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Emerging Economies

Technology Upgrading and China's Growth Strategy to 2020

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Thank you for your interest,

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Author Biographies

John Whalley, FRSC, is one of Canada's most pre-eminent experts in the field of global economics. Currently, he holds a number of academic positions, including William G. Davies Professor of International Trade and Co-Director of the Centre for the Study of International Economic Relations, Department of Economics, University of Western Ontario. He is also a Distinguished Fellow at CIGI, Research Associate at the National Bureau of Economic Research in Cambridge, MA, Coordinator, Global Economy Group, CESifo, University of Munich, and a former Visiting Fellow at the Peter G. Peterson Institute for International Economics in Washington, DC.

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Abstract

It is widely believed in China that in order to meet the target of tripling gross domestic product (GDP) per capita between 2005 and 2020, as set out in China's 11th five-year plan in 2005, a change in China's growth strategy from FDI promotion and export-led growth towards technology upgrading and higher productivity growth in manufacturing needs to occur. This paper seeks to evaluate the potential effectiveness of recent government initiatives to be taken to achieve these ends. In particular, plans these include increased educational spending, tax incentives, large research and development (R&D) projects, and changes to the regulatory environment. In measuring China's economic growth potential towards 2020, this paper employs an economic analysis of Total Factor Productivity and identifies the importance of continued domestic technical innovation.

1. Introduction

China's economic growth, if one accepts the data, has been characterized by remarkably high rates of between 8 and 12 per cent for more than 20 years, significantly raising per capita income and sharply reducing absolute poverty (as measured by numbers of people below the poverty line). The latest targets adopted by the National People's Congress in the 11th five year plan in 2005 are to maintain annual growth at rates of at least 7.5 per cent until 2020 with the aim of raising gross domestic product (GDP) per capita from current levels of a little over $1,000 (2004) to around $3,000.

Like other growth processes earlier and elsewhere in Asia (most notably in Japan and South Korea), China's growth has been characterized by changing and shifting elements as alternative factors and forces have come into play. Both Japanese and Korean growth were achieved, in part, by shifting priorities for credit rationing and government support among key sectors and only increasing openness to trade as both production and exports grew rapidly. There were first of labour intensive manufactures (clothing and textiles), and then heavy industrial products (steel, chemicals), assembled electronics, and subsequently autos and higher technology products. Growth was not a simple application of capital accumulation and input growth as economists often model the process analytically.

China thus far has partly followed but also departed from the Korean and Japanese experiences in having had two distinct phases of growth which have taken different forms. The first was agricultural-led growth from the mid-1970s until the late-1980s, driven by the adoption of an incentive based responsibility system in place of existing collective arrangements. This was accompanied by sharp increases in yields and productivity in agriculture (see MacMillan et al, 1989: 781-807). The second has been manufacturing-led growth since the 1990s through to today and characterized by large inflows of foreign direct investment (FDI) and with it, large increases in manufacturing production and export.[1] Outward orientation, China's integration into the world economy, and accession to the World Trade Organization (WTO) in 2002 have been central elements to this strategy. The emphasis has been placed on increasing manufacturing output, and exports and FDI have been the key drivers. Manufacturing today accounts for a little over 50 per cent of GDP in contrast to numbers of around 20 per cent in Organisation for Economic Co-operation and Development (OECD) economies,[2] and nearly one half of manufacturing output is exported.

For some time, however, it has been accepted in China that this strategy alone would not be sufficient to maintain Chinese growth at the target rates set out in the 11th five year plan out to 2020 and beyond for a number of reasons. One is that further growth driven by simply increasing the share of manufacturing to GDP is unrealistic given its current size. If anything, this share would likely fall with growth in services and increases in public services such as education and health care. Another is that FDI inflows had grown rapidly by the mid-2000s to around $60 billion per year and accounted for over 40 per cent of total OECD outflows to non-OECD economies. With manufacturing costs beginning to increase in China, the prospect seen was for a plateau or even fall in FDI in the future as some of it moved to lower cost locations elsewhere in Asia (such as Indonesia, Vietnam, Cambodia and others). Yet another was that the 40 per cent export growth achieved in 2004 and 2005 was unsustainable annually as it implied an approximate doubling of China's share of world trade

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1 For a discussion of the contribution of FDI inflow to this process, see Whalley and Xin (2006).

2 At the peak in the early 1980s, similar numbers characterized Korea.

every two years. If these export growth rates were to continue, by 2010 China would account for around 50 per cent of world trade.

This sense that changes are needed to facilitate continued high growth in China provides the background for this paper. In both the latest and earlier five year plans, targets for accelerating technological upgrading have been set out, typically in terms of raising the portion of growth coming from total factor productivity growth rather than input growth and raising the ratio of research and development (R&D) expenditures to GDP. The instruments for achieving these targets have been seen as: (i) large R&D projects in a wide range of targeted areas to be co-financed by national governments, provincial governments and enterprises; (ii) tax incentives for R&D; (iii) new approaches to standards settings and the regulatory environment to foster innovation; and (iv) increased expenditures on education and research both in general and in top rank educational institutions. The range of programs and institutions is wide and large. Our focus is the potential contribution to sustaining Chinese growth from any new technology based productivity growth that results.

Our discussion comprises three elements. One is conventional growth accounting, asking how large the technology upgrading is likely to be that is needed to sustain high growth. Another is whether each of the instruments is likely to deliver their required contributions more narrowly, such as tax incentives for R&D. Finally, we discuss Japanese and Korean historical experience seeking pointers as to both likely pitfalls and sources of success.

Our view is that Chinese growth as it is currently evolving is clearly unsustainable in its present form, but change has been true of growth profiles first in Europe following the industrial revolution, in North America since the 1850s, and in Asia since 1945 (earlier in Japan). If Chinese growth is to complete a historic transformation in Polanyi's sense (see Polanyi, 1944), and even build further on it, something has to change and new elements need to emerge. At issue is whether technology upgrading will provide sustainability for this to occur.

2. The Broad Strategy and Targets for Technology Upgrading for Continued Chinese Economic Growth

Not only has China's recent growth primarily reflected high levels of capital accumulation more so than productivity growth, the majority of productivity growth has reflected imported technologies. In a recent study focusing on the contrasts between the FDI part of the Chinese economy and the remainder, Whalley and Xin (2006) report differences in labour productivity of 6:1 excluding agriculture, and 8:1 including agriculture. They report growth rates of 18.8 per cent and 20.4 per cent for the FDI part of the economy in 2003 and 2004 in contrast to growth rates of 6.7 per cent and 7.1 per cent for the remainder, and show that nearly all total factor productivity growth occurred in the FDI portion. The latter suggests that Chinese growth has relied heavily on importing technological improvements, rather than generating these domestically.

While relying more on imported technology to achieve high growth and also the technology gap may be the more efficient route, since the late-1990s, the Chinese government has repeatedly argued the need to refocus economic growth from investment-driven to efficiency improving growth by highlighting the need to also generate technical change at home. In the 10th five-year plan for 2001-2005, a series of planned changes to the current science and technology system were set out. The latest 11th five-year plan (2006-2010) sets out a strategy which relies on the development of China's own innovative capacity to achieve whatever technology upgrading may be needed for its future economic growth as the main element in sustaining high growth. *The Guidelines on National Medium- and Long-term Program for Science and Technology Development 2006-2020* (hereafter referred to as *S&T Guidelines 2006-2020*) were issued on 26 January 2006 by the State Council together with complimentary policies on 7 February 2006 and specify a series of targets and instruments for science and technology development to achieve the objective of continued high economic growth (*The Economist*, 2006). The stated aim is to become what the government calls an "innovative country" by 2020, a term used to justify a series of qualitative and quantitative targets as well as institutional

Table 1. A Schematic Representation of China's Technology Upgrading Growth Strategy

Objectives of The Economic Growth Strategy out to 2020	**Targets for Technology Upgrading to Meet Objectives**	**Major Instruments For Achieving Targets**
• GDP growth rate to exceed 7.5% annually until 2010, then 7.0% up to 2020 • Energy consumption per GDP to be reduced by 20% by 2010 • Pollution emissions to be reduced by 10% by 2010 • water consumption per unit of industrial value added to fall by 30%	*Qualitative Targets:* • Improvement of domestic innovation capacities • Transformation of the national innovation system from state-based to enterprise-based • Development and upgrade of a wide series of strategic technologies, frontline technologies and basic research *Quantitative Targets:* • TFP growth to reach 60% of GDP growth by 2020 • GERD/GDP is to reach 2.5% by 2020. • Foreign technology reliance to reduce to 30% by 2020. • The number of invention-type patent grants gained by Chinese inventors to rank in the top 5 in the world by 2020 • The number of internationally cited scientific papers by Chinese authors to rank in the top 5 in the world* by 2020	• Increase in Science and Technology expenditures from various sources • Tax incentives • Government procurement • Foreign technology import regulation • Strengthened IPR protection • Talent force and education

* Institute of Scientific and Technical Information of China (ISTIC) uses three established index - SCI, EI and ISTP - as ranking tools.

reforms, with indigenous technological development to become the integral part of China's economic growth strategy.

Table 1 sets out the broad elements of this strategy. The objectives set for this strategy are achieving an overall growth rate of 7 per cent until 2020, while reducing the energy consumption to GDP ratio, pollution emission and water consumption. A series of more concrete qualitative and quantitative targets are then set for achieving these objectives, and in turn, instruments set for achieving the targets.

Qualitative targets include: improvements in domestic innovation capacity; a change in the national innovation system from state-based to enterprise-based; and the development of a series of new strategic technologies, frontline technologies and basic research which cover sophisticated manufacturing facilities and product areas such as large-scale integrated equipment, aeroplanes and automobiles, information technology (IT), agriculture, energy (energy exploitation, energy saving and clean energy development), recycling technology, medicine and medical equipment, and national defensive technologies.

Among the quantitative targets, the most significant is that Total Factor Productivity (TFP) is set to increase. TFP measures that portion of growth not directly attributable to input growth, and may be neutral (equal for all inputs) or biased in favour of one input or the other. It is generally believed in China that the current TFP contribution to GDP growth is below 40 per cent. Weiguo Song, a researcher at the National Research Centre for Science and Technology for Development under the Ministry of Science and Technology, along with Jun Li have summarized[3]

[3] Guanhua Xu, Minister of Science and Technology in China, at a press conference of the 4th Session of the 10th National People's Congress argued that in order to achieve the aim of quadrupling GDP by 2020, China has to increase TFP growth over GDP growth ratio from the current 39 per cent to 60 per cent.

TFP studies by various government agencies and scholars, and claim this shows that TFP growth over GDP growth was below 40 per cent during the 9th five-year development plan period (1996-2000). The proposed 60 per cent target reflects a recognition that future increases in both labour and capital inputs will be insufficient to continue to fuel high GDP growth. China's one-child policy since the 1970s implies that while the labour force growth will grow at an average rate of 1.1 per cent during 2004-2010, it will decline to 0.3 per cent during 2010-2020 and labour's contribution to GDP growth will be close to zero by 2020 (Li et al, 2005). With regard to capital's contribution, it is assumed that both FDI and more broadly, capital's contribution to GDP growth will likely decrease as capital deepening occurs. In order to keep high GDP growth, the argument is that TFP has to make more of a contribution, although as already noted how a residual contributes is unclear.

TFP changes can reflect a variety of factors such as improved resource reallocation, institutional reforms, factor productivity improvements, and the use of new technologies. Many earlier

Table 2. Sources of China's Economic Growth since 1978 (%)

	GDP growth	Capital growth	Labor growth	TFP growth
1978-1985	9.8	8.5	3.1	3.5 (35.3)
1985-1989	8.9	9.8	2.6	2 (22.2)
1990-1997	11.2	11.2	1.1	4 (36.1)
1997-2000	7.7	10.7	1.1	0.8 (10.9)
2000-2003	8.4	10.5	1.1	1.6 (19.8)

Note: The parentheses are the factor contribution share to total GDP growth.
Source: Li, Hou, Liu, and He, "China's Economic Growth Potential and Prospect Analysis," *Management World*, vol. 9 (2005).

papers have discussed sources of China's economic growth, some questioning the reliability of China's statistics (Young, 2003: 1220-42), some arguing that China's growth would face a limit sooner or later as growth depended heavily on large increases in inputs with only small improvements in productivity (Krugman, 1994). Borensztein and Ostry (1996: 224-8) also argued that China's TFP growth would slow as the potential for factors other than pure technical progress weakened.

Recent work by Li et al. (2005) (summarized in Table 2) claims that China's TFP growth reached its high point at the beginning of China's reforms in the early 1990s when outward-oriented reforms took hold, then fell by the end of the1990s. This seems to point to the need for dramatic change over the next decade or so if overall growth rates are to be preserved, and that without heightened technical progress China's current high economic growth is unsustainable.

In order to achieve a higher rate of technical progress, the target has been set in the growth strategy for the GERD (Gross Expenditures on Research and Development) over GDP ratio to reach 2.5 per cent by 2020. Currently, this ratio is only around

Table 3. China R&D expenditures 1991?2005, in RMB 100million

	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
GERD	150.8	209.8	256.2	309.8	349.1	404.8	481.9	551.1	678.9	895.7	1043	1288	1540	1966	2450
Annual growth (%)	-	29.0	6.6	0.6	-0.2	9.5	17.6	10.9	20.3	16.9	15.0	23.8	17.2	27.7	20.4
GERD/GDP(%)	0.7	0.8	0.7	0.7	0.6	0.6	0.6	0.70	0.76*	0.90*	0.95*	1.07*	1.13*	1.23*	1.34*

*based on revised GDP

Source: China Science and Technology Statistics Data Book 1998-2006.

1.3 per cent (see Table 3). By comparison, OECD countries on average invested around 2.5 per cent of GDP in Research and Development in 2004 (OECD, Main Science and Technology Indicators, no. 2006/1). This GERD/GDP ratio has increased sharply in recent years and is targeted for further rises.

A third target set as part of the technology upgrading strategy is to reduce foreign technology reliance to 30 per cent by 2020. The Chinese government computes a ratio of foreign technology reliance calculated as foreign technology purchases (see Table 4) over these plus GERD. Currently, this ratio is around 40 per cent (see Table 4 and 5) and China's aim is to improve domestic innovation capacity. The claim is that purchases of foreign technology have not resulted in enhanced domestic innovative capability because too little effort has been put in absorption and assimilation. Chinese manufacturers are claimed to be stuck

Table 4. Foreign Technology Purchases by China in 2005

	Foreign Technology Purchases by China (million US$)	Share (%)
Total	19050.57	100
Patents	1278.38	6.7
Know-how	5095.33	26.7
Technical consulting and other services	4735.99	24.9
Software	432.50	2.3
Trademark licensing	271.81	1.4
Joint Ventures	1722.93	9.0
Key equipment and production lines	5333.11	28.0
Others	180.49	0.9

Source: Science and Technology Agency, Ministry of Commerce. Available online: <http://kjs.mofcom.gov.cn/aarticle/ztxx/dwmyxs/u/200601/20060101418975.html>.

Table 5. China Foreign Technology Reliance in 2004 and 2005 (billion US$)

	2004	2005
GDP (1)	1930	2230
GERD/GDP	1.23%	1.34%
GERD (2)	23.7	29.9
Foreign Technology Purchases (3)	13.9	19.1
Foreign Technology Reliance = (3)/((2)+(3))	36.9%	38.9%

Sources: (1) World Development Indicator; (2) Science and Technology Agency, Ministry of Commerce. Available online: <http://kjs.mofcom.gov.cn/aarticle/ztxx/dwmyxs/u/200601/20060101418975.html>.

in a cycle of purchasing foreign technology, then purchasing again the upgraded technology when the previous version is outdated. This argument is supported by several Western economists. Howard Pack (2000), for example, argues that technology inflows that are not complemented by domestic absorptive capability will have little, if any, impact on a country's productivity. The claim goes specifically to the purchase of key equipment and production lines which account for over a quarter of total purchases. Table 4 indicates that patents and trademark licensing, which are often regarded as among the major forms of technology imports, account for only about 8 per cent of the total.

The last two targets set for the growth strategy aim to enhance China's intellectual property inventory. One emphasizes invention-type patents which are thought to have more value than appliance or design patents (the latter two are also referred to as mini-patents). The target is set for China to rank in the top five countries in numbers of invention-type patents by 2020. The existing government incentives such as patent application fee subsidies have resulted in China already ranking number 10 globally in terms of number of patent applications. However, China's effective capacity in this area is a lot weaker than this ranking suggests. As shown in Table 6, the total number of patents granted to domestic applicants is four times that for foreign applicants, but the number of invention-type patents granted to domestic applicants is only about two thirds that for foreign applicants.

Table 6. Number of patents awarded in China by the State Intellectual Property Office (2004)

	Total	To Domestic Applicants	To Foreign Applicants
Invention	49360	18241	31119
Applied Patents	70623	70019	604
Industrial Design	70255	63068	7187
Total	190238	151328	38910

Source: Ministry of Science and Technology (2006). Available online: <http://www.most.gov.cn/eng/statistics/2005>.

The final target in this area focuses on international rankings of China's published scientific research papers. China ranks number four in the world in terms of the total number of papers,[4] but high quality papers as measured by citation frequency are only a small portion. The target of a top five ranking is now to apply to citations as well as the number of papers.

3. Instruments to be used to Meet Targets

To implement this indigenous technology upgrading growth strategy, a series of instruments are to be used to meet the targets

[4] National Science and Technology Plan 2006 Annual Report stated that "in 2003 the number of published scientific papers registered in SCI, EI and ISTP is 93,000, ranking number 5 in the world." In 2005, the ranking went up to number 4 according to the statistics provided on the official website of Ministry of Science and Technology. Available online: <http://www.sts.org.cn/nwdt/gndt/document/0611091.htm>.

set. Some increase R&D funding by augmenting existing sources, others create new financing sources; others aim to trigger enterprise innovation using government procurement practices, foreign technology import regulation and intellectual property law reform; yet others aim to strengthen long-term innovative capacity through educational improvements.

a) Government Expenditures on Science and Technology (S&T)

Since the mid 1990s, both China's central and local budgetary revenues have grown sharply, but the share of expenditures on science and technology in state budgetary expenditures has not reflected this growth, even though they have grown absolutely. This can be seen from Table 7. To improve on this, the growth in state budgetary expenditures on science and research are to be set at a higher rate than the government financial revenue growth rate in general. The share of budgetary expenditures on science and technology in total budget revenue is to be at least 4 per cent, and its growth to be higher than the state revenue growth. For 2006, planned budgetary expenditures from central government increased 19.2 per cent compared to 2005.

Table 7. State Budgetary Expenditures on Science and Research

	1999	2000	2001	2002	2003	2004	2005
State budgetary expenditures on science and research (100million RMB)	543.9	575.62	703.26	816.22	975.54	1095.3	1334.9
Share of state budgetary expenditures (excluding debt) (%)	4.12	3.62	3.72	3.7	3.96	3.8	3.9

Sources: China's Ministry of Finance, <http://www.mof.gov.cn/1162.htm>; and Ministry of Science and Technology official website, <http://www.sts.org.cn/nwdt/gndt/document/060925.htm>.

State budgetary expenditures on science and technology are in three categories: basic research, public research and research on frontline technologies. The *S&T Guidelines 2006-2020* list a wide series of projects covering strategic technologies, frontline technologies and basic research which are now expected to be substantially funded by the government. The earlier 10th five-year development plan (2001-2005) already organized China's Science and Technology system as what is known as a "3+2" system. "3" refers to a National High-Tech R&D Program labelled "863", and a National Key Technologies R&D Program and a National Program of Key Basic Research Projects labelled "973". "2" refers to R&D Infrastructure and Facility Development and Environment Building for S&T Industries. In this structure, a series of Mega-Projects became the top priority.[5] These projects emphasized the development of a chain of integrated products or technologies instead of piecemeal invention with the aim of enhancing product and industrial capabilities. Among the "3" programs, the 863 and 973 programs were fully financed by state sources.

Since many projects in the existing National Key Technologies R&D program and Mega-Projects are thought to be able to be commercialized quickly, enterprises are now to be encouraged to participate and become the dominating funding source. Hao and Gong (2006: 1548-9) document several big projects often dubbed China's billion-dollar babies. Some are basic research programs such as protein science, quantum research, nanotechnology, development and reproductive biology. Others are engineering programs in Mega-Projects such as next-generation broadband, large-scale oil and gas exploitation, transgenic plant breeding, drug development and even manned moon exploitation.

[5] In the 10th five-year plan, 12 Mega-Projects were carried out.

Hao and Gong also provide details of the Chinese government's planning for GERD and budget expenditures on R&D for 2010 and 2020 (see Table 8). GERD is to grow to 2.5 per cent of GDP by 2020. In 2004, China's GERD already ranked number 7 in the world, even though its absolute value was substantially below that of OECD countries; e.g., US$313 billion for the United States and US$118 billion for Japan. The government-funded part in the United States was also substantial, around US$90 billion.[6] By 2020, China is to move up in these rankings.

Table 8. China GERD and Budget Planning for 2010 and 2020

	GERD ($ billion)	Percent of GDP	Government Contribution ($ billions)
2004	$24.60 (actual)	1.23%	$8.7
2010	$45.00 (planned)	2.00%	$18.00
2020	$113.00 (planned)	2.50%	NA

Source: Hao and Gong, 2006, Research Funding: China Bets Big on Big Science, Science, vol. 311. no. 5767 (2006): 1548-9.

b) Tax Incentives Aiming to Improve Domestic Innovation

A further set of instruments set out in the *S&T Guidelines 2006-2020* to be help meet targets for GERD are new tax measures designed to encourage innovation. In the 1990s, a series of tax incentives were introduced to encourage high technology development. The *S&T Guidelines 2006-2020* takes these measures further. Table 9 compares these new planned incentives with prior ones.

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[6] See OECD, Main Science and Technology Indicator, no. 2005/1. The other 4 countries before China are Germany (US$59 billion), France (US$39 billion), United Kingdom (US$33 billion), South Korea (US$28 billion).

Existing S&T tax incentives have not been effective in stimulating enterprises to invest in R&D because few enterprises benefited. Only profitable enterprises with an annual 10 per cent increase in R&D inputs could use tax deductions, and deductions could not be carried forward or backward. When companies made considerable R&D investments, they were typically not profitable immediately, and even if they made future profits, the deduction would go unused in full since it could not be carried forward.

Depreciation rules were similar in effect. The allowable enterprise capital investment depreciation rate was only 4 per cent, much lower than in OECD countries. The government later raised this to 7 per cent. But as the central government set the aim of improving the financial position of loss-making SOEs in 1997, many SOEs resorted to depreciation rate reductions as a way of removing accounting losses, and increases in depreciation rates for tax purposes went unclaimed for many SOEs.

Another tax issue is the different tax treatment of domestic enterprises and Foreign Invested Enterprises (FIEs). Because of efforts to attract foreign direct investment, China's tax system evolved in the early 1990s to be biased in favour of FIEs. The corporate income tax rate for FIEs is 10-24 per cent while that for Chinese domestic enterprises is usually 33 per cent. 40 per cent of FIEs' reinvestment is tax-deductible while Chinese domestic companies have no tax deduction for capital investment. Chinese domestic companies are only allowed to deduct a portion of employee compensation from corporate taxable income while FIEs can take a full deduction. As a large part of enterprise R&D expenditures (around 50 per cent in OECD countries) goes to employee compensation, China's tax system does not encourage domestic companies to invest in R&D through the tax treatment of wage costs.

Table 9. Improvement on Tax Incentives under the New Technology Upgrading Strategy

Item	Prior Tax Rules	New Tax Rules
Deduction for R&D and training	150% R&D expenses could be deducted from annual taxable income on the condition that the enterprise had made a profit and its R&D expenses were 10% higher than that of the previous year. The redundant part was not allowed to be carried forward or backward.	150% of R&D expenses can now be deducted from annual taxable income; and can be carried forward for five years, but no carry backward. Employees' education training expenses up to 2.5% of total taxable income can now be deducted from corporate income taxable.
R&D equipment and instrument depreciation	Equipment or instruments below RMB100,000 could be deducted.	Equipment or instruments below RMB300,000 can now be expensed. Those over RMB 300,000 have shortened asset lives.
High-tech enterprises	Only high-tech exports got VAT totally refunded, software and integrated circuit manufacturing companies enjoyed a favorable VAT rate of 3-6% instead of 17% Approved high-tech foreign-funded enterprises in high-tech park enjoyed a favorable tax rate of 15%. New enterprises could have two years of tax holiday.	VAT (Value-added Tax) for high-tech enterprises are to move from production-type to consumption-type allowing for deduction of capital expenditures Approved high-tech enterprises in high-tech parks are to get two years tax holiday after earning profit, then enjoy a favorable tax rate of 15% (regular rate is 33%).
Import tariff and import-related VAT exemption	An exemption usually applied to software and integrated-circuit manufacturing companies together with those listed in National High-tech Products List.	Custom duties and import-related VAT are to be removed for imports of R&D-related products by approved enterprises, technology centres, national engineering centres, Mega-projects, National Key Technologies R&D Program and other major projects.
Tech transfer service institutions	Tax exemptions involved mainly the corporate income tax.	For technology enterprises, incubators and national university science and technology parks, business tax, corporate income tax, real estate tax, urban and township land use tax are exempt during an initial period.
Transformed science and research institutions	Favorable policies applied in terms of corporate income tax, land, urban and township land use tax, real estate tax are adopted	Upon expiration of current favorable policies, extensions are expected to apply.
Donation		Donations to S&T SME Innovation Funds and other similar funds are deductible for corporate income taxes
Venture Capital		Favorable taxation terms for venture capital which invest mainly in small and medium-sized high-tech enterprises

Sources: *The Guidelines on National Medium- and Long-term Program for Science and Technology Development 2006-2020*, and various official documents from China's Ministry of Finance.

c) Financial Services to Support Science and Technology (S&T) Enterprises

Besides tax incentives, the Chinese government also plans to improve financial services to encourage enterprise investment in research and development. State policy banks (i.e. the National Development Bank, the China Import and Export Bank and the China Agriculture Development Bank)[7] are instructed to provide loans to S&T enterprises, finance S&T imports and exports, and support agricultural technology application and industrialization. Commercial banks and other financial institutions are encouraged to provide loans to S&T enterprises based on government guarantees, provide discounted interest rates, and create funds for innovative collateral property, including intellectual property. Venture Capital (VC) is also a new source that the government aims to use to develop financing for S&T small and medium enterprises. In addition, a series of measures will be adopted to facilitate S&T enterprises' public listings. Corporate bond issuance is also to be allowed for qualified S&T enterprises.

d) Government Procurement of Innovative Products, Regulation of Foreign Technology Imports and Intellectual Property Rights (IPR) Protection

A further group of instruments to be used to support domestic enterprise innovation include procurement practices, regulation of technology imports, and IPR protection. These are all areas that involve commitments made as part of China's WTO accession terms, and so how they can be used in these ways are constrained. Government procurement practices will be used to create or ensure demand for domestic innovation products. Key engineering

[7] These three banks were separated from the four major commercial banks in 1994 when bank reform was adopted. They are responsible for supporting state policies.

projects undertaken by central or local governments are to be used to support domestic equipment procurement. The government is also to purchase trial or new products which are seen as having potential in the future. Foreign technology import regulation is to be used to reduce foreign technology reliance. Technology import regulation focuses on limiting repeated purchases of foreign technology or obsolete foreign technology and equipment imports. If foreign capital equipment has to be introduced, then after-purchase absorption and innovative capability generated is to be assessed before licenses are issued.

Along with China's commitment to reduce foreign technology reliance and strengthen domestic innovation, IPR protection is to become more rigorous to allow for swifter and more extensive new technology adoption. The idea is to use IPR laws to provide support for enterprises to create new products and technology. Measures include strengthening of intellectual property protection through legislative regulation, improvement of the appraisal efficiency of invention-type patents, and subsidies to domestic applicants for foreign intellectual property. While IPR protection has been a highly controversial issue in China, its strengthening is now seen as a workable incentive to encourage technology upgrading strategy in that it will not only increase the potential profits of inventors but also reduce profits from direct capital good usage, and encourage indigenous R&D.

e) Talent Force and the Education System

The education system is another instrument to be used to heighten innovative capacity and technical progress in the longer term. Currently China's higher education system is seen as having two main problems regarding innovation. First, there is a shortage of leading scientists in various disciplines. Second, there is perceived to be poor communication between science and technology development organizations (such as universities and research institutions) and enterprises.

Responding to the first, the Chinese government has launched a series of initiatives as part of the *S&T Guidelines 2006-2020*, including the cultivation of a younger generation of talent to take the lead in academic research; the cultivation of innovative talent while implementing key national projects; the attraction of overseas talent; and the establishment of a group of world-class universities domestically.

The second thrust in this area is linked to China's institutional reform of its science and technology system. To improve linkage between the science and technology system and enterprises, the Chinese government will shift the system from state-based to enterprise-based by transferring a portion of research institutes (those not responsible for basic research or public research) to enterprises. It will also encourage enterprises to establish new incentives such as stock options to motivate researchers to develop more market-friendly inventions and establish interaction between enterprises and universities and research institutes by allowing senior engineers in enterprises to act as part-time professors or researchers in universities and encouraging researchers in universities or research institutes to take part-time jobs in enterprises. These measures also aim to facilitate the diffusion of technology and improve the speed of technology adoption.

4. Evaluation of China's Technology Upgrading Strategy

While it is the recognition of limits to the current growth process that has caused the Chinese government to set out the objectives, targets and instruments we describe above, the question which follows is whether these will be effective? Can the objectives be met by the instruments and are the targets sufficient to meet the instruments and assure continued high economic growth?

Meeting Growth Targets through TFP Targets

The central quantitative target set fro maintaining GDP growth is to raise the TFP growth rate by 2020 to 60 per cent of overall growth. The most commonly explored analyses linking between economic growth and TFP utilize a growth accounting framework. Following Solow (1957) and Denison and Chung (1976), we can write a simple aggregate production function as;

$$Y(t) = A(t)F(K(t), L(t)) \qquad (1)$$

where Y(t) is output in period t, A(t) is a measure of overall factor productivity, K(t) and L(t) are measures of capital and labour inputs. A time derivative of (1) yields the growth accounting equation

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + s_k \frac{\dot{K}}{K} + s_L \frac{\dot{L}}{L} \qquad (2)$$

where s_K and s_L represent the shares of capital and labour in national income, and $\frac{\dot{A}}{A}$ measures TFP growth. Solow first applied his approach to US growth from the 1870's to the 1950's concluding that the majority of growth (around 87 per cent) was attributable to technical progress rather than input growth. Jorgensen and Griliches (1967) later showed however that a substantial fraction of the residual could be explained by changes in the quality of inputs, such as average years of schooling and better health.

The studies mentioned earlier use a similar approach in analyzing Chinese TFP growth and come to the conclusion that only 40 per cent of Chinese growth since the 1990s is due to technical innovation. This sharply lower proportion also occurred in other Asian economies at earlier stages of industrialization such as Japan and South Korea. This phenomenon is often attributed to the high savings rates in these economies, and large capital accumulation relative to a small initial capital stock as industrialization occurs.

Using the study by Li et al. (2005) summarized in Table 2, one can make computations of the required change in $\frac{\dot{A}}{A}$ as a ratio of $\frac{\dot{Y}}{Y}$ for given reductions in factor input growth rates. These are summarized in Table 10 and suggest that a TFP growth target set as 60 per cent of GDP growth may be realistic to sustain the overall GDP growth objective if the value of $\frac{\dot{A}}{A}$ declines to 7.5 per cent from 10.5 per cent and $\frac{\dot{Y}}{Y}$ falls from 1.1 per cent to 0 per cent. In the worst case scenario that both capital and labour inputs fall in these ways, the highest required $\frac{\dot{A}}{A}$ component of GDP growth is still less than 50 per cent.

In more recent work, Whalley and Xin (2006) apply a two stage growth accounting approach to China in which they consider

Table 10. Required Changes in $\frac{\dot{A}}{A}$ based on Li et al. (2005) to Maintain Chinese Growth under Falling Factor Input Growth Rates

	GDP growth rate	Capital growth rate	Labour growth rate	$\frac{\dot{A}}{A}$
Li (2005) results for 2000-2003	8.4	10.5	1.1	1.6 (19.8%)
Under reduction in $\frac{\dot{K}}{K}$ to 7.5	8.4	7.5	1.1	3.5 (41.2%)
Under reduction in $\frac{\dot{L}}{L}$ to 0	8.4	10.5	0	2.1 (25.0%)
Under reduction both in $\frac{\dot{K}}{K}$ to 7.5 and $\frac{\dot{L}}{L}$ to 0	8.4	7.5	0	3.9 (46.4%)

Note: The parentheses are the percentage of TFP contribution to total GDP growth.

the Chinese economy to be segmented into two distinct subparts. One uses FDI and labour as inputs; the other domestic capital and labour. The outputs from these two sub sectors then aggregate into a single output, as in the Solow approach.

Based on their equation (8) (reproduced here as (3)) and relevant data in Table 2 and Table 5 for 2004 (as shown below) we can make some further speculative calculations. Their growth accounting equation is;

$$\frac{\dot{Y}}{Y} = g^F\left(\frac{\dot{A}^F}{A^F} + s^F_{FDI}\frac{F\dot{D}I}{FDI} + s^F_L\frac{\dot{L}^F}{L^F}\right) + g^N\left(\frac{\dot{A}^N}{A^N} + s^N_K\frac{\dot{K}}{K} + s^N_L\frac{\dot{L}^N}{L^N}\right) \qquad (3)$$

where the superscripts F and N relate to the FDI and non-FDI sectors, and g^F and g^N are the shares of output in the FDI and non-FDI sectors. In their calculations for 2004,

$$\frac{\dot{Y}}{Y}=9.5, g^F=0.224,$$

$$g^N=0.776, s^F_{FDI}=0.841, s^F_L=0.159, s^N_L=0.488, \frac{F\dot{D}I}{FDI}=10.4, \frac{\dot{L}^F}{L^F}=14.8, \frac{\dot{L}^N}{L^N}=0.6, \frac{\dot{A}^F}{A^F}=7.7,$$

$\frac{\dot{A}^N}{A^N}$ =-0.1. Their calculations thus show that all technological progress occurs in the FDI part of the economy, which is also not the indigenous TFP growth that the new Chinese growth strategy focuses on.

If input growth in the FDI sector were to fall due to stagnating FDI, the lost contribution to GDP growth would be about 2.8 per cent. If labour growth by 2020 were zero as predicted by Li et al. (2005), Chinese GDP growth would lose another 0.75 percent, and GDP growth would be a little less than 6 per cent. The TFP component of GDP growth as calculated by Whalley and Xin (2006) is 17.3 per cent for 2004, but this comprises an FDI part which accounts for nearly all TFP growth. If both parts of TFP growth were to increase to 60 per cent, that would yield an increase of $\frac{\dot{A}}{A}$ by about 4 per cent, which is enough to cover the lost growth due to plateauing FDI and labour growth. But if only the non-FDI part of TFP growth is affected by a strategy focused on indigenous technological progress, there is little impact on overall growth which will now fall short of its target. However, if as expected by Chinese officials, both the TFP components of GDP growth were to increase only by 20 per cent (from 40 per cent to 60 per cent), then $\frac{\dot{A}}{A}$ increases by about 2 per cent, inadequate to cover the loss, but still maintaining a 7.5 per cent economic growth rate. If only the non-FDI component increases by 20 per cent, then once again there is no impact on the growth rate and the strategy's objective is not met.

These calculations build on the premise that $\frac{\dot{A}}{A}$ constitutes a meaningful target for policy. However, as a residual there are no direct instruments available in the growth accounting framework to achieve a particular $\frac{\dot{A}}{A}$ value. As such, it also makes speculation on the feasibility of achieving this objective hard to translate into firm policy recommendation.

GERD Targets, Objectives and TFP Growth

The next issue is whether achieving the individual targets set for instruments can assure meeting the overall TFP growth objective. The first target is set for R&D expenditures. The relationship between R&D investment and technological change has been the subject of substantial academic debate with several models developed. Romer (1990), Grossman and Helpman (1991) and Barro and Sala-i-Martin (1995) apply a product-variety approach to technological change under which an increase in product varieties are treated as representative of R&D. In contrast, Griliches (1973) uses a regression approach to assess the effect of R&D on the TFP growth rate. Aghion and Howitt (1992) and Grossman and Helpman (1991) apply a quality-ladders formulation to technological change, presuming that quality upgrading is proportional to R&D outlays. These models calculate TFP growth as the sum of $\frac{\dot{A}}{A}$ and an R&D-specific term. Other models tackle the relationship between R&D and economic growth by treating R&D as a special form of capital (Romer, 2006; Barro and Sala-i-Martin, 1995).

There is no clear theory relating GERD/GDP ratios to TFP growth rates, and so assessing the impact of meeting GERD/GDP targets on TFP growth (and hence broader economic growth) is difficult. Some economists have argued that R&D investment, the number of researchers and scientists, the number of published papers and IPR awards are four major factors determining a country's innovative capacity (Kim and Nelson, 2000).

Meeting the GERD to GDP target seems likely. The goal of a 2.0 per cent and 2.5 per cent share for GERD in GDP for 2010 and 2020 respectively implies an annual growth rate of GERD at 8.6 per cent up to 2010 and 9.6 per cent beyond to 2020. This targeted rate of 8-10 per cent should be possible, since Table 3 shows China's average GERD real annual growth is around 15 per cent since 1996, higher than the required figure.

Meeting GERD Targets with Instruments

Meeting GERD/GDP targets implies using a series of budgetary and tax measures. Table 11 also shows GERD by source of funds, recipient of funding, and sector of performance in 2004. Government financed R&D accounts for 26.6 per cent of GERD, industry financed R&D accounts for 65.7 per cent, and GERD financed from abroad and other sources is 7.7 per cent. The time trend of this funding over the last five years thus shows an increase in industrial funding and a decrease in government funding,[8] while GERD grows at around 20 per cent annually in the last five years, and at around 17 per cent in the last 10 years. This implies substantial growth in industry funding, in large part reflecting encouragement from the central government. Since 1995 more government budgetary funds have been appropriated to science and technology, together with a series of incentives to encourage industry funding. These incentives are not equally available to all enterprises; usually FIEs enjoy more favourable tax terms and State-Owned Enterprises (SOEs) have more government subsidies. The new strategy seeks to remove this discriminatory treatment, and the major increase in industry financed R&D investment is expected to come from non-FIEs.

Table 11. GERD by Source of Funds, Recipient of Funding and Sector of Performance in 2004 (RMB 100million)

	PERFORMANCE SECTORS				
Source of funds	**Research Institutes**	**Business**	**Higher Education**	**Others**	**Total**
Government	344.3	62.6	108.8	7.8	523.6
Business	22.4	1189.3	74.5	5.1	1291.3
Abroad	2.6	19.8	2.6	0.1	25.2
Others	62.4	42.3	14.9	6.6	126.2
Total	431.7	1314.0	200.9	19.7	1966.3

Source: China Science and Technology Statistics Data Book 2005.

[8] In 2003, industry financed R&D accounts for 60.1 per cent of total GERD, increasing 2.5 per cent compared to that in 2000. The percentage of industry financed R&D investment in GERD surpasses 50 per cent for the first time in 2000. Government financed R&D accounts for 29.9 per cent, decreasing 3.5 per cent compared to that in 2000. Foreign funds and other national sources account for 1.9 per cent and 8.0 per cent respectively.

A problem area with meeting GERD targets is that the percentage of R&D expenditures over sales for private S&T enterprises has fallen sharply from 11.5 per cent in 1993 to 2.1 per cent in 2002. According to the *Economic Census Report* by the National Bureau of Statistics,[9] among all the medium-to-large enterprises in China, only 10 per cent invest in science and technology activities and R&D expenditures are only 0.56 per cent of sales[10] while in major developed countries R&D expenditures account for 5 per cent of sales. Among the Large and Medium-size Enterprises (LMEs), only 32 per cent have R&D centers and R&D researchers account for less than 35 per cent of total engineers and researchers in LMEs. The situation in central government affiliated enterprises is better, with R&D accounting for around 1.5 per cent of sales, with most having set up R&D centres.

Several research papers show a positive relationship between financial incentives and R&D investment by enterprises and as China's latest financial incentives are substantial, it may be that a substantial increase in enterprise R&D spending occurs nonetheless. Wang and Tsai studied the impact of three promotional tools in the Taiwanese electronic component industry: R&D tax credits, exemption from tariffs, and accelerated depreciation (Wang and Tsai, 1998). Their results indicate that the scheme generated an increase in industrial R&D investment of about 16 per cent. Russo also concluded that R&D tax credits produce relatively large increases in research effort in Canada and the United States (Russo, 2004: 313-5). Hall and Van Reenan (2000) reviewed the evidence in various studies about the effects of tax systems in OECD countries on the user cost of R&D and concluded that in

[9] National Bureau of Statistics of China, *Economic Census Report* (Beijing: NBS, 2005). For recent and archived statistical data, see <http://www.stats.gov.cn/english>.
[10] For reporting news piece, see <http://news.xinhuanet.com/fortune/2005-12/14/content_3919214.htm>.

the current imperfect state of knowledge, a dollar in tax credit for R&D might stimulate a dollar of additional R&D. The conclusions confirm the results of surveys by Edwin Mansfield in the United State in 1986. A target of increasing GERD over GDP from the current ratio of 1.3 per cent to 2.5 per cent in 2020 implies (given GDP growth of 7.5 per cent) that the annual growth rate of industry financed R&D (after inflation) should be about 12 per cent providing the industry financed share in GERD remains around 60 per cent.[11]

Similarly, if we suppose the government financed R&D share in GERD remains at the current ratio of around 30 per cent, the real annual growth rate of government financed R&D may need to be 12 per cent[12] implying a larger share of budgetary revenues will need to be directed into government financed R&D to achieve the targets set. Over the past 10 years, the share of budgetary expenditures on science and research is around 4 per cent (see Table 12) while total budget revenues grow at over 14 per cent. A trend of budgetary revenue growth higher than GDP growth may be difficult to sustain in the mid-to-long term given that the tax load is already heavy in China.[13] In addition, China's tax incentives for R&D investment and the upcoming Value-Added Tax (VAT) reform aiming to change VAT from production-type to consumption-type[14] narrow the tax base further.

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[11] This calculation is the rate r from the equation: $(1 + 7.5\%)^{15} \times 2.5\% \times 60\% = 1.3\% \times 60\% \times (1+r)^{15}$ where $r \approx 12.3\%$.

[12] Using a similar calculation to that for industry financed R&D.

[13] Since 1995, China's budgetary revenue over GDP has risen from 10 per cent to 18.5 per cent, an average annual growth rate of 1.4 per cent. Though the figure in the US is 28.4 per cent in 2002, given that social security is only a small share in the total budgetary revenue in China and low GDP per capita, China's tax load on enterprises may be heavier than that in the US. Relevant data is from Wu (2005).

[14] Currently VAT accounts for over 30 per cent of total budgetary revenue.

Table 12. Budgetary Expenditures on Science and Research (RMB 100million)

	1996	1997	1998	1999	2000	2001	2002	2003
Budgetary Expenditures (1) on Science and Research	348.63	408.86	438.60	543.85	575.62	703.26	816.22	975.54
Budgetary Expenditures (growth rate) (2)	7937.55 (16.3%)	9233.56 (16.3%)	10798.18 (16.9%)	13187.67 (22.1%)	15886.50 (20.5%)	18902.58 (19.0%)	22053.15 (16.7%)	24649.95 (11.8%)
(1)/(2)	4.39	4.43	4.06	4.12	3.62	3.72	3.70	3.96
Government Revenue (growth rate)	7407.99 (18.7%)	8651.14 (16.8%)	9875.95 (14.2%)	11444.08 (15.9%)	13395.23 (17.0%)	16386.04 (22.3%)	18903.64 (15.4%)	21715.25 (14.9%)

Source: China's Ministry of Finance, <http://www.mof.gov.cn/1162.htm>.

Other sources of funding for R&D include bank loans, the stock market and foreign funds. The fragility of China's financial system, however, raises doubts about these as sources of R&D finances (see Pan et al., 2006). The use of venture capital will be a new initiative to support R&D activities, but will have to build from a small base.

Other Targets and Instruments

The targets of paper citations and rankings in patent awards have not been supported by any new and clear initiatives thus far. Some observers argue that the brain drain and the lack of an innovative culture in the education system are constraints on the achievement of both of these (*The Economist*, 2006). There are more young leaders in research programs who are expected to bring more creativity and innovation to their tasks,[15] and an increasing number of returning overseas Chinese as a result of

[15] For example, in the 973 program, those under 45 have accounted for 44.6 per cent of all chief scientists and 62.8 per cent of all project heads. See National Science and Technology Plan Annual Report (2006).

continued high economic growth and policy encouragement.[16] If the Chinese government can create mechanisms to ensure that talented people can devote their time and energy to research, then China might be able to achieve these two targets, but the link is tenuous at best.

Another target is foreign technology reliance. To meet this target, foreign technology purchases will need to be limited to an 8 per cent annual growth rate on average over the next fifteen years.[17] Between 2000 and 2005, the average annual growth rates of foreign technology purchases exceeded 30 per cent, though with large fluctuations (the lowest around -20 per cent in 2004 and the highest up to nearly 100 per cent in 2002) (see Liu, 2006). Hence a substantial change is needed for China to meet this target. The linkage of this target to broader TFP and GDP growth is also an issue, and in all probability implies negative impacts.

The last set of issues involves education. Human capital is typically seen as important for economic growth for two reasons (see Barro, 2001). First, more human capital facilitates the absorption of superior technologies from technology leading countries. Second, since human capital is slower to adjust than physical capital, a country that starts with a high ratio of human to physical capital can grow rapidly by adjusting upwards the quantity of physical capital. In view of the importance of education in China's economic

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[16] David Zweig (2006) says "A similar 'reverse brain drain' is underway in mainland China. The number of returnees hit 30,000 in 2005, up from 7,000 in 1999." However, over 50 per cent of the returnees lack working experience, "they might be as much a burden as a benefit to the Chinese state."

[17] We calculate y/x from the two equations

$$\begin{cases} x / [\, x + (GDP \times 1.57 \times 1.34\%)] = 38.9\% \\ y / [\, y + (GDP \times 4 \times 2.5\%) = 30\% \end{cases}$$

where GDP is in constant 2000 US dollar, then GDP*1.57*1.34 per cent in the upper equation reflects GERD in 2005, and GDP*4*2.5 per cent in the lower equation reflects expected GERD in 2020 These imply that x/y is about 3.2. The average annual growth rate is derived using a similar calculation to that for industrial R&D.

growth and a shortage of education financing, a series of reforms have been carried out since 1990s, including decentralization of financial responsibilities for education (Bray and Qin, 2001), participation of enterprises, placing companies and research agencies in the management and administration of institutions, and institutional amalgamation (combination of previous separate institutions) (Yang, 2000).

But these reforms have also been criticized. Rui Yang (2000) argues that China separates the underlying values from the system when it adopts from Western education. For instance, China may promote science and technology, but without respect for academic freedom and institutional autonomy. Gopinathan (1997) argues that global economic competitiveness cannot be assured by a model of schooling with a heavy emphasis on a common curriculum and mastery of content as currently emphasized in the Chinese education system. Another problem is rising education expenditures becoming a heavy burden for Chinese households to the point that educational attainment suffers. A survey conducted by Horizon Key (Zhang and Yuan, 2006), a private market survey company, indicates that education expenses may now account for about one third of household outlays on average. The 2004 National Economic and Social Development Statistics issued by the National Bureau of Statistics show that the growth of education expenses in rural households has been over 20 per cent since 1997, while their net income has increased only 6.8 per cent.

The impacts of qualitative targets in the growth strategy remain. Though achieving quantitative targets may lead to changes in scientific and technical activities, they do not in themselves explain how these activities lead to product or process innovations. Thus Freeman (1995), Kim and Nelson (2000) and others have argued that qualitative factors affecting the national system of innovation need to be taken into account as well as quantitative indicators since they facilitate change. For China's case, the qualitative targets as listed in Table 1 summarizing the *S&T Guidelines 2006-2020* are supported by institutional reform initiatives, but as these changes can only be implemented gradually, their impact will likely be slow and diffuse.

Summary

In summary, a TFP target set as 60 per cent of GDP growth could meet a GDP growth objective of a minimum of 7.5 per cent per year until 2020 both if the initial TFP residual is high enough and policy initiatives are assumed to affect TFP growth of both foreign invested enterprises and other enterprises equally. If only TFP growth of non-FIEs is affected, the initiative would seem likely to fall short. Moreover, the links between TFP growth and various instruments to raise it, such as the GERD/GDP ratio, foreign technology reliance, number of patents or published scientific papers are unclear. It is also unclear whether targets for these instruments can be met. Among the four, GERD/GDP is the most likely to be achieved given the substantial budgetary commitments and tax incentives the Chinese government is providing. Changes in foreign technology reliance seem hard to achieve if there is little change in foreign technology purchases and it is also unclear if these affect TFP growth positively or negatively. The two remaining targets, i.e., number of invention-type patents and number of internationally cited scientific papers rely heavily on domestic intellectual capabilities, and if human capital is slow to adjust, these targets may be ambitious.

5. Comparisons with Japan and South Korea

We finally turn to the issue of whether experience elsewhere in Asia offers any guide as to the likelihood of success in the Chinese technology upgrading strategy. Japan and South Korea are two clear examples representing extraordinary success first at both technological and economic catch-up and subsequently sustained growth - Japan's growth is of long standing, going back to the Meiji restoration of 1868. After the Second World War, Japan rapidly recovered and achieved "Miracle Growth" from 1953 to the late-1970s. However, in the 1990s, growth slowed substantially and turned negative for several years. South Korea achieved rapid growth per capita output of 7 per cent annually from the 1960s, growth rates were especially high in the 1980s and 1990s, and still has strong growth today.

What were the sources of this high economic growth and are there common features with China accounting for their success? Could China's technology policy improve the chances of maintaining a high growth rate by drawing on these experiences?

From a historical perspective, all three of these countries have followed (or will follow) a similar sequencing in terms of sources of output growth in the process of the industrialization, i.e. physical capital, human capital and finally technical progress. Though the sequencing seems to apply to most developed and developing countries in their industrialization processes,[18] what distinguishes Japan is the relatively long high growth period. Japan underwent industrialization for nine decades from the 1880s to the 1970s. Thus even before it entered the "Miracle Growth" stage, it has already established the necessary infrastructure, enhanced human capital, accumulated physical capital, imported and adapted of foreign technology, and achieved scale economies (Mosk, 2004).

[18] Lau (1996) argues that much of the economic growth in the late nineteenth and early twentieth centuries can be similarly (now with New Industrialized Economies) explained by the growth in tangible capital and labour inputs. Technical progress was not found to be a significant source of US economic growth until the studies of Abramobitz (1986) and Solow (1957) for the period starting in the late 1920s. The same was also true of the Japanese experience.

South Korea's industrialization is more recent, beginning in the 1960s. At that time, it was short of both capital and technology, so it had to rely on long-term foreign loans to finance industrial investment and promote technology transfer.

Exploring sources of high output growth, Denison and Chung estimate that of Japan's average annual real national income growth of 8.77 per cent over 1953-71, input growth accounts for 3.95 per cent (accounting for 45 per cent of total growth) and growth in output per unit of input contributes 4.82 per cent (accounting for 55 per cent of total growth) (Denison and Chung, 1976). Maddison (1998) produces similar findings, indicating that productivity growth was important, but not the sole determinant of growth. Hayami (1999) compares the changes in the sources of modern economic growth in Japan and the United States, finding that the Japanese High Growth period (1958-1970) was characterized by both high capital input growth and technical progress while US growth was mainly driven by technical progress in the comparable period (1929-1966) as reflected in the TFP contribution figure of 53 per cent in Japan and 80 per cent in the United States.

This raises the issue of why Japan did not make the same shift to efficiency-based growth as in the United States, especially in "High Growth" period when Japan was able to catch up the advanced industrial economies in the West. Hayami concludes that a significant lag in any shift to efficiency-based growth characterizes newly industrializing economies in their process of catching up advanced economies using borrowed technology. According to Alexander Gerschenkron (1962), the later a country starts industrialization, the more heavily it relies on technology borrowed from its predecessors. Furthermore, the later the start of industrialization the more advanced high capital intensity and labour-saving technology tends to be imported.

Hayami (1999) argues that capital-using and labour-saving biases in borrowed technology for recipient economies can be strengthened by international trade and foreign direct investment. One explanation lies in the theory of product cycles of Raymond Vernon (1966) which implies that advanced industrial economies tend to specialize in R&D and new product development activities with intensive use of high human capital, whereas Newly Industrializing Economies (NIEs) tend to specialize in standardized mass production based on automatic machinery and cheap labour. Another explanation lies in the fact that more capital goods embodying new technologies are imported from advanced economies. Thus the physical capital-using bias in NIEs and the human capital using bias in advanced economies reinforce each other through international trade and foreign direct investment.

Both of these features - sequencing of sources of output growth and catch-up development based on technology borrowing - imply that low wage countries will rely more heavily on capital input growth than technological progress during their early industrialization period. However, such a development pattern is not sustainable. Chang-Soo Lee (1998) studied the South Korean manufacturing sector using a disaggregated growth accounting approach and found that the contribution of capital to growth is high for South Korean manufacturing. However, productivity growth was still the largest contributor to output growth in eight of fifteen industries, and productivity growth explained about 38 percent of output growth for manufacturing overall. He also found that an interaction between productivity growth and capital input growth was present for nine of the fifteen industries, supporting the hypothesis of embodied technology in capital input growth. He drew the conclusion that the argument that disembodied technological change is the only source of sustainable economic growth may hold for a leader country which achieves higher productivity growth mainly by accumulating new knowledge through innovation. However, the growth process for a follower country is different, it will adopt neither a typical accumulation-based nor an efficiency-based growth pattern but a mixture of the two.

There are both common and different elements between all three countries. The high savings rate shared by Japan, South Korea and China is also an important source of high capital input growth. Savings rates were especially high during high growth periods for these countries. The ways in which these three countries have executed transfers of technology are, however, different. Japan was import substitution-oriented while both South Korea and China were export-oriented. Given the channel of technology transfer, China is more reliant on FDI for technology transfer while Japan was more dependent on technology trade.

Sakakibara and Cho (2002) document how Japanese policies restricted imports and direct investment until 1964 when Japan obtained the status of an article eight country in the International Monetary Fund. They also argue that restrictions on imports and direct investment facilitated technology transfer from western countries to Japan in the early post-war years because the only way foreign firms were able to profit from their technology in Japan was to sell it. In Japan, the introduction of foreign technology was mainly through licensing of essential technologies, and the Ministry of International Trade and Industry (MITI) played an important role. Acting as a single buyer of technology, it successfully reduced the royalties Japanese firms had to pay for technology licenses. It also encouraged rapid diffusion of technology by keeping domestic patent periods short (Mosk, 2004). This strategy worked so successfully that even developed countries admitted that the rate of technical change and of economic growth depended more on efficient diffusion than on being first in the world with radical innovations, and as much on social innovation as on technical innovation (Freeman, 1995).

In South Korea, its first five-year economic development plan which started in 1962 began with promotion of import-substituting industries, but soon shifted to export-oriented industries to repay foreign loans. However, its technology transfer has been more reliant on foreign loans than on FDI. In order to expedite the development of export industries, the government adopted a policy of promoting assembly industries of final goods which prompted importation of foreign capital goods, essentially the "turnkey" system. The government organized large-scale foreign loans and allocated them for investments in selected industries, and industries later reverse-engineered the imported capital goods to acquire the necessary technology. But the pattern was different across sectors. Its light industries relied on original equipment manufacturer (OEM) production arrangements, chemical industries resorted to turn key-plant importation with technical training, electric and machinery industries depended relatively more on foreign loans.

China adopted its policy of opening in the early-1980s and its policy of promoting FDI inflows in the early-1990s. Since then, China has become progressively more reliant on foreign trade and FDI. In 2004, FIEs produced 22 per cent of China's GDP and over 55 per cent of China's exports (Whalley and Xin, 2006). Trade surpluses and inward FDI have also contributed to capital supply, and in turn, economic growth. The growth of FDI has brought with it new technologies, termed by the Chinese government the "market for technology".

Even though FDI's positive role in technology transfer (or technology spillover) is emphasized in older studies,[19] more recent

[19] See for example Caves (1974); Globerman (1979); and Blomstrom (1986).

work casts doubt on this conclusion. Aitken and Harrison (1999) showed that earlier findings in support of positive spillovers are likely to be driven by the endogeneity of FDI which means FDI chooses to go to better performing industries. Once industry specific factors are controlled for, there is no evidence for positive spillovers. Hu and Jefferson (2002) studied China's electronic and textile industries and argued that in the short-run, firm level FDI enhances the productivity of FDI receiving firms, but it also depresses that of non-FDI domestic firms. FDI can thus reduce the productivity and market share of domestic firms in the short term, but in the longer term those domestic Chinese firms that are able to survive in the face of competition from FDI firms seem able to capture some of the technology and know-how that is introduced from abroad. Hu et al. (2002) also argue based on Chinese LME data that FDI can create channels that reduce the transactions cost of technology transfer within firms, but that the presence of foreign investment and foreign expertise need not enhance arm's length market-mediated foreign technology transfer. Both Hu et al. (2005) and Markusen and Venables (1999) thus argue that R&D and technology transfer are highly complementary.

This phenomenon of shift is supported by Kim and Stewart's (1993) empirical study on the relationship between domestic R&D and imports of technology for 10 countries. They found strong complementarity between technology imports and domestic R&D for Japan and South Korea, weak for France, none for Germany and the US. However, Japan revealed a sharp decline in the ratio of technology payments to R&D spending; and Korea followed in its steps. So they argue that complementarity appears to weaken in later stages as technology development strategies shift from dependent to imitative to autonomous or offensive technology development.

Consistent with the hypothesis of sequencing of sources of output growth, Japan and South Korea both moved to indigenous R&D, the route that China is now attempting to follow. In Japan, the shift from technology licensing to domestic R&D occurred in the 1960s when the technology cycle was still relatively long, and Japanese firms were able to digest and sequentially develop activities in the whole value chain. R&D in Japan was mostly undertaken by the private sector, and industrial policy was mainly focused on encouraging companies to conduct R&D. By the early-1970s, large Japanese manufacturing enterprises had by and large become internationally competitive, even though Japan later continued to close the gap in income per capita between itself and the United States (Mosk, 2004).

In South Korea, indigenous R&D promotion occurred in the 1980s.[20] At that time, there was an increased demand for complex and sophisticated technologies and an increasing reluctance of foreign countries to transfer technology. Korea now ranks sixth in R&D investment among OECD countries. GERD over gross national product (GNP) has risen from 0.77 per cent in 1980 to 2.96 per cent in 2001.[21] The ratio of government to private funding has fallen from 64:36 in 1980 to 26:74 in 2001. However, it is also widely accepted that Korea has not achieved the same degree of success as Japan in indigenous R&D, and the research component in R&D is small. A summary of this might be that Japan has been successful in both imitation and indigenous R&D while Korean successes lie in creative imitation rather than in

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[20] Sakakibara and Cho (2002) argue that the first R&D promotion policy can be found in the Technology Development Promotion Law of 1972. However, the Korean government did not play a significant role in R&D promotion until the 1980s. The role of the government in R&D promotion was limited to the establishment of national research to support industrial technological learning, and funding university based R&D.

[21] These numbers are cited from Youngrak Choi's presentation at PICMET'04 Symposium, 31 July-4 August 2004.

indigenous R&D, while China, up to now, has not been especially successful even in creative imitation.

The challenge that China sees for itself is to encourage indigenous R&D. According to the World Development Indicator database, GDP per capita measured in constant 2000 US dollars was already above 7,000 in Japan in the 1960s, over 3,000 in South Korea in the 1980s when their technologically-led growth accelerated, however China is now only around 1,500 in 2006. If the domestic market is insufficient to absorb high technology products, China has to rely on world market, and will face more competition than South Korea from world markets. Competition also comes from FIEs in domestic markets as well. Both Japanese Keiretsu and Korean Chaebol played an important role in the catching-up process, but comparable firms have yet to emerge so strongly in the manufacturing sector in China.

The later a country starts industrialization, the more capital rather than technology reliant it must be in its early growth phase. In South Korea and China, export-oriented growth increased reliance on growth of capital inputs. In the face of competition in export markets, they resorted to capital good imports to increase productivity. South Korea probably did better than China in acquiring technology embodied in capital goods through reverse-engineering, perhaps due to their indigenous R&D effort. If China is to use an indigenous R&D strategy, domestic demand and domestic enterprise structure pose two outstanding challenges. China does have some advantages, such as potential but as yet unapplied technology based on a long-standing national science and technology system and defence industry, overseas talent expected to be attracted by China's high economic growth, financial support reflecting the size of both current GDP and further economic growth. Under this view, China might have a promising future in technology upgrading and in turn continued economic growth through indigenous R&D, but it is far from certain that it will be sufficient alone to sustain current high growth rate.

6. Conclusion

As China's current trade- and FDI-driven growth is perceived to face growing problems in the years ahead, this paper turns to an analysis of China's latest technology upgrading strategy. Relative to previous science and technology strategies for sustaining high growth, developing domestic innovation capacity is emphasized as the dominant focal point.

A series of objectives, targets and instruments are set out in both the 11th five-year plan and the guidelines for the period 2006-2020. The overall objective set is to meet a minimum annual growth rate of 7.5 per cent until 2010, and 7.0 per cent until 2020 under the constraints of mandatory indicators for environmental protection and energy saving. Shifting growth from input-driven (including capital, energy and environment) to technology upgrading-driven is thus the priority issue on Chinese government's growth agenda. A series of targets have been set for the next 15 years, including: TFP growth is to reach 60 per cent of GDP growth; GERD over GDP ratio to reach 2.5 per cent; foreign technology reliance to fall to 30 per cent; the number of invention-type patent grants gained by Chinese inventors to rank in the top five in the world; and the number of internationally cited scientific papers by Chinese authors to rank in the top five in the world.

Instruments for achieving these targets have also been announced. The first is to increase funding for science and technology from both government and private sectors. The second is to improve the efficiency of use of funds through monitoring mechanisms, enterprise-based market mechanism, large capital equipment and knowledge sharing platforms and basic scientific information sharing platforms. The third is to promote domestic innovation through government procurement of domestically innovated products, foreign technology import regulation aiming to force advanced technology import and prevent repeated imports of technology; intellectual property rights protection and integration of innovation indicators into performance appraisal systems for both local government and SOEs; and finally, talent force accumulation through domestic talent cultivation and overseas talent attraction.

The question is whether these instruments can meet the required targets and whether the technology upgrading strategy can meet overall GDP growth objectives consistent with environmental protection and resource-saving targets. We report calculations based on growth accounting studies, suggesting that a TFP target of 60 per cent of GDP growth may help to meet the GDP growth objective, but also note that TFP as a target is hard to discuss in a growth accounting framework since TFP is a residual. Also, there is a critical issue of whether the majority of TFP growth is currently FDI related and non indigenous, and hence largely beyond the reach of current policy. Given the substantial R&D tax and other incentives in the strategy, targets for GERD over GDP may well be achieved. In turn, the targets for foreign technology reliance might be achievable, but whether they relate positively to TFP targets remains unclear. Two remaining targets relate to scientific papers and invention-type patents and these will be subject to a slow adjustment process and might take longer to realize.

Finally, we examine Japanese and South Korean growth experience to see whether there are any indications from international comparison as to whether it is possible for China to sustain its future growth using a technology upgrading strategy. The commonality of experience shared by these three countries is that they have initially achieved extraordinarily high growth based largely on technology borrowing, and large capital input contribution to GDP growth, but this growth eventually becomes unsustainable. Japan and South Korea thus moved to indigenous R&D generation along with improved foreign technology adoption as well as enhanced domestic innovation capacity. To implement China's indigenous R&D strategy, there are new challenges, including more competition in both export market and from FIEs on domestic market, together with limited domestic demand. However, China has advantages that Japan and South Korea did not have, among which are large potential labour transfers from rural to urban areas.

Whether China will be successful with their strategy remains to be seen. The current expectation globally seems to be that China is embarked on a historic transformation involving sustained growth for several decades, and so continued growth is factored into both asset markets and investment decisions in China. But we have seen interruptions of growth elsewhere in the world, and interruptions cannot be ruled out in the Chinese case. The new strategy while vague, however, is concrete and seems realistic and can only help in maintaining growth. Whether the cost in foregone consumption today of implementing the strategy pays is perhaps the harder question to answer.

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