America's Voluntary Standards System: A "Best Practice" Model for Asian Innovation Policies (2013); Entry on "Production and innovation networks, global" *(Encyclopedia of global studies, 2012)*; Indigenous Innovation and Globalization: The Challenge for China's Standardization Strategy (2011; also published in Chinese); China's Innovation Policy Is a Wake-Up Call for America (2011); A New Geography of Knowledge in the Electronics Industry? Asia's Role in Global Innovation Networks (2009): Can Chinese IT Firms Develop Innovative Capabilities within Global Knowledge Networks? (2008); China's Emerging Industrial Economy: Insights from the IT Industry (with Barry Naughton, 2007); Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks (2006); Complexity and Internationalization of Innovation: Why is Chip Design Moving to Asia? (2005); "Limits to Modularity - Reflections on Recent Developments in Chip Design" (2005); Global Production Networks, Knowledge Diffusion and Local Capability Formation (with Kim Linsu, 2002)*;* International Production Networks in Asia: Rivalry or Riches? (2000); and Technological Capabilities and Export Success: Lessons from East Asia (1998).

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This book is a collection of essays on questions that are of great importance for policy debates and management strategies in emerging economies:

- What are the driving forces and characteristics of these global networks?
- What do we know about the increasing diversity and complexity of these networks?
- What are possible impacts on the geographic distribution of knowledge?
- Where does China's ambitious strategy to upgrade its economy through innovation fit into this new geography of innovation?
- And what lessons, if any, could be drawn for policies in emerging economies that seek to capture the gains from global network integration?

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