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

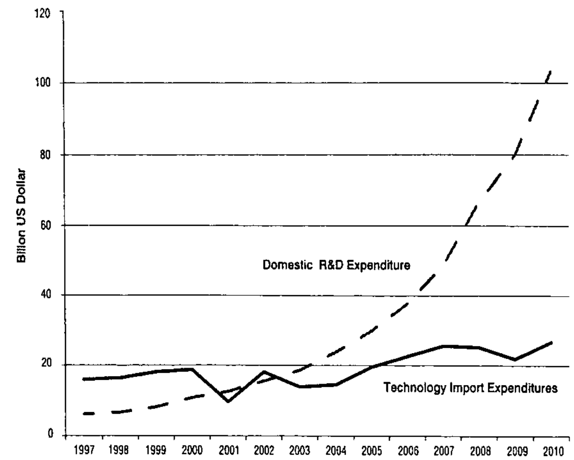
exports are highly misleading (or even more so, about China's total high technology exports in comparison to the high technology exports of the US)[6].

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, *Value Added and Factors in Trade. A Comprehensive Approach*, World Input-Output Dababase Working Paper # 7, April, pages 1-22

Expenditure on Domestic R&D and Technology Import



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.

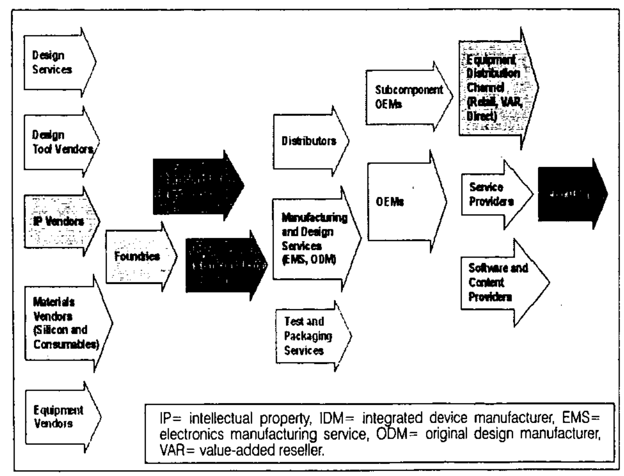
9. For the economics of global vertical disintegration in IC design, see Ernst, D., 2005, "Complexity and Internationalization of Innovation: Why is Chip Design Moving to Asia?", *International Journal of Innovation Management:* and Ernst, D., 2005, "Limits to Modularity - Reflections on Recent Developments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

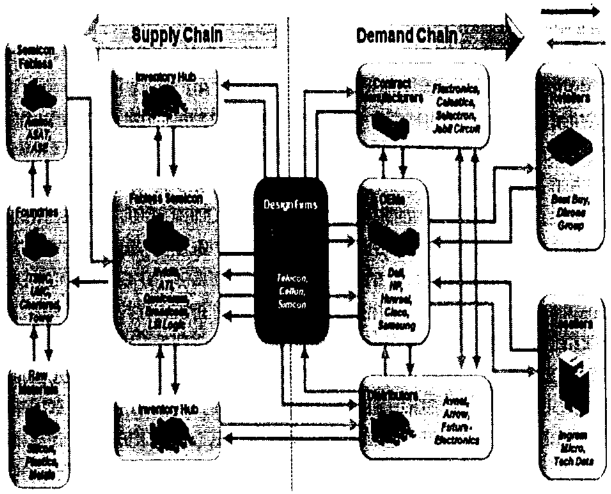
This part describes the participants in the semiconductor value chain, and their specific role as technology holders and technology users. [See slide 1] Of the almost 20 participants in the semiconductor value chain, the paper highlights the role of providers of EDA tools, design IP building blocks, 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

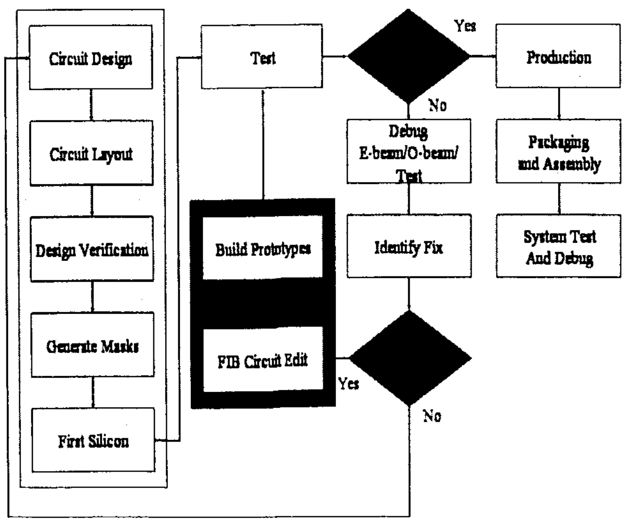


Gartner, 2005.



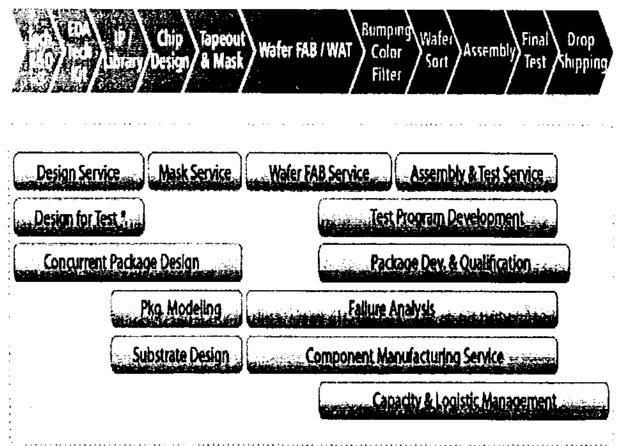
EDI (Electronic Data Interchange)

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