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Belton M. Fleisher

Mi Zhou

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CENTRAL UNIVERSITY OF FINANCE AND ECONOMICS

中央财经大学中国人力资本与劳动经济研究中心

39 Xueyuan South Road, Haidian District, Beijing, China 100081

Web: http://humancapital.cufe.edu.cn

Phone & Fax: 86-010-62288298

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Belton M. Fleisher

Department of Economics Ohio State University &

Center for Human Capital and Labor Market Research,

Central University of Finance and Economics &

IZA

and

Mi Zhou

College of Economics and Trade Hunan University

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Abstract

Has upgrading and enforcing its patent laws slowed China's economic growth? The answer we draw from detailed analysis of provincial aggregate data covering roughly the period 1990 through 2007 is strongly negative. An upper bound estimate is that the patent laws contributed nearly two-thirds of China's TFP growth over the period following adoption of the 1993 patent law. A more plausible, difference-in-difference, estimate of the impact of the 1993 and 2001 patent laws is that in their absence China's TFP growth over the period 1993-2007 would have been marginally smaller after we control for the impacts of Deng Xiaoping's "South Trip" and China's accession to WTO. The patent laws are estimated to have increased TFP growth through increasing the rate of new technology embodied in physical capital and also through intangible capital associated with FDI inflows. Virtually none of the laws' impact on TFP growth can be directly associated with increased R&D, although R&D is strongly positively correlated with promulgation of the patent laws. The insignificant, or possibly negative, impact through R&D may be due to inadequate GDP accounting for R&D expenditure in GDP and investment accounts.

JEL Codes: O31, O33, O34

Key words: Patent law, Intellectual Property Rights, TRIPS, TFP Growth

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1. Introduction

One of the most important aspects of China's entry into the World Trade Organization (WTO) in November 2001 was the requirement that it participate in the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs). Participating in TRIPs required that China adopt stricter Intellectual Property Rights (IPR) protection, so that its patent law, first passed in 1984, promulgated in 1985, and revised in 1992 (effective first day of 1993), and its enforcement would more closely match standards accepted by the world's major trading partners (Smith, 2005; Yueh, 2009). We use the 1992 and 2001 legislative milestones to investigate the impact of IPR protection on aggregate correlates of innovative activity and its impact on technology growth in China. To the extent that a developing country, such as China, has benefited from externalities generated through copying innovations generated elsewhere, without paying to do so, it may experience a slowdown in productivity growth as innovation is discouraged and technological growth retarded. On the other hand, if innovative activity is increased because investors in R&D can now reap more of the gains obtained because of increased patent protection both in the developing country and in advanced economies, then economic growth may be enhanced. In the next section we briefly survey the literature in the impact of IPR protection in a global context. Section 3 presents an overview of the data on R&D expenditure and patent applications in China and develops hypotheses tested in this paper. Section 4 presents our empirical results, and section 5 concludes.

2. Recent Research in IPR Protection in the Context of International Trade.

A major issue in research on intellectual property rights (IPRs) is whether a country with relatively little original innovation activity will benefit from strong patent protection. Effective patent laws increase imitation costs but do not necessarily increase innovative activity, and research on whether innovation falls or rises after increased IPR protection has produced mixed results. Much early research on the impact of patents on imitation costs finds that patents do increase imitation costs but fail to provide perfect protection to patent holders from imitation, that patent protection did not seem essential for the introduction of a significant number of innovations, and that the impact of patent protection on innovation and the number of patents varies widely across industries (Mansfield, Schwartz and Wagner, 1981, Levin, Klevorick, Nelson and Winter, 1988, Arundel, 2001, Moser, 2005). On the topic of developing nations in particular, theoretical work of Chin and Grossman (1991) sets the issue in a North-South framework and concludes that under strong and effective patent protection, the less-advanced "South" will lose benefits derived from copying technologies developed by the industrially advanced "North." Grossman and Helpman (1991a and 199b) and Deardorff (1992) add that IPR protection is likely to strengthen the market power of innovating firms in the North vis-à-vis the South and leads to higher prices in developing countries. Branstetter, Fisman, and Foley (2006) provide a concise summary of much of the previous research on the "North-South" impact of increased IPR protection in developing nations. Helpman (1993) adds that patent laws in the South can lead to more direct competition with innovations from developed countries and lead to a reallocation of manufacturing towards higher priced Northern products and a reduction in global welfare. Grossman and Lai (2004) expand on earlier work to consider the implications of requiring all participants in WTO to join in TRIPs. Their analysis leads them to conclude that the international coordination of IPRs under TRIPs has more to do with the distribution of the gains from trade to the benefit of the North rather than promoting increased global efficiency. In related work, Glass and Saggi (2002) develop a model in which the disincentive effects of the South's increased difficulty to imitate under effective IPR protection lead to resource waste and reduction of both foreign direct investment (FDI) and innovation in the South.

Arguments that IPR protection effectively benefits developed economies over the developing notwithstanding, there is a substantial body of research that points in the opposite direction. Most of these papers attack in one way or the other the implicit or explicit assumption that developing countries would have the same access to existing technology innovated in the North with and without stronger patent protection. If stronger patent laws do no more than to increase imitation costs, developing economies may lose, at least in the short run. Perhaps most fundamentally, writers supporting the possible beneficial impact of agreements such as TRIPs argue that the technological needs of the North and the South are likely to be dissimilar[2]. Diwan and Rodrik (1991) allow Northern and Southern

[2] Another line of this contrarian scholarship points out that Northern countries have the

countries to have different technology requirements. This is a reasonable assumption given that North and South are postulated to have different relative factor endowments. They argue that without the Southern protection of IPRs, Northern countries would not develop technologies beneficial to the South. Clearly, potential gains from trade and the optimal international allocation of resources will not be realized to the extent that global trade and investment is discouraged by limits on the ability of the North to reap returns on their R&D investments (Maskus and Penubarti, 1995; Maskus, 1998). Moreover, it is likely that IPR protection, especially if there is a body of well-trained workers (whose salaries are relatively low) encourages R&D activity in the South (Chen and Puttitanun, 2005). China appears to have experienced such an increase in R&D (Chen and Chen, 2006). One specific example of an important technology advance is described in Huang, Zhang, Song, and Lang (2007).

Hu and Jefferson (2009) use data from China's annual Survey of Large and Medium Size Enterprises (LMEs) to explore five hypotheses potentially explaining the surge in patents applied for and granted in China since the mid 1990s. The LME surveys began after adoption of the 1993 patent law, so only the impact of the 2001 patent-law upgrade can be estimated. However, their sample permit them to estimate the separate impacts on patent applications of R&D expenditures, FDI, type of patents typical of an industry ("discrete" or "complex", that is a single patent for a product or a set of interrelated patents for a product), and type of ownership (private, state, foreign invested, etc.). They find a significant impact of the 2001 patent law and also positive impacts of R&D and of ownership type. However, they do not to attempt estimate the impact of the 2001 patent law on FDI and R&D expenditures.

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option of protecting their R&D investments informally by making their technology more difficult to copy, which not only involves deadweight costs and reduction of R&D expenditure worldwide, but also reduces the profitability of imitation (and hence "free" technology transfer) by the South. This reaction can result in less efficient research technology and less Northern innovation than there would be under IPR protection (Taylor, 1993, 1994; Yang and Maskus, 2001).

3. Overview and Modeling the Impact of China's 1993 and 2001 Patent Laws

We first provide an overview of major trends in the major variables analyzed in our research and next develop simple hypotheses to test the impacts of IPR protection on important indicators of the development of intangible technology capital and its embodiment in physical capital. In our overview we focus on three economic activities that are likely to be directly impacted by effective IPR protection: (i) patent applications[3] is perhaps the most obvious; (ii) R&D expenditure, because investment in the development of new technology is likely to become more profitable to the extent it becomes easier for firms to internalize the resulting economies through patent protection; and (iii) FDI,[4] because the kind of technology embodied in FDI as well as the quantity of inward FDI is likely to respond positively to a reduction in the likelihood of unwanted loss of secrets of the trade that can be provided by increased IPR protection.

It is also useful to provide a background for our categorization of industries by technology level. Table 1 shows the manufacturing industries covered in this research, grouped by technology level as measured by the ratio of R&D expenditure to sales (R&D intensity). This categorization follows the method used for OECD economies as described in Hatzichronoglou (1997)[5]. The OECD classification consists of four categories : high-technology, medium-high-technology, medium-low-technology, and low-technology industries. Although the classification of Chinese industries according to R&D intensity is quite similar to the placement of the same industries in OECD countries as reported in Hatzichronoglou (1997),

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[3] We focus on patent applications rather than patents granted because the lag between applications and grants is not fixed and thus makes it more difficult to specify meaningful lags in specifying structural relationships to be estimated. Awukose and Yin (2009) actually use patent applications as their principal measure of IPR protection in study of the impact of IPR protection on FDI in China. The reason for this would appear to be that they do have usable data on changes in IPR protection within all of the countries in their cross-national sample.

[4] We refer to the OECD/IMF definition of FDI, which can be found at http://www.oecd.org/dataoecd/10/16/2090148.pdf

[5] There are actually two OECD industry classifications. The other one uses only the direct R&D intensity expressed as the ratio of R&D expenditures over either gross output or value-added and distinguishes three categories of industries, namely the high-technology, the medium-technology, and the low-technology industries. The one this paper used is the revised one.

the *level* of R&D intensity in China has been much lower than in OECD countries.[6] As indicated in the table, we group Chinese industries into only two categories: high-tech and low-tech, because visual inspection of the differences in R&D intensity suggests that little is to be gained by a finer definition, and we benefit from the simplicity of using two, instead of four, categories.

Patent Applications. It is perhaps most obvious to begin our overview of the impact of increased IPR protection with an examination of patent applications. Chinese patent law classifies patents in two categories: (i) innovation patents (inventions) and (ii) design patents (utility models & designs). The second category mainly applies to packaging and other external aspects of products, while the first category more closely approximates new production technology. Innovation patent applications receive much more intense scrutiny for validity than do applications for design patents (Hu and Jefferson, 2009). In figure 1, we see that total innovation patent 7 applications have been rising steadily since 1985, when the first patent law became effective. A comparison with the log-linear trend fit to the data indicates that while patent applications rose above trend around the time of the 1993 patent law and following the 2001 patent law, the overall series is notable more for its steady pace rather than sharp upticks following the 1993 and 2001 laws. As Hu and Jefferson (2009) show, IPR protection is only one of a number of possible explanations for China's "patent explosion."

Figures 2a and 2b depict patent applications broken down by enterprise ownership8 and industry technology level as defined above. These data are available only for large and medium enterprises and exclude patent applications by small enterprises and other

[6] Another definition of an industry's technology level might be based on patent citations divided by industry sales as used in Vichyanond (2009), table 1. This index appears to be less satisfactory than the index based on R&D expenditures. For example, the industry Pottery, china, and earthenware has a patent intensity index much closer to that of the industry Professional and scientific equipment than to Food products in the patent-intensity definition; the Furniture, except metal industry is in the top quartile of industries according to patent intensity. These industry placements appear to lack face validity and are far different than their placements according to R&D intensity.

[7] All references to "patents" in this paper refer to innovation patents unless otherwise indicated.

[8]A firm that is partly or wholly owned by a foreign entity is classified as a *foreign invested enterprise (FIE)*; all other firms are classified *domestic*.

institutions, such as universities and research academies. They are available in published documents only since the year 2000. The two figures both indicate a roughly steady upward trend in innovation patterns over the period 2000 through 2007, with a marked uptick for FIEs following adoption of the 2001 patent law. The response by FIEs is consistent with the hypothesis that bringing IPR up to TRIPs standards (or at least taking major steps to do so) stimulated FIEs to apply for patents in China that represent a stock of technology previously developed in their home countries. .[9]

R&D Expenditure by Ownership and Technology Level. Figure 3 illustrates total R&D expenditure in China from 1990 and figures 4a and 4b depicts R&D expenditures by LMEs, broken down by foreign and domestic ownership, and for high-tech industries, respectively for the years1998 through 2007. (1990 and 1998 are the first years for which public data are available.) through 1997. Visual inspections of the series in figure 3 suggests an acceleration of R&D growth prior to both the 1993 and 2001 patent laws. This uptick is also apparent among FIEs in the high-tech sector in figure 4b (before the 2001 law).

FDI and Foreign Invested Enterprises. The relation between FDI, technology transfer, and economic growth has been subject to a vast amount of research on China and other developing and advanced economies. The growth of China's inward FDI has been spectacular, as shown in figure 5 (measured in 1990 U.S. dollars), increasing by more than 400-fold between 1980 and 2007. Visual inspection of figure 5 suggests a marked increase in the trend

[9] Strictly speaking, we should divide technology into two categories: (i) managerial technology, which may be embodied in foreign management personnel and (ii) technology embodied in physical capital. Neither category is necessarily associated with FDI, which may involve only a foreign enterprise taking a significant share ownership in a domestic firm without any investment of fixed capital or contribution of managerial knowledge or personnel, although such a hands-off approach to foreign investment would seem unlikely. However FDI, even if no managerial or fixed capital are directly contributed by the foreign investor, may well be associated with transfer of patented or non-patented technology (e.g. chemical formulas, management structure, and so on). If the technology is patented in the home country, then we should expect the foreign investor to apply for a patent in the host country. Application for a patent in the host country may well be a necessary condition for investment in physical equipment that embodies the new (to the host country) technology. Data on (ii) are approximated by fixed investment of foreign-involved enterprises (FFI). Unfortunately, FFI data are not available by province for the time period studied in this research.

of FDI preceding the 1985 and 1993 patent laws, but no such surge following the 2001 law and China's WTO accession. Figure 6 shows how FDI has generated the importance of FIEs in total industrial output. Since 1998, the first year for which such data are available in public sources, the ratio of the output of FIEs to total output of LMEs has surged from slightly more than 20% for all manufacturing to about 40% and from about 26% to nearly 50% in high-tech manufacturing. Visual inspection suggests a significant increase in the upward trend following the 2001 patent law, especially for enterprises in the high-tech manufacturing sector.

Innovation, Technology Transfer, and Embodied Technology. We expect that FDI as well as investment in R&D by both domestic and foreign-invested enterprises increases in productivity due to new technology that may be embodied in new capital formation, but which may also be embodied in human resources, e.g., managerial technology. In order to gain perspective on the degree to which innovation activity is channeled through new technology, we follow Nelson (1964) and Wolff (1991) and postulate that an important component of new technology is embodied in new physical capital, and the rate of embodied technology growth should be positively related to acceleration of the physical capital stock (first difference of the rate of increase in the capital stock). Acceleration of the physical capital stock in China since 1984 is depicted in figure 7; acceleration increased following both the 1993 and 2001 patent laws, which suggests there may have been a positive influence of IPR protection on new technology embodied in physical capital.

Methodology and Hypotheses. Obtaining unbiased estimates of the 1993 and 2001 patent laws it is complicated two problems: (i) by the existence of immediately preceding or contemporary events that could in principal also influence variables of interest, including R&D, patent applications, FDI, and technological progress and (ii) possible endogeneity of some regressors. We discuss our procedures for dealing with these two complications below.

(i. Contemporaneous events). The 1993 patent law followed closely on Deng Xiaoping's famous "South Trip" that encouraged acceleration of various market reforms and possibly the 1993 patent law itself, while the 2001 patent law was a condition of China's entering WTO. Thus the problem arises, how to separate the impact of patent legislation from the effects of other major changes in the political and economic environment that occurred at nearly the same time? Our method is to specify ways in which the South Trip and entering WTO affected the Chinese economy other than through IPR protection and to estimate their impacts, if any, simultaneously with the impact of the patent-law innovations on R&D expenditure, patent applications, and FDI, and the embodiment of new technology.

One of the major policies following the South Trip was the expansion of various special business zones (e.g., Special Economic Zone, Economic Development Zone, Bonded Area, New and High-Technology Development Zone) to previously less-favored cities and provinces. These zones feature a heterogeneous mix of reduced tax rates, tariff reductions, absence of restrictions on foreign financial institutions, and other policies designed to attract foreign investment and FIEs. Before the South Trip, such zones were found in widely varying numbers mainly in coastal provinces and the northeast, although there were some small zones in inland provinces as well. Beginning in 1992, the number and variety (in terms of special tax rates, favorable treatment for FIEs, foreign investment, and other inducements to new businesses) of these zones increased sharply in both number and geographical distribution. The evolution of special business zones after 1992 was unevenly distributed across locations and over time, whereas the 1993 patent law occurred at a unique point in time and, at least in principal, applied to all locations equally. We include the number of special business zones in each of three categories as a proxy for the quality of the business environment in each province that should permit us to separately identify the impacts of Deng Xiaoping's South Trip the 1993 patent law innovation on variables affected by IPR protection.

Separating the impact of China's accession to WTO from the impact of the 2001 patent law also requires us to specify a variable distributed over space and time in a way that is plausibly distinct from the impact of increased IPR protection. The value of exports varies widely across provinces and is our choice of a variable to reflect the direct impact of WTO accession that is distinct from the impact of patent-law protection. Since exporting firms are geographically concentrated, while the impact of increased IPR protection presumably improves the innovation environment everywhere, incorporating the value of exports should allow identification of separate WTO and patent-law effects. There is possibly an endogeneity problem with an export variable. The payoff to R&D and patent activity comes from lower production costs and improved product quality and variety that would lead to increased exports. However, it is likely that these effects on exports occur with a much longer lag than that of WTO accession's direct effect on sales of Chinese firms to other countries starting at the end of 2001. Thus concurrent or lagged exports should serve as a suitable variable to identify the impact of WTO accession on R&D, patent activity, and technology growth separately from that of the 2001 patent law.

Our use of the number of special zones and of exports to capture the impact of omitted variables correlated with the impact of the patent laws can be challenged on grounds (1) that they are imperfect proxies for the events they represent and (2) that there may be other, unobserved, omitted variables that are correlated with the impact of the patent laws. In order to meet this challenge we specify regression equations that can yield difference-in-difference (DID) estimates of the patent law impacts. In order to obtain DID estimates we impose the hypothesis that industries with a high ratio of R&D expenditures are more likely to benefit from patent protection than are other industries. On the basis of this assumption, we calculate the ratio of production in high-tech industries (as defined above) to provincial GDP for each province in our sample. After examination of the distribution of this ratio across all provinces in the year 2000 (the earliest year for which we can obtain data on industry production by province), we identify seven "high-tech" provinces and 21 non-"high-tech" provinces.[10] We then infer the impact of the patent laws from their estimated impact in high-tech provinces relative to the others while holding constant the other variables specified above to represent the South Trip and WTO impact.

(ii. Endogeneity) All of the regression equations specified below contain a function of at least one of the variables hypothesized to be impacted by the patent laws as a regressor. We treat any regressor that is a function of one of the five variables of interest enumerated above as possibly endogenous, test for endogeneity, and where indicated we estimate each regression using ordinary least squares (OLS) and two-stage least squares (2SLS).[11] For example, R&D stock is a regressor in the equation for innovation patent applications. To the

[10] Details are provided in the Appendix.

[11] Our first-stage equations do not use identical instruments, so we do not use 3-stage least squares.

extent that conditions affecting R&D activity depend on the likelihood of applying for a patent, there is a strong possibility of endogeneity between patent applications (dependent variable) and R&D (regressor); if there is learning-by-doing in FDI, current FDI will depend in part on expected future FDI; to the extent that the cost of R&D is lowered by past R&D and this economy is anticipated, another source of endogeneity is introduced. .

In addition to the procedures outlined above, we control for unobserved province-specific omitted variables by including a dummy variable for each province in every regression (one-way fixed effects).

We specify four equations, one for each of the possible channels through which IPR protection may influence variables basic to economic growth, as follows.

$$\ln Pat_t = \gamma_0 + \gamma_1 t + \gamma_2 Law93 + \gamma_3 Law02 + \gamma_4 Law93*High + \gamma_5 Law02*High + \gamma_6 \ln \sum_{t=0}^{t-1} FDI_t + \gamma_7 \ln \sum_{t=0}^{t-1} RD_t + \gamma_8 \ln Exp_t + \gamma_i \sum_{i=9,z=1}^{i=11,z=3} \alpha_i Z_z \quad (1)$$ [12]

Where all variables are province-specific (subscripts suppressed) except as noted, and

- Law93 and Law02 = dummy variables = 1 for years 1993 and later and 2002 and later, respectively; (the 2001 law was enacted in July, 2001); these variables are not province-specific;
- *Pat* = the number of innovation patent applications;
- *RD*= R&D expenditures measured in constant 1990 prices and the R&D stock is depreciated at an annual rate of 15%;
- *FDI* = foreign direct investment per worker, measured in constant U.S. dollars deflated to 1990, and the FDI stock is depreciated at an annual rate of 15%;
- *High* = a dummy variable = 1 for provinces that have a high proportion of "high-tech" industries, where the level of technology is based on the ratio of R&D expenditure to industry sales as defined above. The high-tech provinces, based on their R&D intensity ranking in the year 2000, are Zhejiang, Jilin, Guangdong-Hainan, Jiangsu, Beijing,

[12] Equation (1) is similar to the patent production function used in Hu and Jefferson (2009). However, our use of aggregate provincial data rather than micro firm data leads to differences between our specification and theirs.

Shanghai, and Tianjin, in ascending order;[13]

•*Exp* = the volume of exports at the national level in 1990 prices;

•*Z1, Z2, and Z3*, are the number of special business zones of types 1, 2, and 3, respectively;

• *t* = year of observation, 1988 through 2007 unless noted otherwise;

Full descriptions of the special business zones are contained in the Appendix.

We treat the lagged R&D stock, lagged FDI stock as endogenous variables in equation (1). In the absence of effective protection, firms may choose to avoid the risk of being copied by keeping their R&D results secret (and may engage in less R&D than otherwise). After a law becomes effective, firms may seek to patent innovations associated with their accumulated R&D stock. Current R&D may depend on anticipated patent applications. FDI may depend on the expected payoff to future R&D and to the likelihood of applying for patents (although FIEs have been less likely to apply for host-country patents than domestic enterprises).

$$\ln RD_t = \alpha_0 + \alpha_1 t + \alpha_2 Law93 + \alpha_3 Law02 + \alpha_4 Law93 * High + \alpha_5 Law02 * High + \alpha_6 \ln \sum_{t=0}^{t-1} FDI_t + \alpha_7 \ln \sum_{t=0}^{t-1} RD_t + \alpha_8 \ln Exp_t + \alpha_i \sum_{i=9,z=1}^{i=11,z=3} \alpha_i Z_z \qquad (2)$$

where variables are defined above.

We incorporate the lagged R&D stock as a regressor in equation (2) to capture the effect of accumulated past R&D expenditure. Following Romer (1990), we postulate that the return to R&D investment is an increasing function of prior R&D. Lagged R&D is treated as endogenous, because current R&D is plausibly linked to future conditions, e.g., anticipated patent-law changes and the impact of future productivity of R&D on the benefits of engaging in R&D today. We recognize that FDI is possibly endogenous in relationship (2) to the extent that R&D expenditures induce productivity growth, which in turns attracts more FDI (Li and Liu, 2005; Fleisher, Li, and Zhao, 2009). We justify using *S*, a measure of schooling in the workforce, as an instrument for FDI in relationship (2) (thus excluding it from the second-stage equation), because to the extent that some measure of human capital affects

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[13] The proportion of high-tech industries in total provincial GDP in the high-tech group ranges from about 41% to nearly 80%. In the remaining provinces, the proportion of high-tech industries in provincial GDP ranges from about 5% to about 31%

R&D, it is reflected in the lagged R&D stock.

The expected sign of FDI in relationship (2) is negative, given the much lower R&D expenditure exhibited by FIEs shown in figures 4b-4d. This hypothesis is consistent with the findings of Hu, Jefferson, and Qian (2005). However, improved IPR protection may contribute to a change in where FIEs conduct R&D. To the extent that in the absence of effective IPR protection, companies prefer to develop new technologies in countries where patent protection is more effective, the adoption of better patent protection in conjunction with China's growing population of highly trained scientists and engineers is likely to have altered China's comparative advantage in the production of new technologies (Chen and Dean, 2006). Thus, the relationship between the FDI stock and R&D expenditure and between the FDI stock and patent applications may well have been changed with the increased IPR protection incorporated in the 1993 and 2001 patent laws.

We recognize that FDI is possibly endogenous in relationship (2) to the extent that R&D expenditures induce productivity growth, which in turns attracts more FDI (Li and Liu, 2005; Fleisher, Li, and Zhao, 2009). Although the lag between the effect of R&D on productivity growth and the impact on FDI is likely to be considerably more than a year, we instrument FDI in 2SLS estimation of relationship (2). The instruments for FDI include the variables representing schooling, highway length, and wage (*S, H,* and *W*), lagged one year, as used in relationship (1) To the extent the level of workforce schooling affects R&D, it is reflected in the lagged R&D stock included as a regressor in relationship (2).[14]

$$\ln FDI_t = \beta_0 + \beta_1 Law93 + \beta_2 Law02 + \beta_3 Law93 * High + \beta_4 Law02 * High + \beta_5 \ln \sum_{t=0}^{t-1} FDI_t + \beta_6 \ln Pat_{t-1} + \beta_7 \ln S_t + \beta_8 \ln H_t + \beta_9 W_{t-1} + \beta_{10} \ln Exp_t + \beta_i \sum_{i=11,z=1}^{i=13,z=3} \beta_i Z_z + \beta_j \sum_{j=14,p=1}^{j=41,p=28} P_p * t \quad (3)$$

where

[14]School funding and highway construction are determined administratively. The incentives to spend on human-capital and infrastructure investment surely include anticipated impacts on productivity and economic development, but are unlikely to be determined by anticipated future FDI. Rather they are actions taken to influence both domestic and foreign investment. Thus we believe it is legitimate to treat them as exogenous variables. We lag the wage variable one year, and thus it is unlikely to be influenced current FDI.

•S = a measure of worker schooling;

•H= a measure of highway length per area of land; and

•W = a measure of wage rates; and

•P = *provincial dummy*

We incorporate a separate trend variable for each province in equation (3) in order to capture the highly dispersed pattern of FDI across provinces. The lagged flow of innovation patent applications is included in equation (3), because securing patent protection in the host country may be a precondition for patentable technology transfer via FDI or FFI. The ratio of national FFI to national FDI roughly tripled in the years following the 2001 patent law and China's accession to the WTO. We treat patent applications as a possibly endogenous variable in our estimation of equation (3).

The accumulated stock of FDI is included as an endogenous regressor in equation (3). To the extent that the gap between the marginal return to investment in the home country and in the destination country declines as the stock of foreign capital in the destination country increases, *cet. par.*, the expected sign of the FDI stock is negative; however to the extent that there is intangible learning capital acquired as foreign enterprises continue their investment activities in the host country, accumulated FDI may lower the costs of further FDI, thus offsetting the tendency of the rate of return to decline as the capital stock increases. Moreover, to the extent that there is learning-by-doing in FDI, current FDI will depend in part on expected future FDI. The schooling, highway, and wage variables are included in equation (3) to reflect the impact of infrastructure capital, human capital, and labor cost, respectively on the return to FDI. The expected signs of infrastructure and human capital are positive and that of wage is negative. These three variables are also used as instruments in estimating first-stage regressions for endogenous regressors in all our other equations. Their lagged values are used as instruments for the lagged FDI stock in equation (3).

$$\Delta\Delta K_t = \delta_0 + \delta_1 t + \delta_2 Law93 + \delta_3 Law02 + \delta_4 Law93 * High + \delta_5 Law02 * High + \delta_6 \ln \sum_{t=0}^{t} FDI_t$$
$$+ \delta_7 \ln \sum_{t=0}^{t-3} RD_t + \delta_8 \ln \sum_{t=0}^{t-3} Pat_t + \delta_9 \ln K_{t-3} + \delta_{10} \ln Exp_t + \delta_i \sum_{i=11,z=1}^{i=13,z=3} \alpha_i Z_z \quad (4)$$

where

•K = the stock of physical capital in constant 1990 prices[15], and

$$\Delta\Delta K_t \equiv \frac{(K_t - K_{t-1})/K_{t-1}}{(K_{t-1} - K_{t-2})/K_{t-2}};\ \ \Delta \ln K_t - \Delta \ln K_{t-1}];$$

Equation (4) represents our attempt to learn whether increased IPR protection has lead to new technology embodied in physical capital.. This measure of embodied technological change has been shown to be a significant contributor to TFP growth in China (Fleisher, Li, and Zhao, 2009).[16] We hypothesize that the sign of the estimated coefficient of the lagged capital stock is negative; and accumulated FDI and either R&D capital or the stock of innovation patents should all positively influence the creation of new technology and its embodiment in physical capital; thus their expected signs in equation (4) is positive. To the extent that technology growth embodied in physical capital is positively affected by IPR protection but not fully captured by the FDI, R&D, and patent variables, the contribution of the 1993 and 2001 patent laws should be reflected in positive estimated coefficients of *Law 93* and *Law 2001* and their interaction terms.

To the extent that future technology gains are anticipated and affect current R&D and FDI, the R&D and FDI regressors may be jointly determined with capital-stock acceleration. Thus the depreciated R&D stock and FDI stock and the innovation patent stock are treated as endogenous in equation (4).

IPR and Economic Growth. One of the major aims of this paper is to assess the degree to which IPR protection may boost economic growth, using China as a case study. Our tool for this task is Equation (5).

$$\begin{aligned}\Delta \ln TFP_t = {} & \lambda_0 + \lambda_1 t + \lambda_2 Law93 + \lambda_3 Law02 + \lambda_4 Law93 * High + \lambda_5 Law02 * High + \lambda_6 \Delta\Delta K_{t-2} \\ & + \lambda_7 \ln TFP_{t-2} + \lambda_8 \ln Exp_t + \lambda_i \sum_{i=9,z=1}^{i=11,z=3} \alpha_i Z_z \end{aligned} \qquad (5)$$

where

[15] Details of the construction of the physical capital stock are contained in Fleisher, Li, and Zhao (2009).

[16] We do not deny that technology transfer via FDI almost surely includes managerial and other human “know how” that affects productivity through channels other than physical capital alone.

•*TFP*= total factor productivity, obtained following the method of Fleisher, Li, and Zhao (2009) in which the factor weights are obtained from a function based on provincial data, and $\Delta \ln TFP_t = \ln TFP_t - \ln TFP_{t-1}$;

Our major hypotheses are that the channels through which TFP growth is enhanced by IPR protection is through new technology embodied in physical capital as reflected in $\Delta\Delta K_t$ and through technological change that is embodied in management technology, entrepreneurship, and other intangibles that are captured by the Law dummy variables and their interactions with industry technology levels. Lagged TFP is included as a regressor to reflect factors affecting TFP that are not captured by the variables that reflect Deng's South Trip, WTO accession, and changes in the patent laws. We treat $\Delta\Delta K_t$ as endogenous, because investment in new physical capital is likely to reflect anticipated TFP growth.

5. Empirical Results

All regressions use fixed-effect estimation, with provincial aggregate data in which dummy variables are included for each of 28 provinces. R&D data for large and medium enterprises (LMEs) only. We first present benchmark OLS estimates of relationships (1) through (4) in table 3. Each benchmark regressions contains the following variables: trend (for years 1990 through 2007); dummy variables for the 1993 and 2001 patent laws; and the control variables export and the three special zone variables.

Column (1) of table 3 contains the benchmark estimation results for innovation patent applications. Trend is positive, although not significant by conventional standards. The coefficients of the two Law dummy variables are opposite in sign—1993 negative and 2001 positive, but again not significant by conventional standards. The interaction term between high-tech provinces and the law dummies are also opposite in sign, again negative for 1993 and positive for 2001, but the estimated coefficient for High x 2001 is highly significant, and the total estimated impact of the 2001 patent law on innovation patent application among high-tech provinces is rather large (about 0.94) indicating that on average, annual innovation patent applications in high-tech provinces increased by more than two-fold after the 2001 patent law, *cet. par.* The difference-in-difference (DID) impact for the 2001 patent law is reflected in the coefficient of the interaction term, High*law2001. It is 0.96, about 6 times larger than the negative DID estimate for 1993, implying that the 2001 resulted in an increase in patent application of approximately 160 % on average during the years following adoption of the law.

The benchmark estimations results for R&D expenditure are shown in column (2). Trend is significantly positive, but the coefficient of the 1993 law dummy is negative, significant, and much larger than the coefficient of trend. The estimated coefficient of Law 2001 is positive, but smaller in magnitude to the Law 1993 dummy. The DID estimates of both the 1993 and 2001 patent laws are positive, although that for 1993 is not significant by conventional standards. They imply an approximate 15 % increase in average annual R&D expenditures in the high-tech provinces that is attributable to each of the two patent laws. However, the sum of the sum of the 1993, 2001 and the respective interaction-term coefficients imply a negligible total impact of the patent laws on R&D expenditures. The mixed results for the net impact of the patent laws on R&D expenditures is likely due to the rapid growth of FIEs, which we have seen spend less on R&D than do domestically owned enterprises.

The benchmark estimation results for FDI in table 3 are based on a specification that includes only a single trend variable. They are shown in column (3). The estimated coefficient of trend is negative and statistically significant, which is perhaps surprising given the surge in China's FDI that started around 1993. Probably this surge is reflected in the large, positive coefficients of the 1993 law dummy and exports. The estimated DID impacts of the 1993 and 2001 patent laws are both negative, although not significant at conventional levels.

The capital stock acceleration regression result is reported in table 3, column (4). The negative and statistically significant trend coefficient is substantially outweighed by the large and positive estimated coefficients of the two law dummies, implying a surge in the growth of technology embodied in physical capital following the first patent law and a further jump following the second patent law. The estimated DID effects of each of the patent laws are negligible.

Augmented Regressions. The augmented regression results for equations (1) through (4) are reported in tables 4 and 5. The last three rows report the result of weak IV test, the

Sargan statistic of over-identification test, and the Durbin-Wu Hausman test for endogeneity. The IVs for each equation are listed in the tables' notes.

Patent Applications. The estimated coefficient of trend is quite small and highly insignificant, as are the coefficients of the two law dummies. The estimated DID impact of the 1993 patent law (the coefficient of the High*law1993 interaction term) is negative and significant, indicating in a decline in patent applications in high-tech provinces during the period following enactment of the 1993 patent law and enactment of the 2001 law. However, the DID impact for 2001 is positive, about twice the magnitude of the DID coefficient for the 1993 law, and highly significant. The estimated patent-law coefficients are quite similar in sign and statistical significance to those in the benchmark patent equation, but in the 2SLS augmented equation the difference in absolute value between the 1993 and 2001 DID estimates is considerably smaller (although "large") than in the benchmark, OLS estimation results.

The coefficient of R&D stock implies a positive and significant elasticity of patent applications to R&D stock of between about 1.7. This estimate is considerably larger than the elasticities reported by Hu and Jefferson (2009) for data based on large and medium enterprises in the period , and roughly comparable twice the magnitude of comparable elasticities for OECD countries that they report. The estimated impact of FDI stock on patent applications is quite insignificant. A negligible impact of the patent laws on the association between FDI and patent applications is not inconsistent with the hypothesis that FDI serves as a channel for the transfer of technology without going through a formal purchase of rights or license by domestic (Chinese) firms from foreign enterprises (Hu, Jefferson, and Qian, 2005). But to the extent that such technology is transferred by FIEs, the negligible coefficient implies that any increase in patent applications by FIEs offsets their lower propensity to apply for patents in the host country than that of domestically owned enterprises. Moreover, Hu and Jefferson (2009) do find that FIEs have a positive impact on patent applications by large and medium-size domestic enterprises, and they suggest that domestic-enterprise patent applications may in part result from strategic motives to preempt FIEs from obtaining patents. Thus, an increase in patent applications coinciding with an increase of the presence of FIEs does not necessarily imply that the patent applications are coming from FIEs, even though the increase may be in a sense caused by the surge of foreign investment. Our regression results are likely to reflect these quite complex interactions.

R&D. The estimated coefficient of trend is positive and significant, and about four times the magnitude of the estimated trend coefficient for the benchmark R&D equation reported in table 3, column (2). A striking difference between the 2SLS augmented and OLS estimation results is the reversal in sign of the 1993 law dummy coefficient, which is a negative 0.32 in the OLS estimation and a positive 0.46 in the 2SLS estimation, both highly significant; the coefficient of the Law2001 dummy in the 2SLS regression is quite insignificant compared to positive and significant in the OLS regression. A similar reduction in statistical significance is also seen in the coefficients of the high-tech—law interaction terms. The 2SLS estimation results imply a positive impact of the 1993 patent law on R&D expenditure, which was not increased by passage of the 2001 law. The total impact of the two laws following 2001 implied by the sum of the regression coefficients for the 1993 and 2001 law dummies is approximately a 50% increase in average annual R&D expenditures. However, the DID estimate of the laws' impacts on R&D is negligible in the 2SLS estimation results, compared to positive and significant in the benchmark results.

The estimated coefficient of the lagged R&D stock is positive and significant, consistent with the hypothesis that the return to R&D investment is an increasing function of prior R&D. The estimated impact of FDI stock is negative and significant. This negative association is expected, because R&D intensity of FIEs is much smaller in China, the host country than is that of domestic enterprises , as discussed above.

FDI per worker. Table 3, column (3) contains the results for the FDI regression. We report only the OLS estimate, because under the Durbin-Wu-Hausman test we cannot reject the null hypothesis that the FDI stock and patent applications are exogenous. As discussed above, the augmented FDI regression includes a separate trend variable for each province; the 28 trend coefficients are not shown in table 3. The coefficients of the two law dummies are both negative and significant, compared to significantly positive and negative, respectively in the benchmark regression. The estimated coefficient of the High*law1993 term is positive and significant compared to insignificantly negative in the benchmark, while the coefficient of the High*law2001 term is negative and insignificant in both regressions. The estimated coefficient of the lagged FDI stock is positive and significant, consistent with positive "learning by doing" among foreign investors. The coefficient of the lagged flow of patent applications is positive and highly significant, implying an elasticity of about 0.5 between FDI flows and lagged patent applications. The implied elasticity of FID with respect to patent applications appears to be consistent with the results reported by Awokuse and Yin (2009), albeit our estimates are based on a far different data base. We take our estimation results as *prima facie* evidence that inward FDI has been encouraged by the lower risk of technology piracy associated with patent protection. The estimated impacts of the proportion of college graduates in the labor force and real wage rates are positive and negative, respectively, as hypothesized, but the estimated impact of highway infrastructure is negligible.

Acceleration of the Capital Stock. Regression results for $\Delta\Delta K$ are reported in table 5 . There are two specifications, because we cannot obtain usable estimation results when R&D stock and patent stock are both included as regressors. The specification in column (1) includes the R&D stock but not the patent stock; that in column (2) drops the R&D stock and includes the patent stock. Both regressions include the FDI stock. We limit our discussion to the estimation results in column (2). The estimated trend coefficient is negative and significant, similar to that in the benchmark regression. The coefficients of the two law dummies are negative and positive, respectively, while those in the benchmark specification are both positive. In the augmented regression, the estimated coefficient of the 2001 law dummy is about twice as large as that in the benchmark regression. The sum of the coefficients of the two law dummies in the augmented regression is approximately 1.0, compared to a sum of about 2.4 in the benchmark specification. The coefficients two High*law interaction terms are both positive, and that of the 1993 interaction term just falls short of significance at a conventional level. The estimated coefficient of the FDI stock is positive and significant, consistent with embodied technology in new physical capital associated increased FDI. This interpretation would appear to be consistent with the analysis of Hu, Jefferson, and Qian (2005) and Liu (2008).

IPR and TFP Growth. Estimation results for equation (5) are shown in table 5, column (4). The OLS estimates in columns (1) through (3) are included to show some simple benchmark relationships and to compare the OLS estimation of equation (5) with the 2SLS estimation. To simplify presentation, the dependent variable is multiplied by 100. The OLS regressions in columns (1) and (2) have large and highly significant coefficients of the two law variables that are robust to the addition of the South Trip and WTO control variables. When the High*law dummy variables, lagged KTFP and the capital-stock acceleration variables are included (column (3)), the magnitude of the Law2002 dummy falls by nearly half and becomes insignificant. The DID estimate of the laws' impact obtained from the Law*year interaction terms are both statistically insignificant. Moreover, the coefficient of the important variable, $\Delta\Delta K$, is negligible. Estimation by 2SLS produces a drastic turnaround: The estimated coefficient of $\Delta\Delta K$ becomes positive and highly significant. The coefficients of the two Law dummies are positive and significant, but the Law*year interaction terms remain small and insignificant, implying no DID impact of the patent laws on TFP growth through organizational, managerial, or other forms of intangible technology.

We now use the estimation results for equations (1) through (5) to construct counterfactuals of the respective series. The purpose of this exercise is to provide further insight into the channels through which IPR protection may have influenced patenting behavior, R&D, FDI, and economic growth.

Counterfactual Calculations: Patents. A convenient summary of the impact of the 1993 and 2001 patent laws is obtained by constructing a counterfactual series for the respective dependent variables. The counterfactuals are obtained by subtracting the direct impacts implied by the respective coefficients of the law dummies and the indirect impacts through the laws' estimated impact on endogenous regressors. We perform the counterfactual calculations separately for the low-tech and high-tech provinces. To illustrate, we calculate the counterfactual patents in 1993 for high-tech provinces in the year as follows. The natural log of patent applications in the high-tech provinces in the year 1993 was 8.3. From this, we subtract the estimated coefficient of the 1993 law dummy plus the coefficient of the High*law 1993 interaction term. We then subtract the estimated coefficient of the R&D stock and FDI stocks multiplied by the differences between their actual values in 1993 and their counterfactuals1993. The counterfactual R&D and FDI stocks are is obtained by adding to the actual depreciated 1992 stocks the counterfactual R&D expenditure and FDI for 1993, where the counterfactual R&D and FDI flows are obtained in manner similar to that as described above for patent applications. The lag structures of the various equations assure that we avoid circularity in calculating the counterfactual differentials for regressors that are dependent variables in other equations.

The counterfactual patent application results are depicted in figures 7a-7d. There are four charts, one for the 21 low-tech provinces and three for the 8 high-tech provinces. One of the charts for the high-tech provinces includes only the DID impact of the patent laws and another plots the *difference* between the actual number of patent applications and the DID counterfactual. All four figures include a polynomial trend for the actual and counterfactual series. When the total patent-law impact is considered, both the low- and high-tech charts indicate a positive and growing gap positive gap between actual and counterfactual patent applications starting in 1993, the year of the first patent law considered in our research. By the year 2007, total patent applications in the low-tech provinces had risen to more than 47,000 and in the high-tech provinces to nearly 94,000. The counterfactuals for 2007 were approximately 9,400 and 27,400, respectively. In the year 2007, the gap between log patent applications and the counterfactual for low-tech provinces is 1.61. In sharp contrast to figures 7a and 7b, the DID counterfactual in figure 7c, which by definition is for high-tech provinces only, lies uniformly above the actual series. The DID difference between actual and counterfactual is plotted in figure 7d, and the upper bound of a 95% confidence interval for the DID difference series lies uniformly in negative territory.[17] It is difficult to reject the null of no impact of the patent law on patent applications in the DID counterfactual. It is

[17]We do not have estimates of covariances among the regression coefficients for our separate equations and therefore cannot compute the true standard error of the counterfactual series. We view the use of the confidence interval for the DID counterfactuals as a useful heuristic for judging whether the null of no difference can be rejected.

important to note, however, that our DID estimates rely on the very strong assumption that the patent laws impacted only the high-tech provinces. The negative (albeit small relative to the magnitude of patent applications) DID effect may appear to contradict the large and significant coefficient of the High*law2001 interaction term in our regression results.

Our finding of a small negative impact of the patent laws themselves on patent applications is not inconsistent in our view with the conclusions drawn by Hu and Jefferson (2009), who note, "Opening up, deepening economic reform, and a relatively stronger legal system have together created a more patents-friendly environment and have increased the return to patenting" (Hu and Jefferson, 2009, p. 68.). If our controls for the South Trip and WTO accession do adequately capture the impacts of these major changes in China's legal and economic environment, then we can view the patent-law impact as bounded by the small, negative DID impact and the large, positive impact that reflects the coefficients of all the patent-law dummies.

Counterfactuals: R&D The counterfactual results for the R&D regression are depicted in figures 8a through 8d. As with the patent-application calculations, the basic counterfactuals indicate a large, positive impact of the patent laws in both high-tech and low-tech provinces. The counterfactual for the low-tech provinces for the year 2007 indicates that the log of R&D would have been 0.87 less than actual R&D. The counterfactual gap for the high-tech provinces in 2007 is 0.41, about half the magnitude for the low-tech provinces. Again, similar to the case for patent applications, the DID counterfactual implies a negative, but very small impact, of the patent laws on R&D expenditures. It is this negative that is a major contributor to the negative DID impact of the laws on patent applications described above. The 95% confidence interval is quite narrow. Although we find it difficult not to reject the null that the DID impact of the patent laws on R&D in the high-tech provinces has been zero, this small negative effect must be viewed as the lower bound of a range that includes large positive effects in both low- and high-tech provinces.

Counterfactual: FDI. The counterfactual calculations for FDI are depicted in figures 9a through 9d. The gap between actual and counterfactual FDI is positive in high-tech provinces but small and variable in the low-tech provinces. The DID gap is also positive, but the implied impact of the patent laws is smaller. As shown in figure 9d, the DID excess of actual FDI over its counterfactual exceeds 30% until around 2001 and falls to a minimum of about 20% by 2007.

Although the estimated coefficients of the law dummy variables in the benchmark and augmented regressions imply a positive impact of IPR protection on FDI in China, consistent with the research reported in Awokuse and Yin (2009) our counterfactuals suggest a much more cautious interpretation, especially when the impact of IPR protection on patent applications is fully evaluated, as we discussed above.

Counterfactuals: $\Delta\Delta K$. The counterfactual results for capital stock acceleration based on the regression results shown in table 4, column (1)[18] are shown in figures 10a through 10d.. The gap between actual and counterfactual DDK is negative prior to 1999 in the high-tech provinces and prior to 2000 in the low-tech provinces. In the year 2004, for which the gap is quite large, the gap between actual and counterfactual $\Delta\Delta K$ is approximately 4 percentage points for both the low- and high-tech provinces. The DID counterfactual for capital stock acceleration presents a strikingly different pattern than the counterfactual based on all law-dummy coefficients, indicating a positive gap between actual and counterfactual $\Delta\Delta K$. In figure 10d, we see that the DID gap between actual and counterfactual $\Delta\Delta K$ exceed 4 percentage points between 1996 and 2005 and falls below zero only in 1993 and 1007..

Counterfactuals: TFP Growth. The counterfactual calculations for TFP growth based on the estimation results in table 5, column (4) The counterfactual calculations based on the coefficients of all the law dummy variables follow a pattern similar to those of the $\Delta\Delta K$ counterfactuals, becoming positive approximately mid way between 1993 and 2007. The mean difference between actual TFP growth and its counterfactual is about 3.4 percentage points, or nearly two-thirds of mean province-weighted TFP growth over the period.

[18]The regression in column (2) includes Patent stock as a regressor, but not R&D, whereas the regression in column (1) includes R&D rather than Patent stock. Despite the fact that neither variable's coefficient is significant in its respective regression, the estimated coefficients of other regressors are different. Notably the coefficient of the FDI stock is much larger and more significant with R&D in the regression than when Patent stock is included. The counterfactual gap calculated on the basis of the column (1) regression indicates a greater positive impact of the patent laws on capital stock acceleration than that based on the regression of column (2)

The DID counterfactual suggests a negative impact of the patent laws before 1997 and a positive impact thereafter through 2006. The magnitude of the positive gaps are smaller than when the coefficients of all the law-variable coefficients are used to calculate the counterfactuals. Nevertheless, the mean difference between actual TFP growth and its DID counterfactual is 0.19 percentage points. Province-weighted mean TFP growth over the 1993 through 2007 for the high-tech provinces was about 5.4percentage points. Thus, our low-bound estimate of the contribution of the patent laws to China's TFP growth would have been somewhat smaller had the patent laws not been adopted.

Channels of influence. We gain perspective on the impacts of the patent laws by using the counterfactuals to show the channels through which the they contributed to additional TFP growth. We use the year 2004, for which the difference between the DID counterfactual and actual TFP growth is largest to illustrate. TFP growth in 2004 exceed its counterfactual by 1.24 percentage points. Multiplying the comparable DID counterfactual for $\Delta\Delta K$ by its regression coefficient in table 5, we obtain a product of 1.65 percentage points, while the sum of the coefficients of the two large variables is -0.28. We infer an impact of the patent laws coming entirely through new technology embodied in physical capital. Taking this exercise back one step, we can calculate the channels through which the patent laws impacted $\Delta\Delta K$ for 2002 ($\Delta\Delta K$ is lagged two periods). We have calculated that the DID impact of the patent laws on $\Delta\Delta K$ was to raise it by 0.8 percentage points in 2002. This impact was channeled through FDI (in 2002), 0.67 percentage points and the two patent laws' coefficients (reflecting intangible technology), which added up to 0.56 percentage points after 2001. The other channel, R&D stock is calculated to have reduced $\Delta\Delta K$ by 0.3 percentage points. This counterintuitive result may be attributable to the impact of expensing R&D expenditures in financial and GDP accounting rather than treating them as investment (Fraumeni and Okubo, 2002)

6. Conclusion

Has upgrading and enforcing its patent laws slowed China's economic growth? The answer we draw from a detailed analysis of provincial aggregate data covering roughly the period 1990 through 2007 is negative. Although it is difficult to reject the null of no positive impact net of the effects of correlated institutional and political changes, it is worthwhile to . The channels through which stricter protection of intellectual property rights have may have contributed to more rapid productivity growth are complex, and success in unraveling them has proven to be elusive. Our estimates that average TFP growth increased significantly and substantially following both the 1993 and 2001 patent laws are robust to simple controls for the impacts of Deng's South Trip and China's WTO accession. In our simplest regression controlling for these two events, the sum of the coefficients of the two law dummies is approximately 4.7, suggesting that after adoption of the 2001 law, China's annual TFP growth was boosted by 4.7% per year, which is only slightly smaller than GDP-weighted provincial average TFP growth over the period 1990 through 2007. It is difficult to credit the 1993 and 2001 patent laws for nearly all of China's TFP growth over the fourteen year period ending in 2007.

In an attempt to identify the channels through which the patent laws may have affected China's TFP growth, we extract a causal link between the patent laws and productivity growth we estimated a set of linked equations relating the patent laws, to patent applications, R&D expenditure, FDI, and capital-stock acceleration. We then estimated equations in which these channels through which the patent laws are likely to have operated to TFP growth. We use these estimation results to calculate the extent to which the patent laws, operating through new patent applications, R&D, FDI, and the accelerated growth of the capital stock have contributed to TFP growth in China. We apply the coefficients estimated in the provincial fixed-effects FDI regression equation to national aggregate data and calculate the counterfactual path that FDI would have followed had there been no changes in patent law. The difference between the counterfactual and actual FDI is then applied to calculation of the counterfactual for patent applications, R&D, FDI and DDK in the national aggregate data. The difference between actual TFP growth and the counterfactual is our measure of the contribution of the patent laws to TFP growth. Using the DID estimate of the contribution of the patent laws to TFP growth, we find that the contribution of the patent laws to TFP growth is on average approximately 0.5% points per year, with the channels running….. We repeat our caveat that this calculation is based on a number of imprecisely estimated regression coefficients.

We recognize that TFP growth depends on conditions associated with the privatization of firm ownership, the extent of marketization of the economy and, particularly in the case of China, the shift of labor out of agriculture. How much did IPR protection contribute to these transitions? In an example of how studies at the micro level can help unravel these complex relationships, Jefferson, Hu, Guan, and Yu (2003) document that between 1994 and 1999 state-owned enterprises decreased from 67.9% to barely half of LMEs, and private enterprises grew from virtually none to 1.4% of LMEs. At the same time, the share of LMEs in total industry sales fell from 47.3% to barely one-third. Jefferson, Hu, Guan, and Yu document that SOEs had the second-lowest TFP in 1995, exceeding only the TFP of privately owned enterprises but that by 1999, not only did privately owned enterprises increase their share of total output, but also their TFP exceeded that of every other ownership category except that of FIEs. The nature and direction of R&D activity was also changing, as was the proportion of new products. We conjecture that similar patterns characterized the behavior of smaller enterprises whose share of total output surged over this period. We are tempted to conclude that much of this transformation was aided, if not solely caused by, improved IPR protection following the 1993 patent law.

Another aspect of the contribution of IPR protection to TFP growth lies in the ability of a country (China) adopting increased protection to generate its own innovations and to absorb technology transferred from abroad either through market mediated processes (licensing) or through information "spillovers" associated with FDI and simply "learning by watching". Yang and Maskus (2009) demonstrate theoretically that welfare in the host country (South) increases in response to stronger IPR protection if its absorptive capacity is sufficiently high. Fleisher, Li, and Zhao (2009) provide empirical evidence that increases in China's ability to benefit from technology transfer has been significantly enhanced by its rise in the stock of human capital. The increased level of schooling in China has increased the effectiveness of IPR protection in promoting TFP growth and is another factor underlying the residual impact of the 1993 and 2001 patent laws identified in our research.

Both privatization and the growth of the human capital stock have contributed to China's labor force shifting from relatively unproductive agricultural work to the manufacturing and service sectors—a major contributor to productivity growth. Indeed, one may postulate that our analysis has the causal chain reversed: China's privatization, industrialization, and increased openness may have been the forces driving the adoption of greater protection for patents[19]. After all, adopting laws consistent with TRIPS was a precondition of entering WTO. But our conjecture, await more rigorous testing. These elements of the "mystery of economic growth" (as coined by Helpman, 2004) are challenges for future research.

[19] This conjecture is consistent with the views of Clarke, Murrell, and Whiting, 2008.

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Tables and Figures

Table 1 Industries by Level of Technology in China.

Categories		Industries
Our Categories	OECD Categories	
Low-tech	Low technology	Processing food from Agricultural products Manufacture of foods Manufacture of beverage Manufacture of textiles Textile wearing apparel, footware and caps Leather, fur ,feather and its products Processing of timbers, manufacture of wood bamboo, rattan, palm, straw Manufacture of furniture Paper and paper products Printing and reproduction of recording media
	Middle low technology	Articles for culture, education and sport activity Process of petroleum, coking, processing of nuclear fuel Manufacture of rubber Manufacture of plastic Non-metallic mineral products Processing of ferrous metals Processing of non-ferrous metals Manufacture of mental products
High-tech	Middle high technology	Chemical raw material and chemical products Manufacture of chemical fiber Manufacture of general purpose machinery Manufacture of special purpose machinery Manufacture of transport equipment Electrical machinery and equipment
	High technology	Manufacture of medicines Communication, computer, other electronic equipment Measuring instrument, machinery for cultural and office work

Note: Technology intensity is measured by the ratio (Total R&D expenditure / Total Sales). Data are come from Large and medium-sized industrial enterprises documented by China statistical yearbook on science and technology 2000-2007

Table 2 Benchmark Regressions for R&D Expenditures, Patent Applications, FDI, and Capital Stock Acceleration. (Year: 1990-2007)

	(1) Ln Innovation Patent Applications	(2) Ln R&D Expenditure(LMEs)	(3) Ln FDI per worker	(4) Ln Capital Stock Acceleration (coefficients multiplied by 100)
Trend	.018 1.24	.030** 2.07	-.085** -2.12	-.379*** -5.76
Law1993	-.096* -1.66	-.322*** -5.39	.856*** 6.08	1.147*** 4.29
Law2001	.074 1.27	.165*** 2.75	-.464** -2.43	1.328*** 4.95
High*law1993	-.162* -1.86	.139 1.54	-.204 -1.04	-.079 -0.20
High*law2001	.962*** 15.08	.123* 1.86	-.227 -1.31	-.182 -0.62
Ln Export_national	.733*** 7.54	.692*** 6.88	1.396*** 4.32	2.190*** 4.87
Zone1	.593*** 2.67	.240 1.05	1.688*** 3.05	.758 0.74
Zone2	.053*** 3.71	.085*** 5.74	.030 0.84	-.050 -0.75
Zone3	-.007 -0.33	-.053** -2.41	.365*** 6.96	-.081 -0.83
Adj R-squared	0.9553	0.9490	0.8552	0.1794

Notes:
1. All regressions are OLS.
2. Dependent variables are logs of the variables named in column titles.
2. T-statistics are in parentheses. The stars *, ** and *** indicate significance levels at 10%, 5%, and 1%, respectively.
3. All nominal variables are deflated to base year 1990.
4. Law 1993 Dummy = 1 for t = 1993…2007; 0 otherwise, in FDI regression Law 1993 Dummy = 1 for t = 1994…2007; 0 otherwise.
5. Law 2001 Dummy = 1 for t = 2002…2007; 0 otherwise , in FDI regression Law 2001 Dummy = 1 for t = 2003…2007; 0 otherwise.
6 . Zone1 represents the total number of Opening Cities in a province; Zone2 is the total number of Duty-Free Cities, High-Tech, or Economic Development Cities or Zones in a province, and Zone3 is the number of National Special Economic Zones in a province. The degree of tax preference increases from Zone1 to Zone 3. The tax rates can be found in "Income Tax Act for FIE Invested Firms and FIE Firms in People's Republic of China."
7. All regressions include dummy variables for each of 28 provinces (Tibet is excluded) .

Table 3 Regressions for R&D, Patents and FDI (Year: 1990-2007).

	(1) 2SLS	(2) 2SLS	(3)OLS
	Ln Innovation Patent Applications	Ln R&D Expenditure(LMEs)	Ln FDI per worker
Endogenous variables	FDI stock, R&D stock	FDI stock, R&D stock	
Trend	.004 0.10	.123*** 3.58	
Law1993 Dummy	.136 0.51	.462** 1.98	-.371** -2.24
Law2001 Dummy	.036 0.31	-.057 -0.57	-.272* -1.72
High*law1993	-.313*** -2.71	.012 0.12	.454* 1.95
High*law2001	.619*** 5.67	-.043 -0.50	-.267 -1.18
Ln R&D Stock	1.713*** 4.44		
Ln R&D Stock (t-1)		.661*** 2.86	
Ln FDI Stock	.019 0.09	-.541*** -3.07	
Ln FDI Stock(t-1)			.588*** 7.09
Ln_patent(t-1)			.512*** 4.42
Ln College&Above			.319*** 2.75
Ln Wage (t-1)			-1.531*** -5.64
Ln Higway Intensity			-.179 -1.00
Ln Exports_national	-.481 -1.60	.234 1.19	1.351*** 4.52
Zone1	.289 1.00	.099 0.39	1.853*** 3.91
Zone2	-.061** -2.03	.036* 1.71	.056* 1.70
Zone3	.065** 1.97	.031 1.07	.192*** 4.00
Provincial Dummy	yes	yes	yes
Trend*Provincial dummy	no	no	yes
Weak IV test F-statictics	4.65***(FDI Stock) 5.84***(R&D Stock)	6.51***(FDI Stock) 2.47***(R&D Stock)	
Overidentification Test Chi-square (Pr > F)	4.293 (0.23148)	11.292 (0.18570)	
Durbin-Wu-Hausman Test Chi-square (Pr > F)	26.60417*** (<0.00001)	24.116*** (0.00001)	
Adj R-squared			0.9240

Notes: Instrumental variables for 2SLS are (i) proportion of college graduates and above lagged 1 period behind the date of the respective endogenous variable; (ii)) log wage lagged 2 period behind the date of the respective endogenous variable; (iii) log highway intensity lagged 1 period behind the date of the respective endogenous variable; (iv) zones 1, 2 in RD regression lagged 1 period behind the date of the respective endogenous variable; zone1,3 in patent regression lagged 1 period behind the date of the respective endogenous variable.

Table4 Regressions for Capital Stock Acceleration (Year: 1990-2007)

	(1) 2SLS	(2) 2SLS
	Ln Capital Stock Acceleration	
Endogenous variables	FDI stock, R&D stock	FDI stock, Patent stock
Trend	-.335*** -2.62	-.535** -2.15
Law1993 Dummy	-1.233 -1.50	-1.096* -1.69
Law2001 Dummy	2.075*** 4.99	2.051*** 4.87
High*Law1993	-.114 -0.17	.865 1.62
High*Law2001	.672* 1.79	.260 0.58
Ln R&D Stock (t-3)	.865 0.84	
Ln FDI Stock	2.056*** 3.08	1.274** 2.61
Ln Patent Stock(t-3)		1.152 0.78
Ln Capstock(t-3)	-4.684*** -4.35	-3.097*** -5.34
Ln Exports_National	1.687** 2.33	2.185*** 4.62
Zone1	2.357 1.12	1.155 1.07
Zone2	.071 0.43	-.038 -0.37
Zone3	-1.042 -1.16	-.215* -1.92
Provincial Dummy	yes	yes
Weak IV test F-statictics	4.56***(FD I) 8.00***(RD)	5.02***(FDI) 4.36***(Patent)
Overidentification Test Chi-square (Pr > F)	8.076 (0.32592)	11.774 (0.30049)
Durbin-Wu-Hausman Test Chi-square (Pr > F)	19.89*** (0.00005)	21.34*** (0.00002)

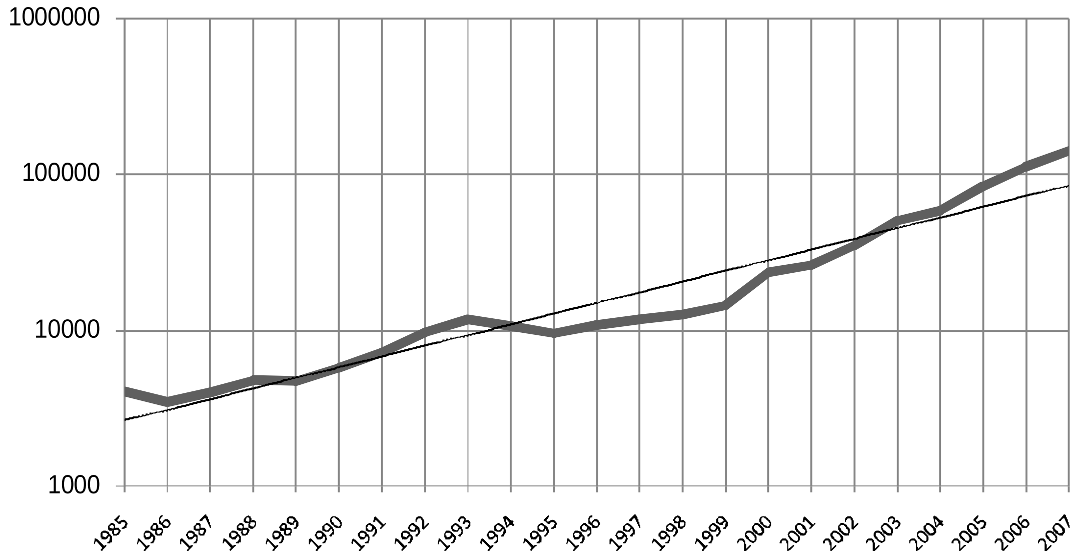
Notes: Instrumental variables for 2SLS are (i) proportion of high school graduates or above(for R&D stock and patent stock) lagged 1 period behind the date of the respective endogenous variable, proportion of college graduates or above (for FDI stock) lagged 1 period behind the date of the respective endogenous variable; (ii)) log wage lagged 2 period behind the date of the respective endogenous variable; (iii) log highway intensity lagged 1 period behind the date of the respective endogenous variable; (iv) zone1,2 and 3 lagged 1 period behind the date of the respective endogenous variable. (some IV be dropped because of endogenous IV problem)

Table 5 Regressions for TFP Growth. (Δ Ln TFP (x 100); Year: 1990-2007)

	(1)OLS	(2)OLS	(3)OLS	(4) 2SLS
Endogenous variables				DDK
Trend	-.310*** -4.63	-.755*** -4.82	.163 0.89	1.052*** 3.05
Law1993 Dummy	4.107*** 7.27	3.077*** 5.00	2.704*** 4.55	2.082** 2.53
Law2001 Dummy	2.064*** 3.48	1.630*** 2.65	.774 1.27	3.11*** 3.00
High*law1993			-.956 -1.07	-.769 -0.64
High*law2001			.027 0.04	.495 0.55
Ln TFP (t-2)			-15.451*** -8.84	-20.417*** -7.52
Ln DDK (t-2)			-4.803 -0.49	205.055*** 3.54
Ln Exports_National		3.116*** 2.90	2.894*** 2.78	-4.011* -1.72
Zone1 Zone2		6.177*** 2.64 .082 0.55	6.187*** 2.73 .233 1.59	4.148 1.33 .349* 1.74
Zone3		.931*** 4.00	.549*** 2.50	.217 0.70
Weak IV test F-statictics				4.25***
Overidentification Test: Chi-square (Pr > F)				6.630 (0.24962)
Durbin-Wu-Hausman Test Chi-square (Pr > F)				27.51944*** (<0.00001)
Adj R-squared	0.1296	0.1820	0.3038	

Notes: Instrumental variables for 2SLS are (i) proportion of college graduates or above lagged 1 period behind the date of the respective endogenous variable; (ii)) log wage lagged 2 period behind the date of the respective endogenous variable; (iii) log highway intensity lagged 1 period behind the date of the respective endogenous variable, (iv) zones 1, 2, and 3 lagged 1 period behind the date of the respective endogenous variable.

Figure 1 Patent Applications



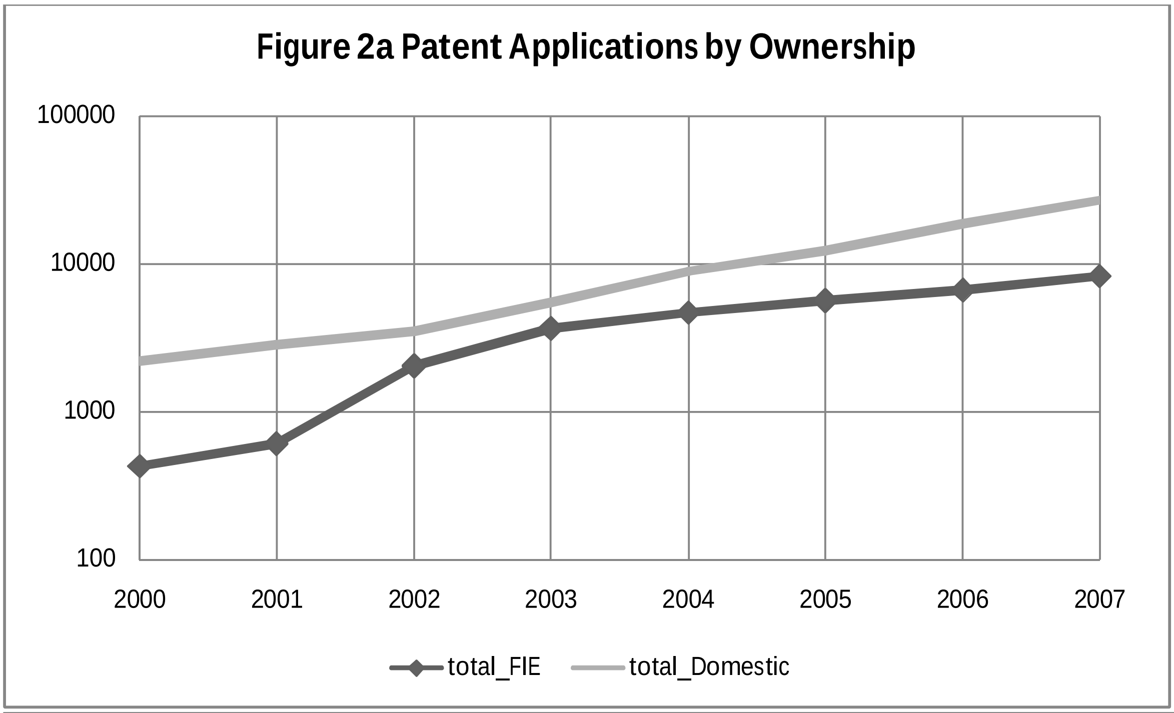


Figure 2a Patent Applications by Ownership
100000
10000
1000
100
2000
2001
2002
2003
2004
2005
2006
2007
total_FIE
total_Domestic

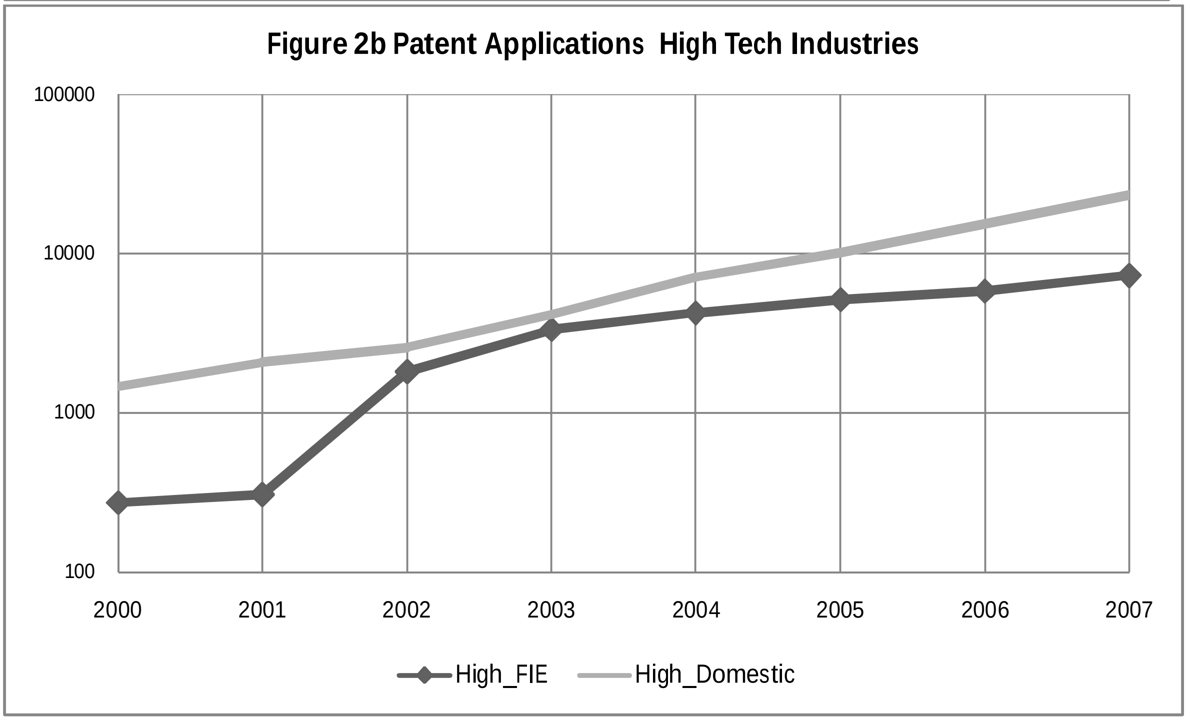


Figure 2b Patent Applications High Tech Industries
100000
10000
1000
100
2000
2001
2002
2003
2004
2005
2006
2007
High_FIE
High_Domestic

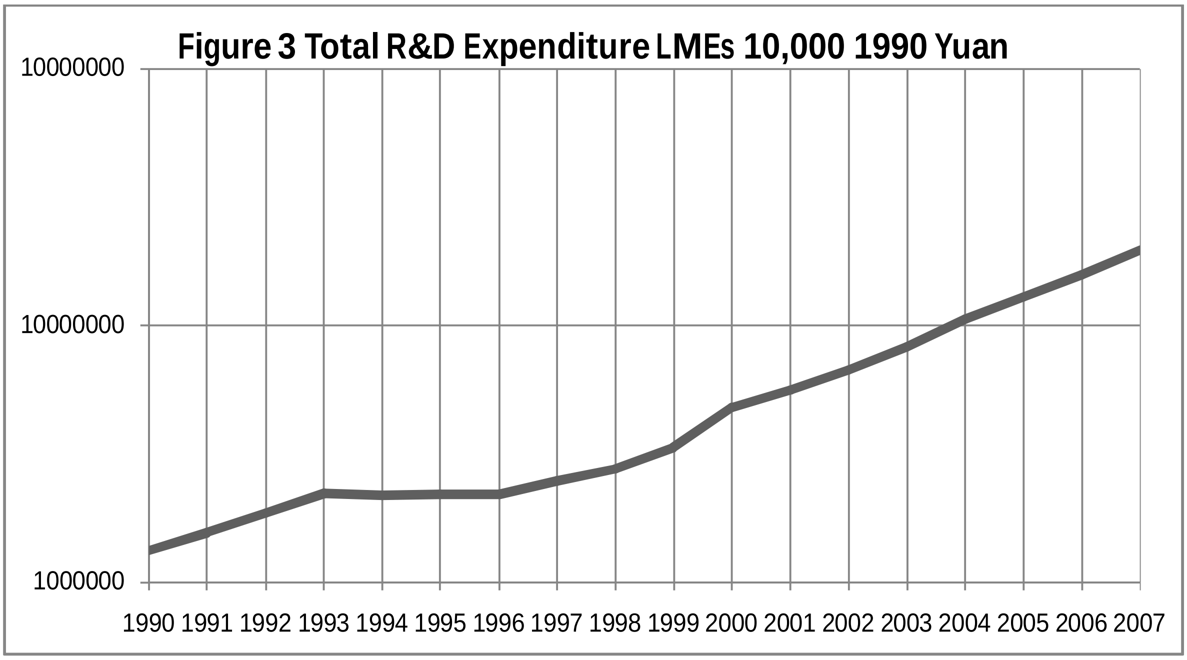


Figure 3 Total R&D Expenditure LMEs 10,000 1990 Yuan
10000000
10000000
1000000
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007

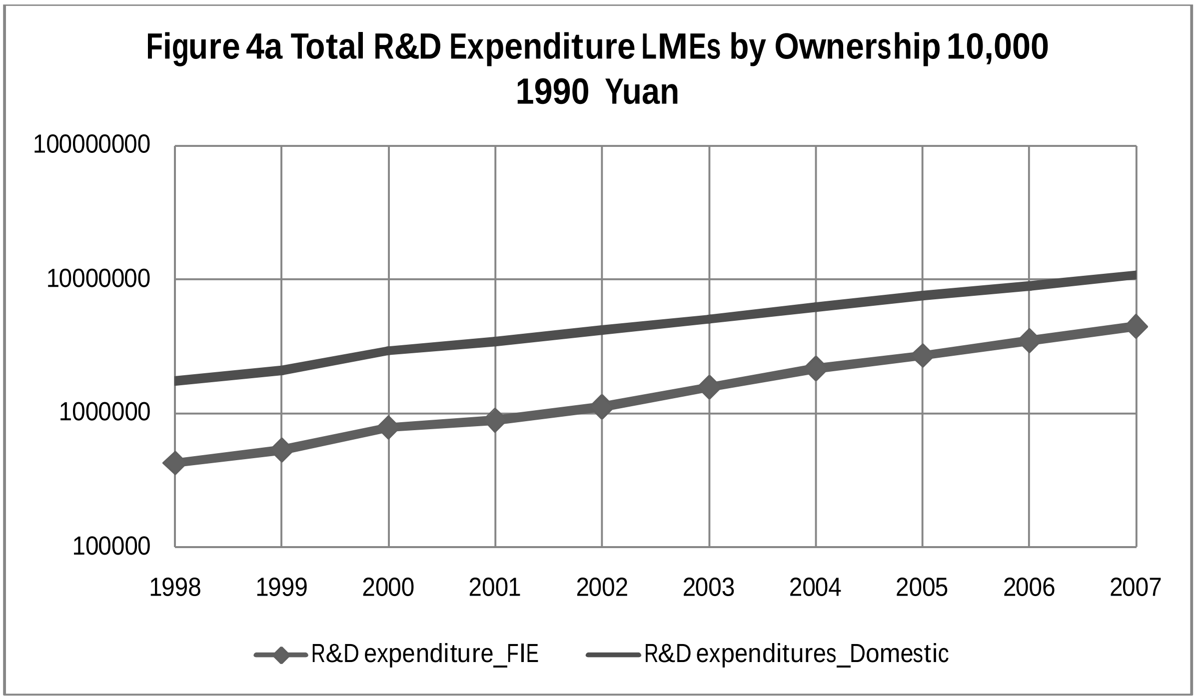


Figure 4a Total R&D Expenditure LMEs by Ownership 10,000 1990 Yuan
100000000
10000000
1000000
100000
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
R&D expenditure_FIE
R&D expenditures_Domestic

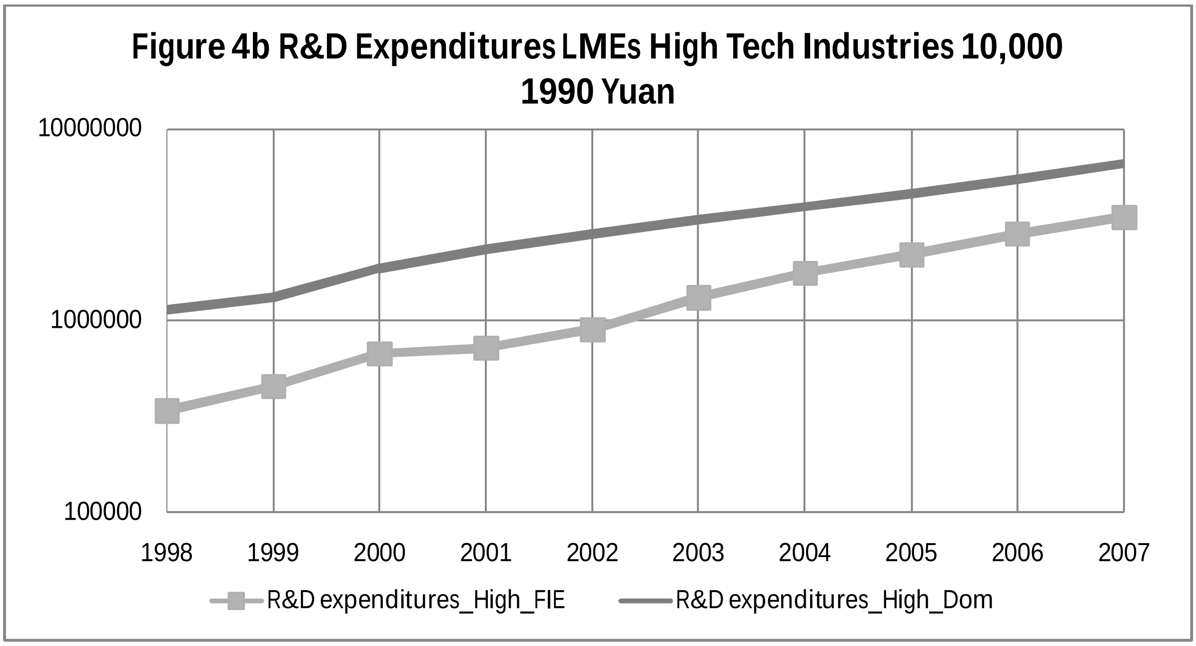


Figure 4b R&D Expenditures LMEs High Tech Industries 10,000 1990 Yuan
10000000
1000000
100000
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
R&D expenditures_High_FIE
R&D expenditures_High_Dom

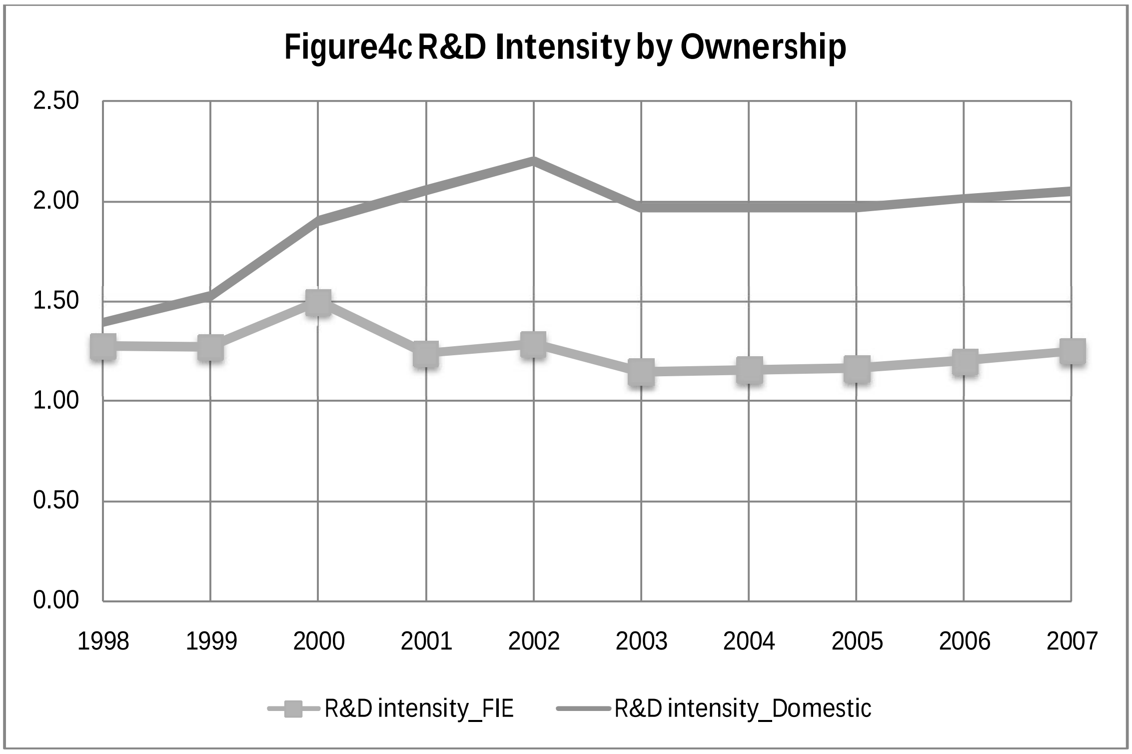


Figure4c R&D Intensity by Ownership
2.50
2.00
1.50
1.00
0.50
0.00
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
R&D intensity_FIE
R&D intensity_Domestic

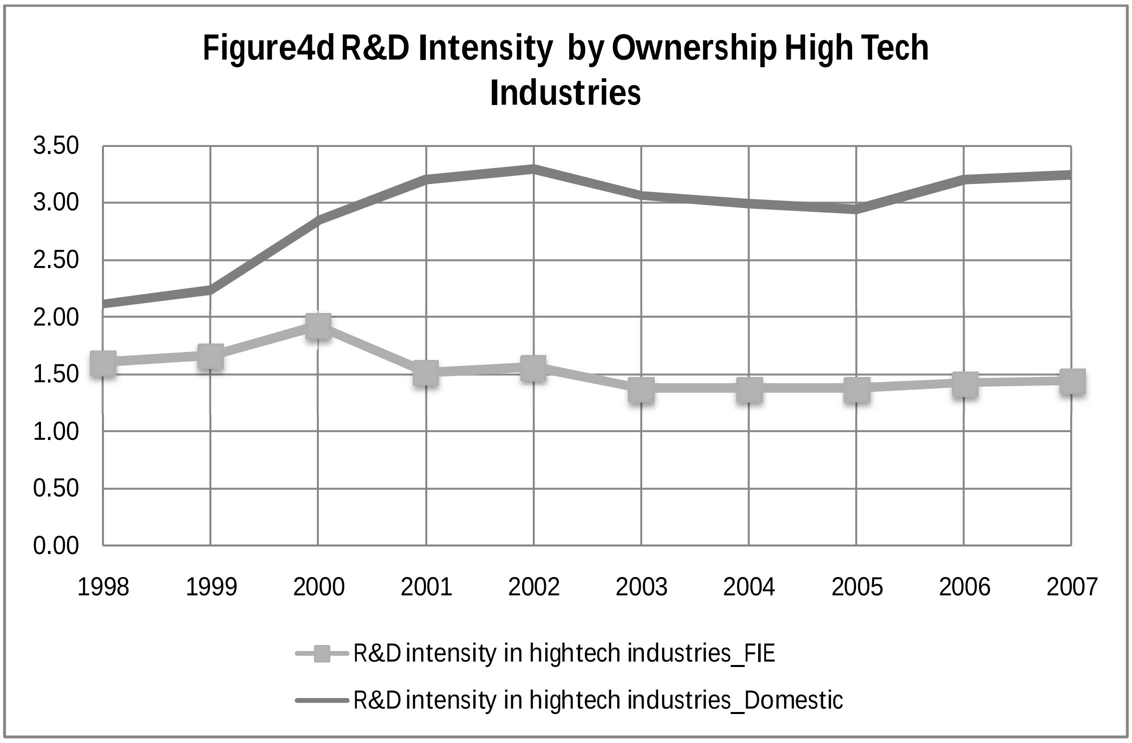


Figure4d R&D Intensity by Ownership High Tech Industries
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
R&D intensity in hightech industries_FIE
R&D intensity in hightech industries_Domestic

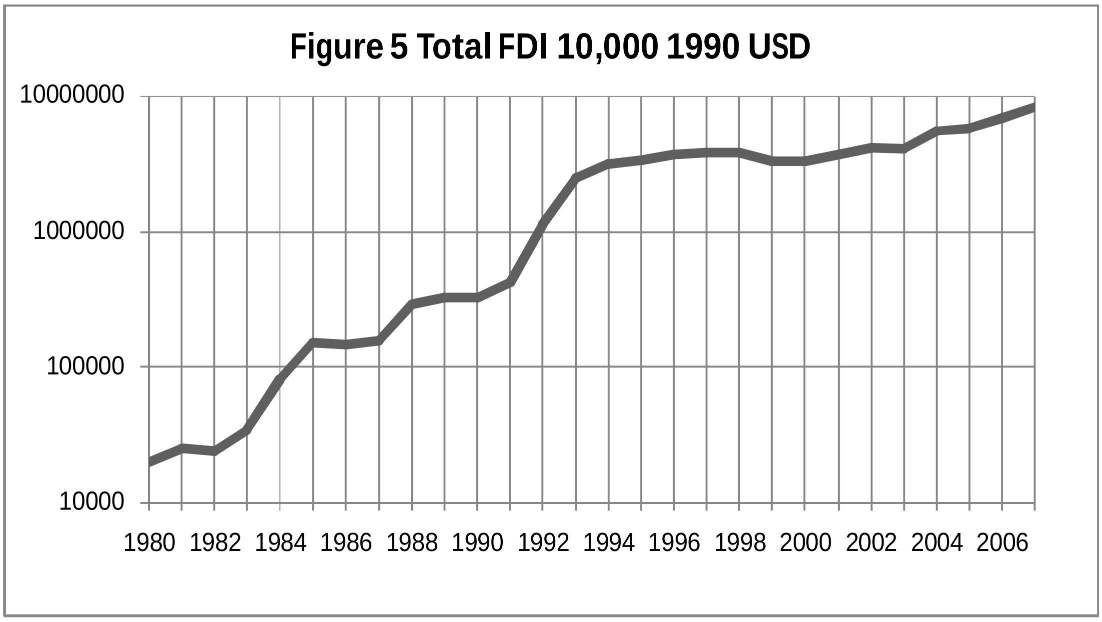


Figure 5 Total FDI 10,000 1990 USD
10000000
1000000
100000
10000
1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006

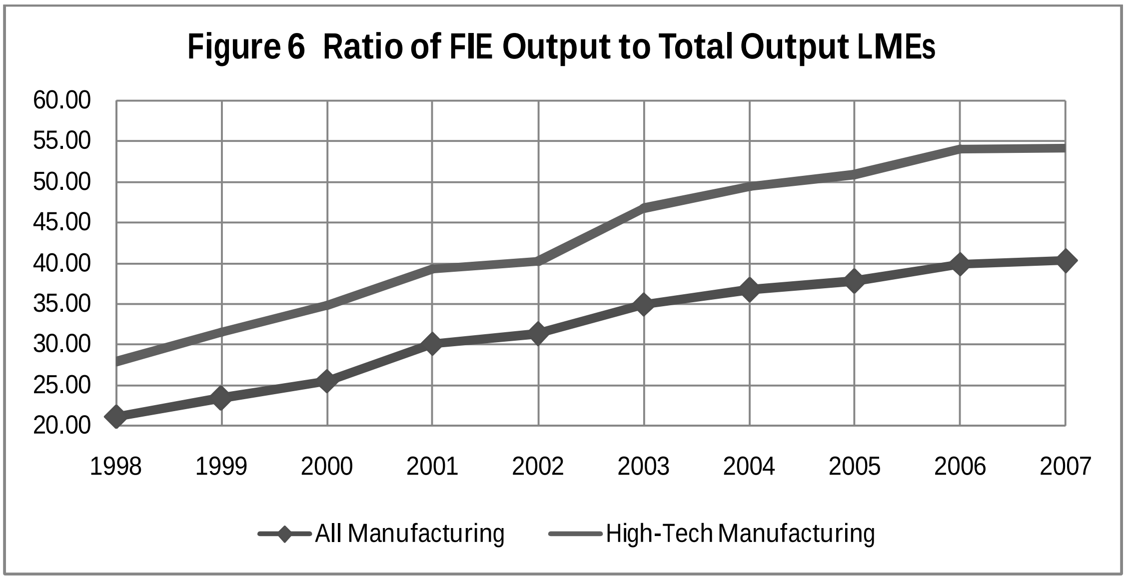


Figure 6 Ratio of FIE Output to Total Output LMEs
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
All Manufacturing
High-Tech Manufacturing

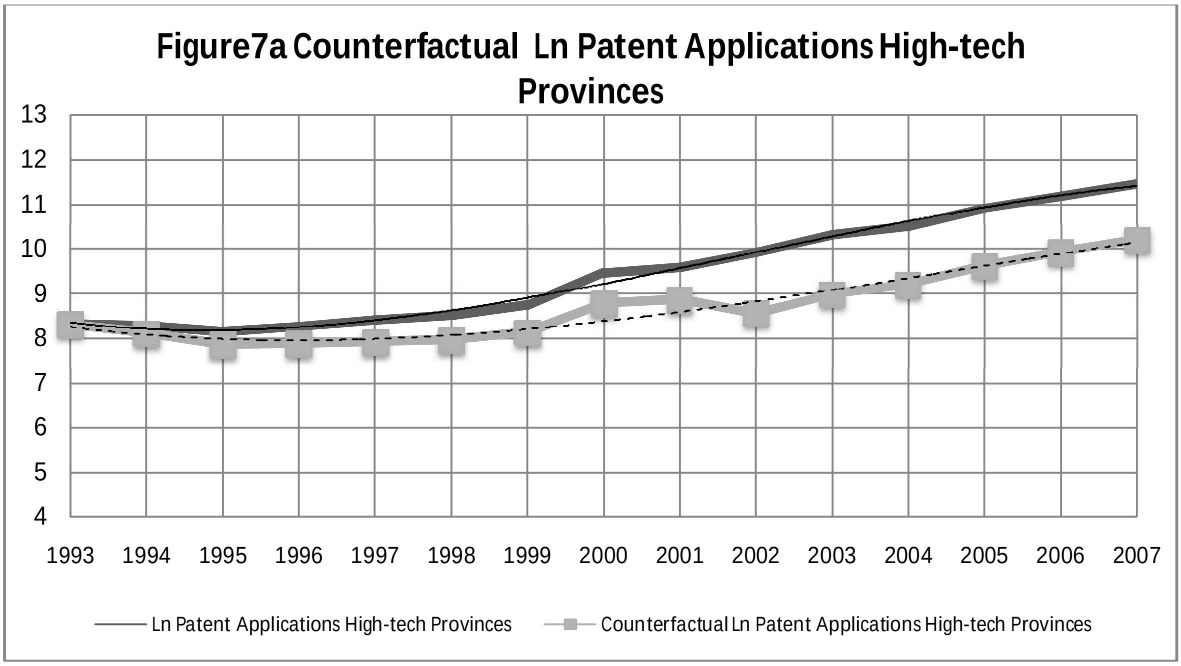


Figure7a Counterfactual Ln Patent Applications High-tech Provinces
13
12
11
10
9
8
7
6
5
4
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Ln Patent Applications High-tech Provinces
Counterfactual Ln Patent Applications High-tech Provinces

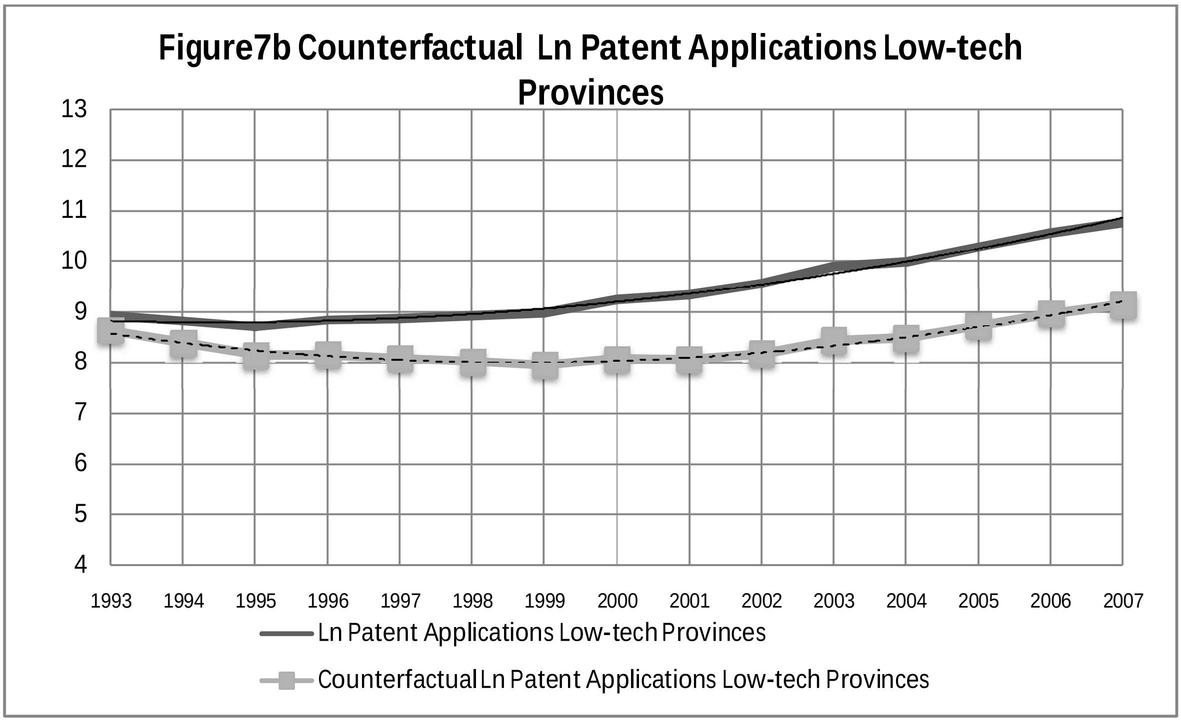


Figure7b Counterfactual Ln Patent Applications Low-tech Provinces
13
12
11
10
9
8
7
6
5
4
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Ln Patent Applications Low-tech Provinces
Counterfactual Ln Patent Applications Low-tech Provinces

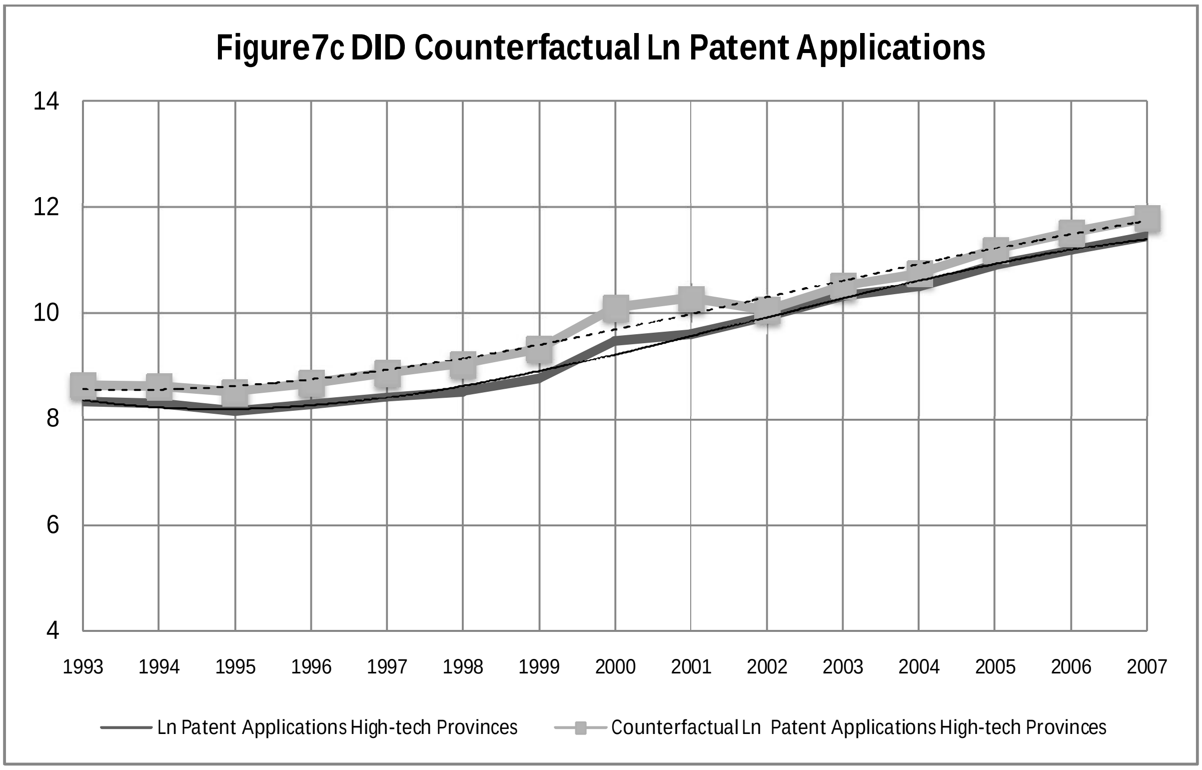


Figure7c DID Counterfactual Ln Patent Applications
14
12
10
8
6
4
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Ln Patent Applications High-tech Provinces
Counterfactual Ln Patent Applications High-tech Provinces

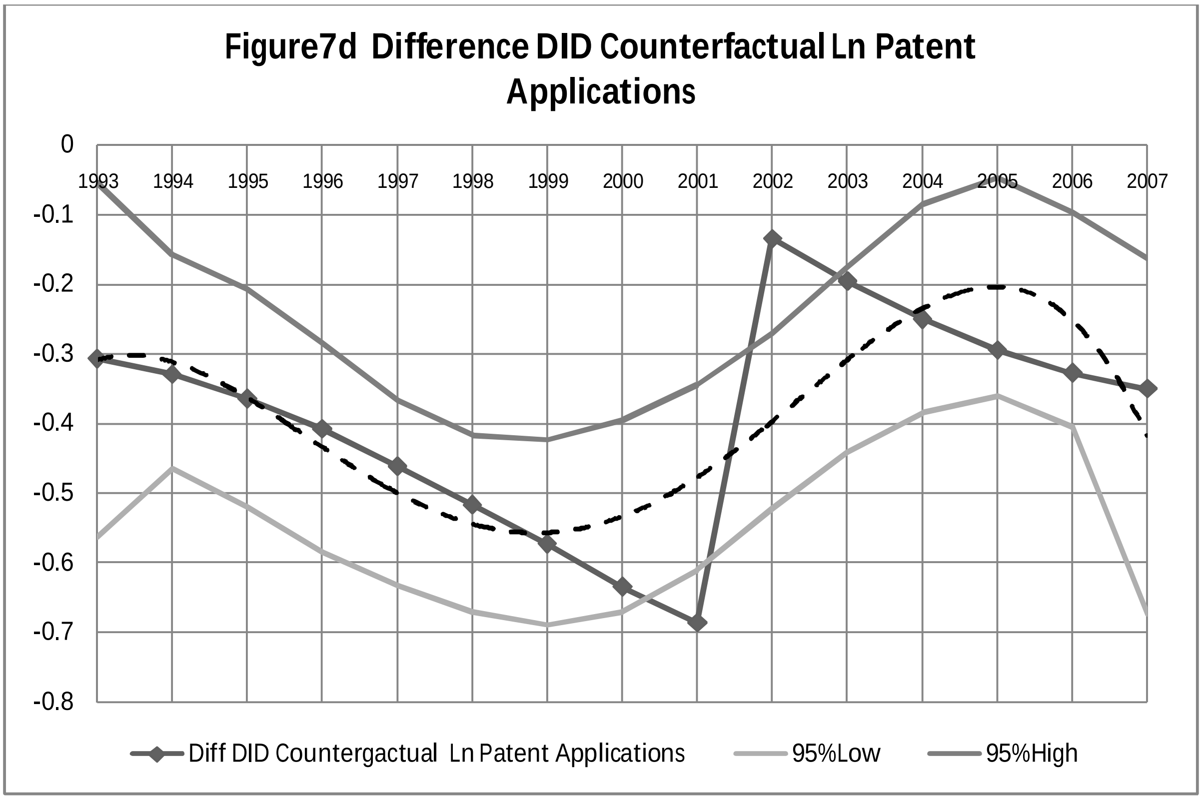


Figure7d Difference DID Counterfactual Ln Patent Applications
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Diff DID Countergactual Ln Patent Applications
95%Low
95%High

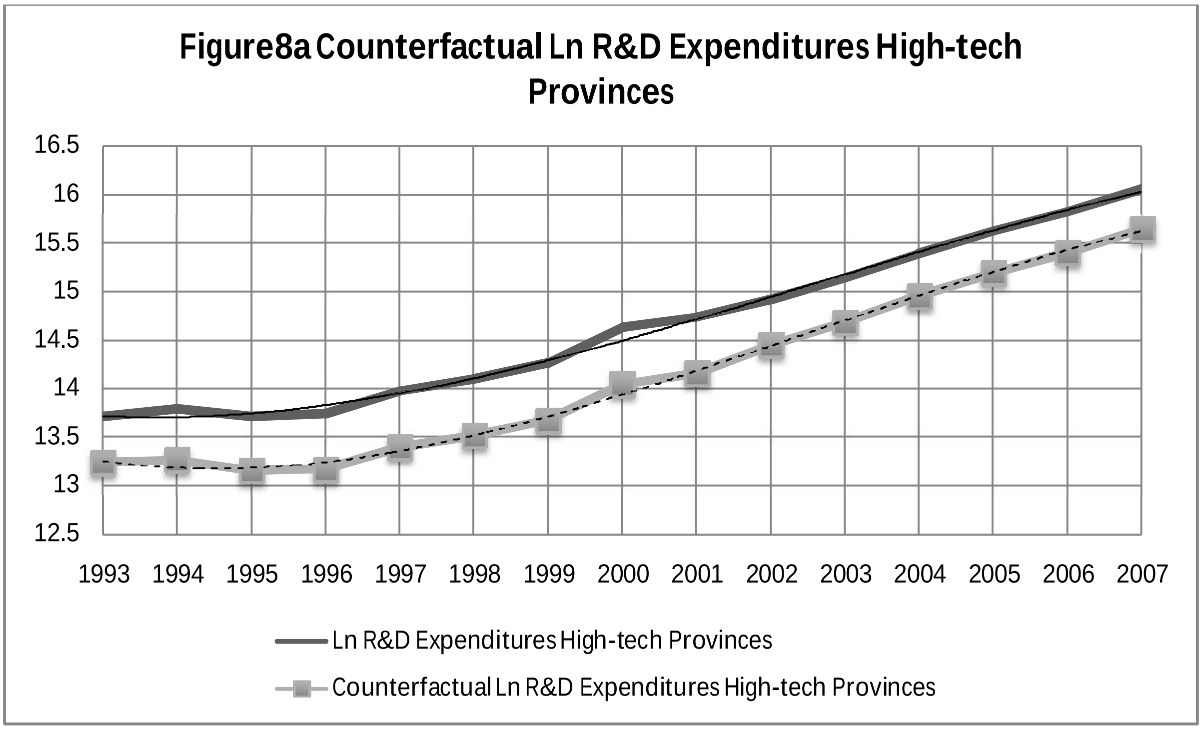


Figure8a Counterfactual Ln R&D Expenditures High-tech Provinces
16.5
16
15.5
15
14.5
14
13.5
13
12.5
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Ln R&D Expenditures High-tech Provinces
Counterfactual Ln R&D Expenditures High-tech Provinces

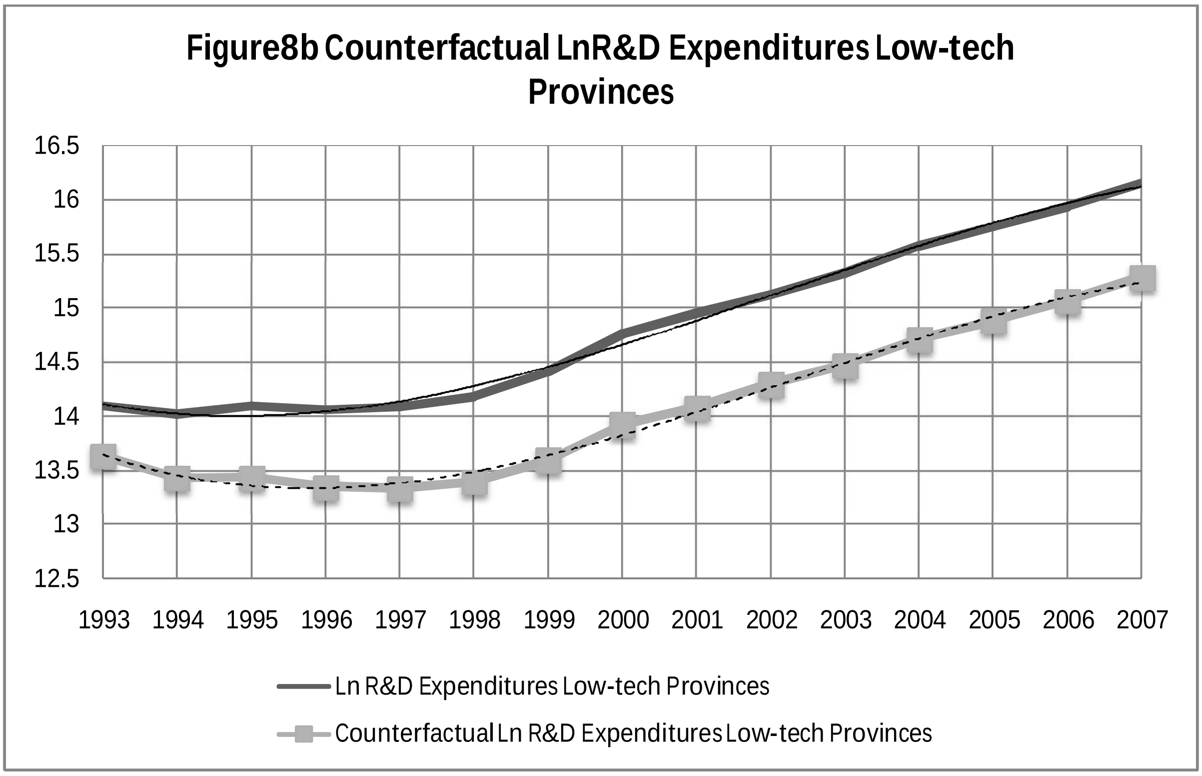


Figure8b Counterfactual LnR&D Expenditures Low-tech Provinces
16.5
16
15.5
15
14.5
14
13.5
13
12.5
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Ln R&D Expenditures Low-tech Provinces
Counterfactual Ln R&D Expenditures Low-tech Provinces

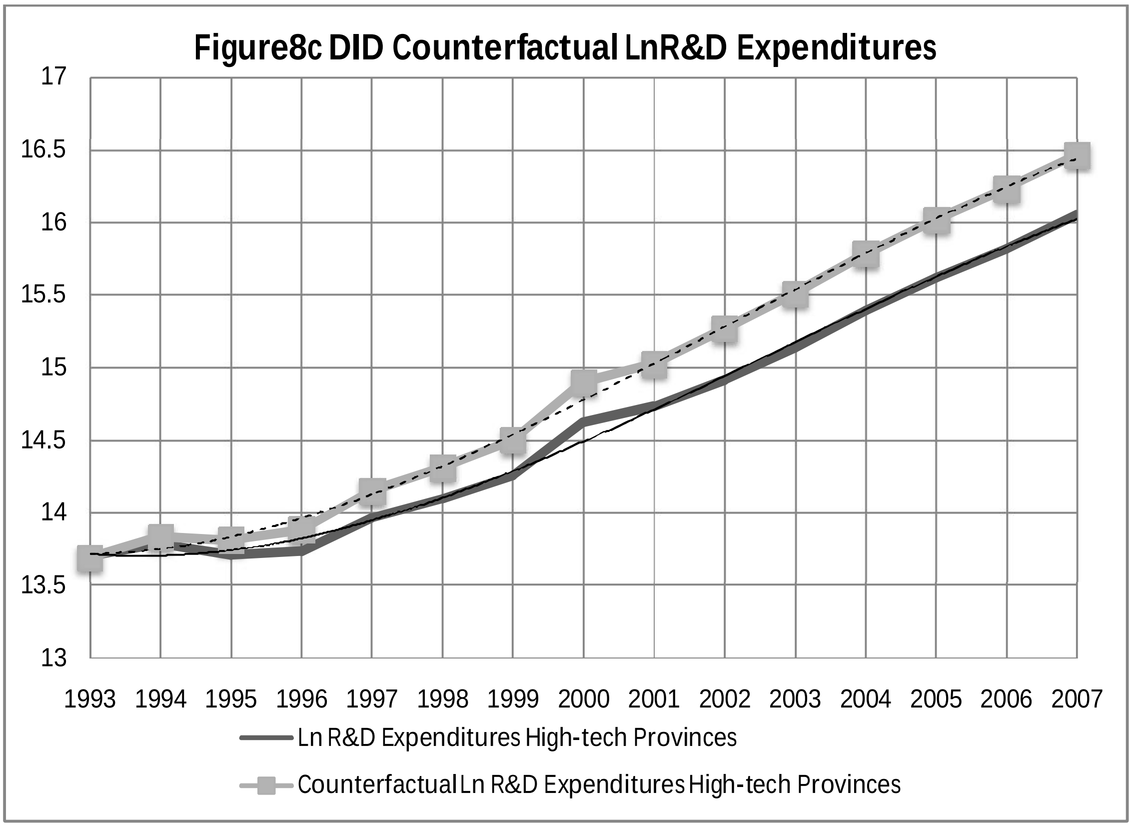


Figure8c DID Counterfactual LnR&D Expenditures
17
16.5
16
15.5
15
14.5
14
13.5
13
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Ln R&D Expenditures High-tech Provinces
Counterfactual Ln R&D Expenditures High-tech Provinces

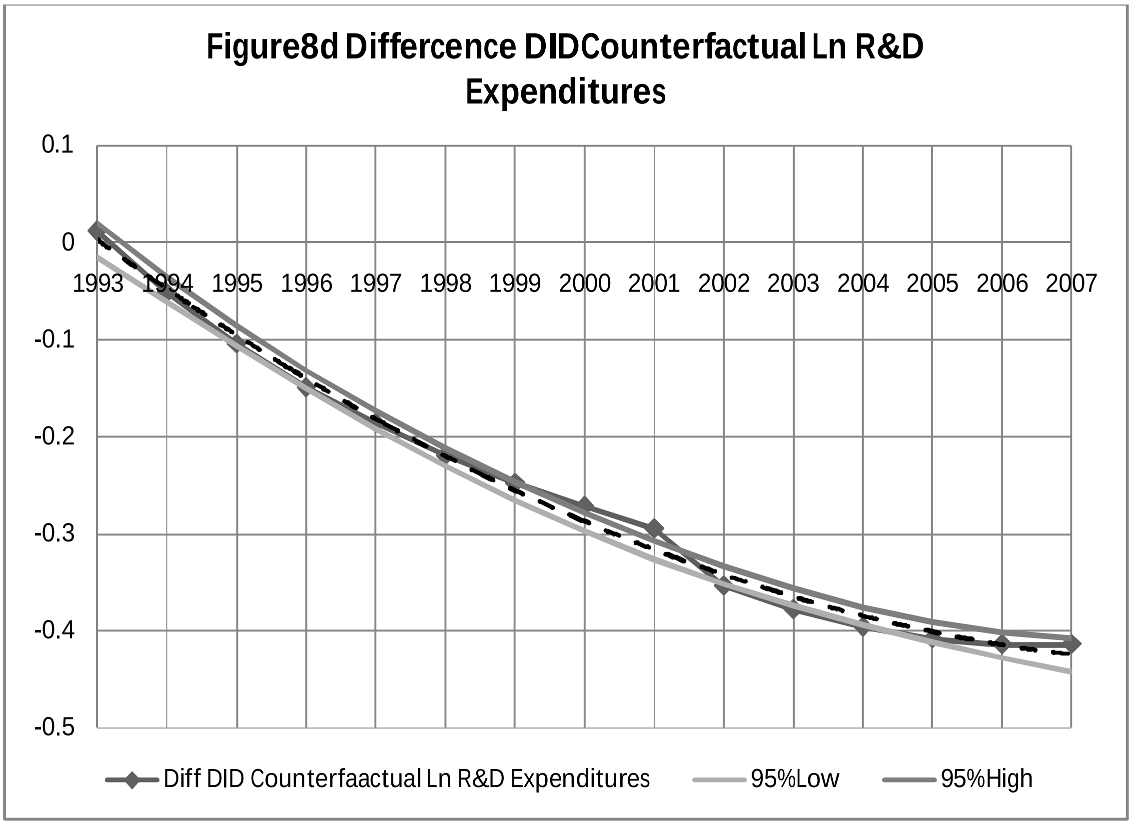


Figure8d Differcence DIDCounterfactual Ln R&D Expenditures
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Diff DID Counterfaactual Ln R&D Expenditures
95%Low
95%High

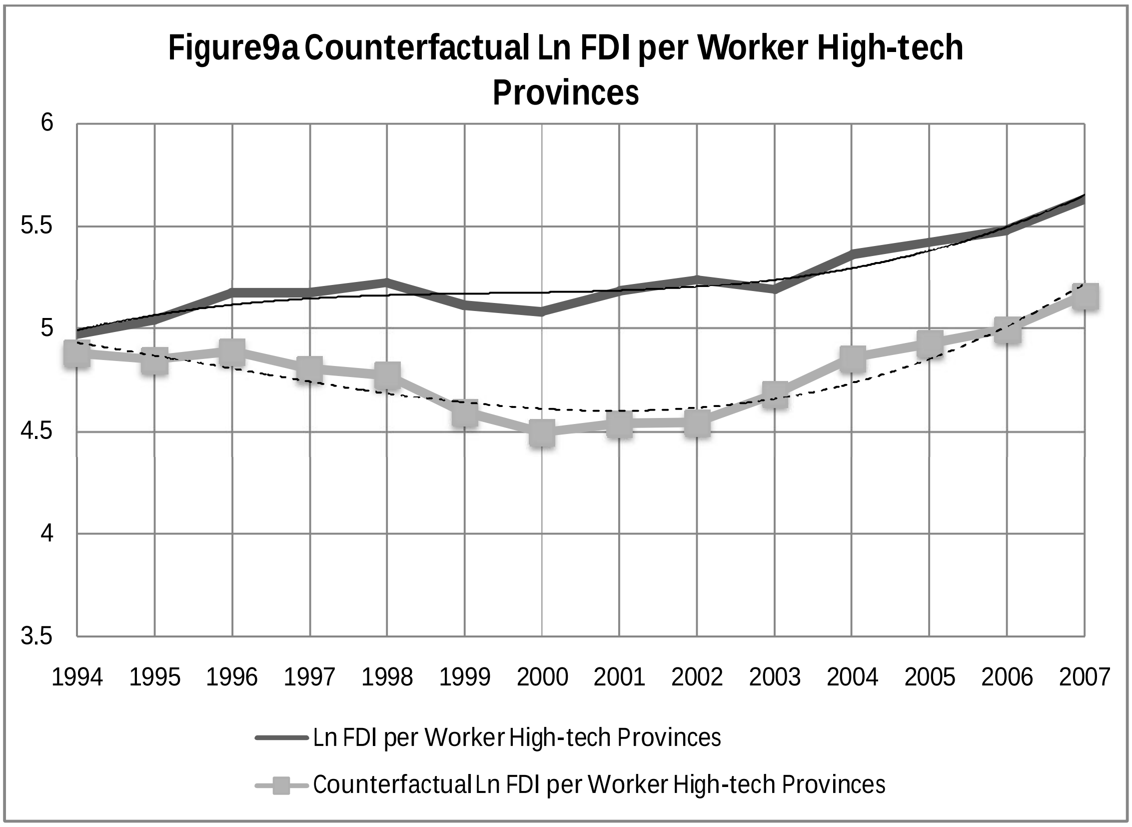


Figure9a Counterfactual Ln FDI per Worker High-tech Provinces
6
5.5
5
4.5
4
3.5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Ln FDI per Worker High-tech Provinces
Counterfactual Ln FDI per Worker High-tech Provinces

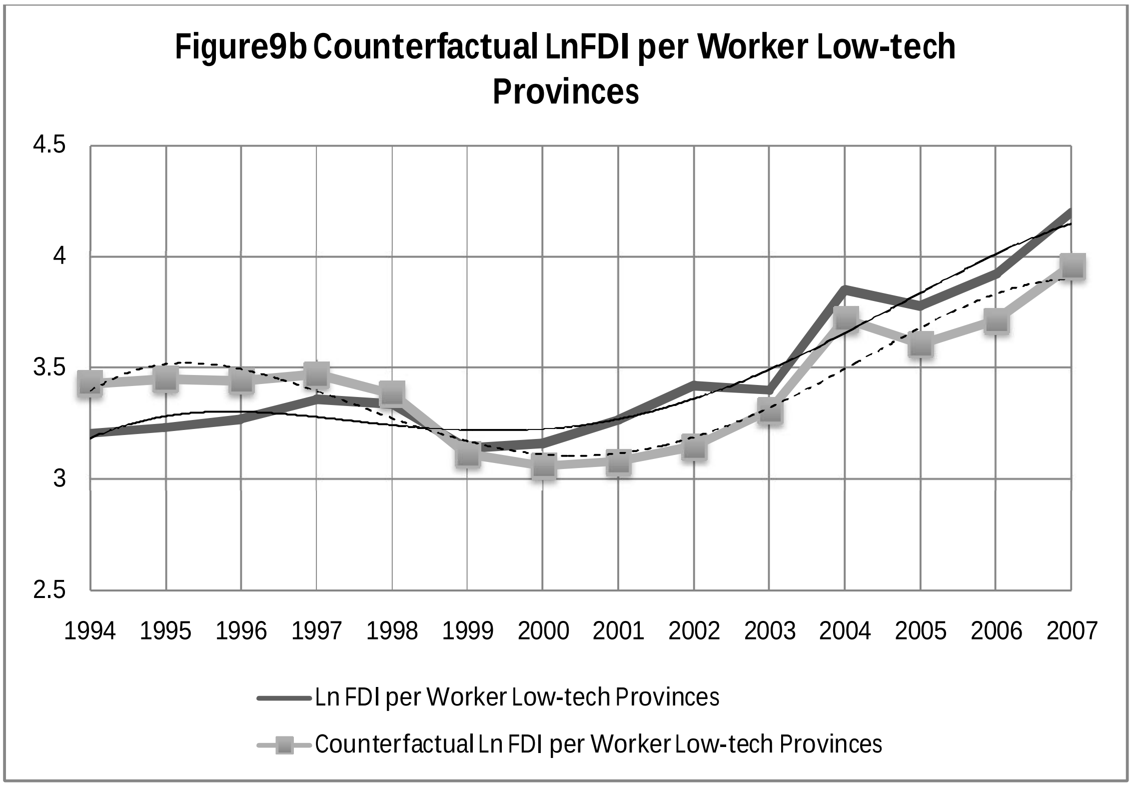


Figure9b Counterfactual LnFDI per Worker Low-tech Provinces
4.5
4
3.5
3
2.5
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Ln FDI per Worker Low-tech Provinces
Counterfactual Ln FDI per Worker Low-tech Provinces

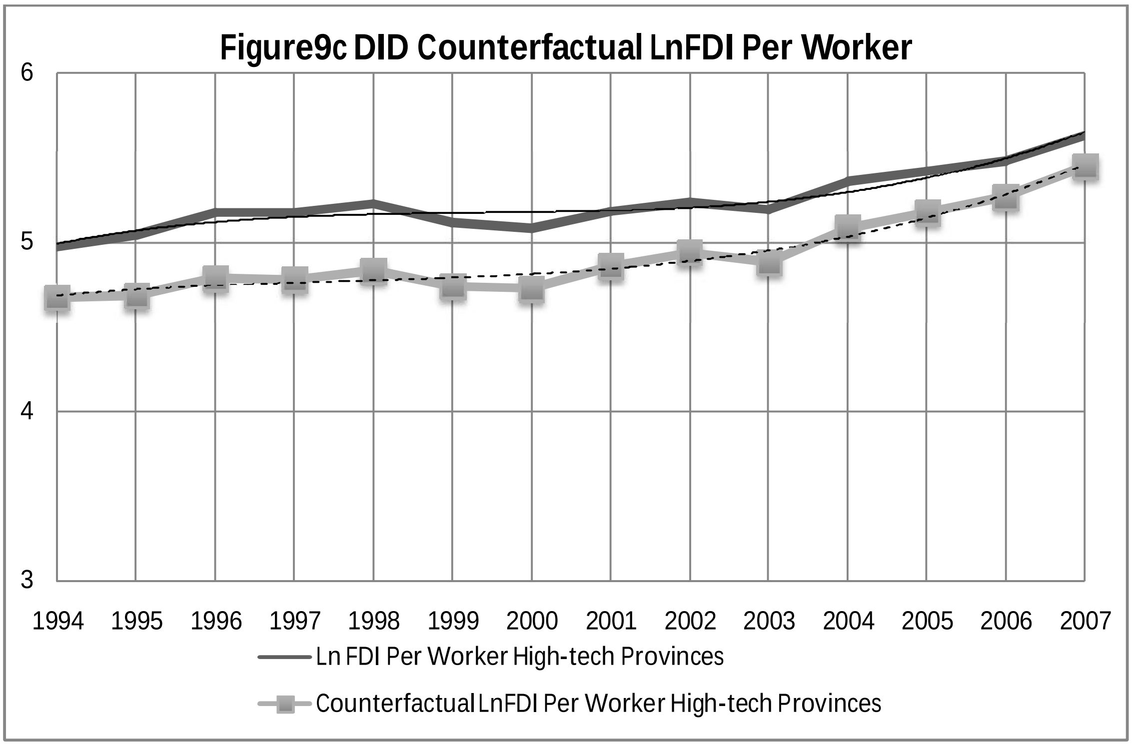


Figure9c DID Counterfactual LnFDI Per Worker
6
5
4
3
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Ln FDI Per Worker High-tech Provinces
Counterfactual LnFDI Per Worker High-tech Provinces

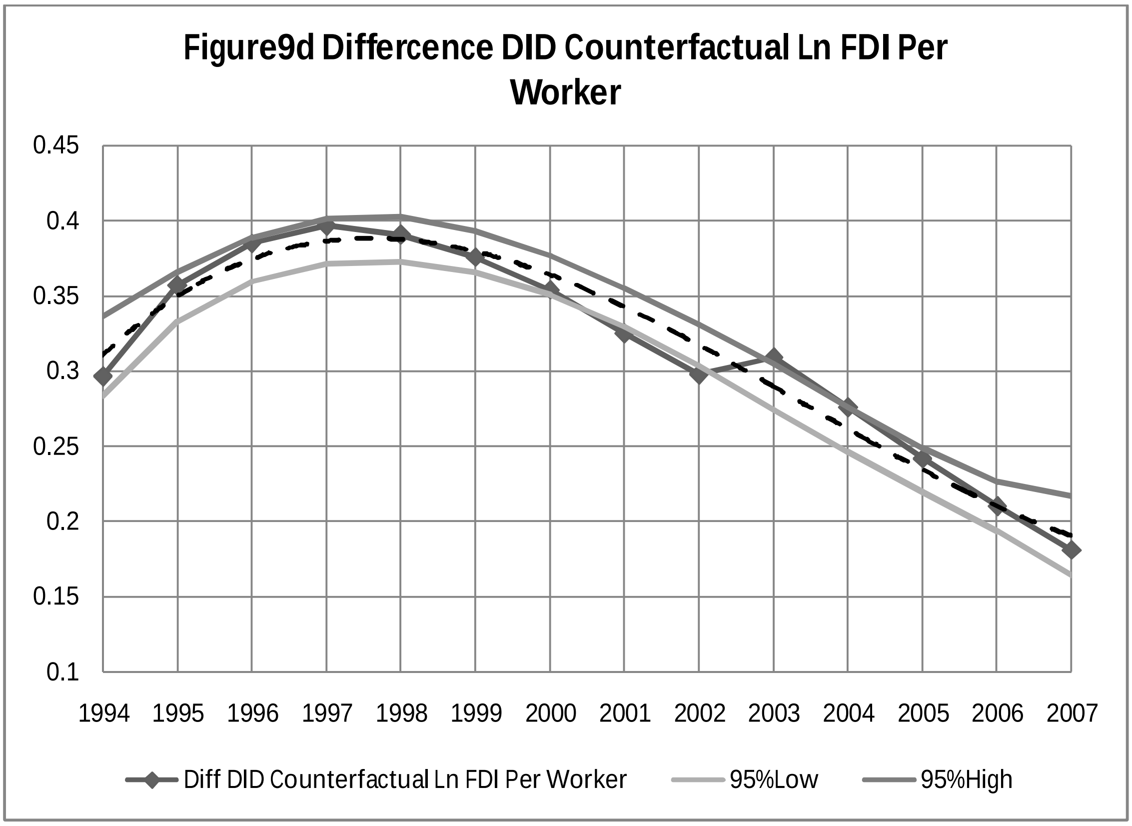


Figure9d Differcence DID Counterfactual Ln FDI Per Worker
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Diff DID Counterfactual Ln FDI Per Worker
95%Low
95%High

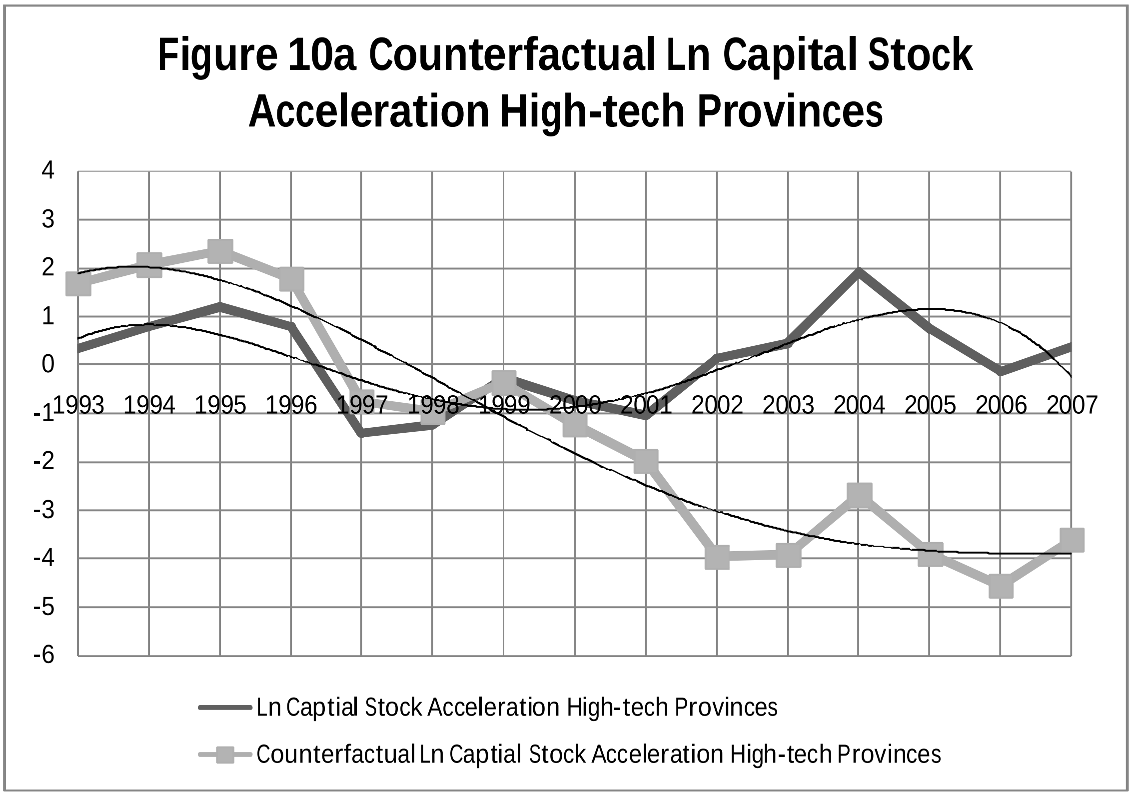


Figure 10a Counterfactual Ln Capital Stock Acceleration High-tech Provinces
4
3
2
1
0
-1
-2
-3
-4
-5
-6
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Ln Captial Stock Acceleration High-tech Provinces
Counterfactual Ln Captial Stock Acceleration High-tech Provinces

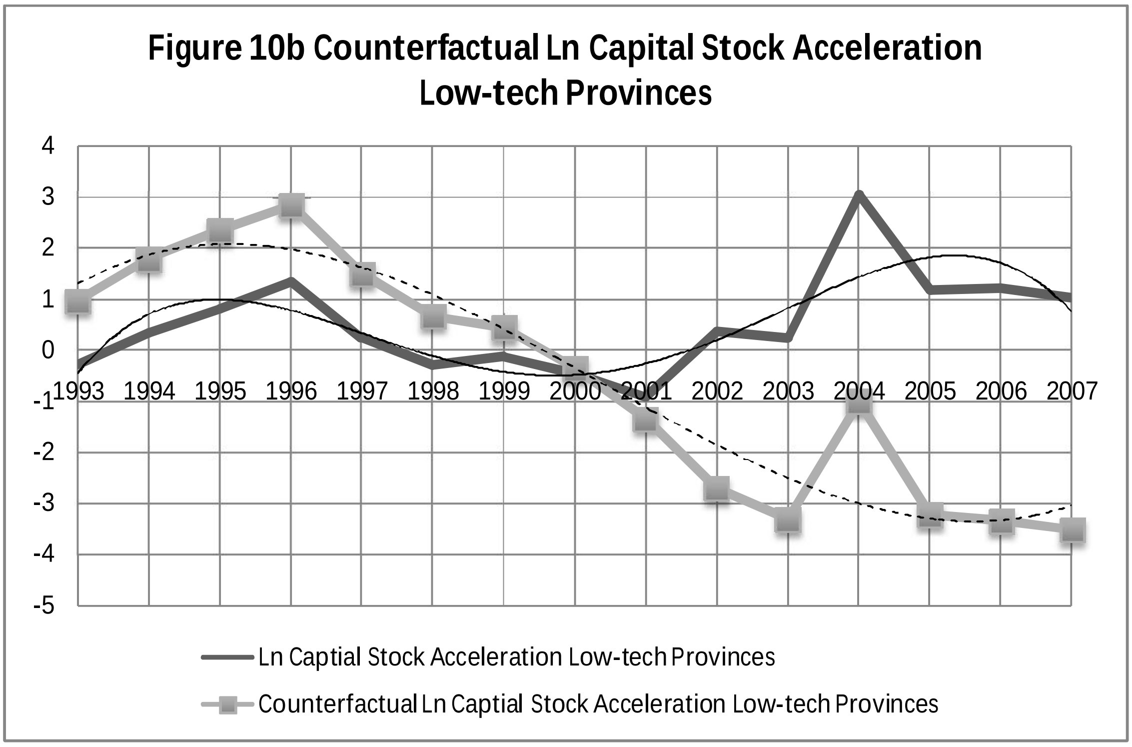


Figure 10b Counterfactual Ln Capital Stock Acceleration Low-tech Provinces
4
3
2
1
0
-1
-2
-3
-4
-5
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Ln Captial Stock Acceleration Low-tech Provinces
Counterfactual Ln Captial Stock Acceleration Low-tech Provinces

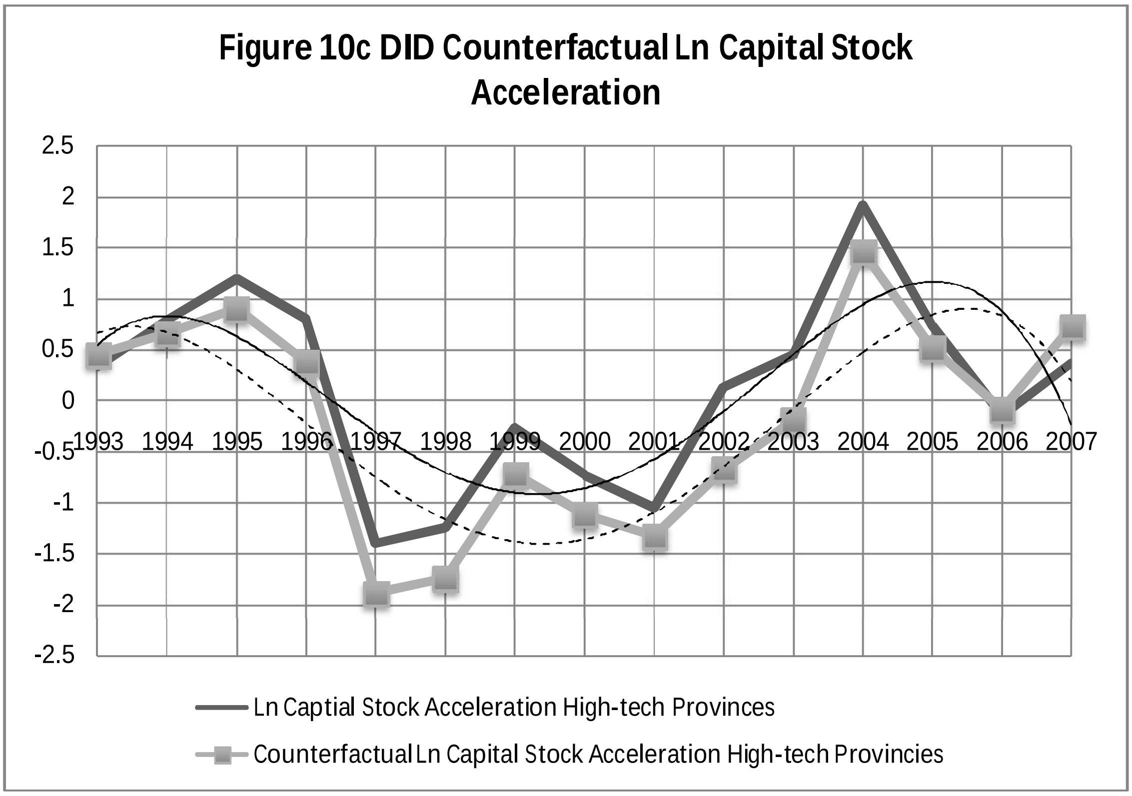


Figure 10c DID Counterfactual Ln Capital Stock Acceleration
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Ln Captial Stock Acceleration High-tech Provinces
Counterfactual Ln Capital Stock Acceleration High-tech Provincies

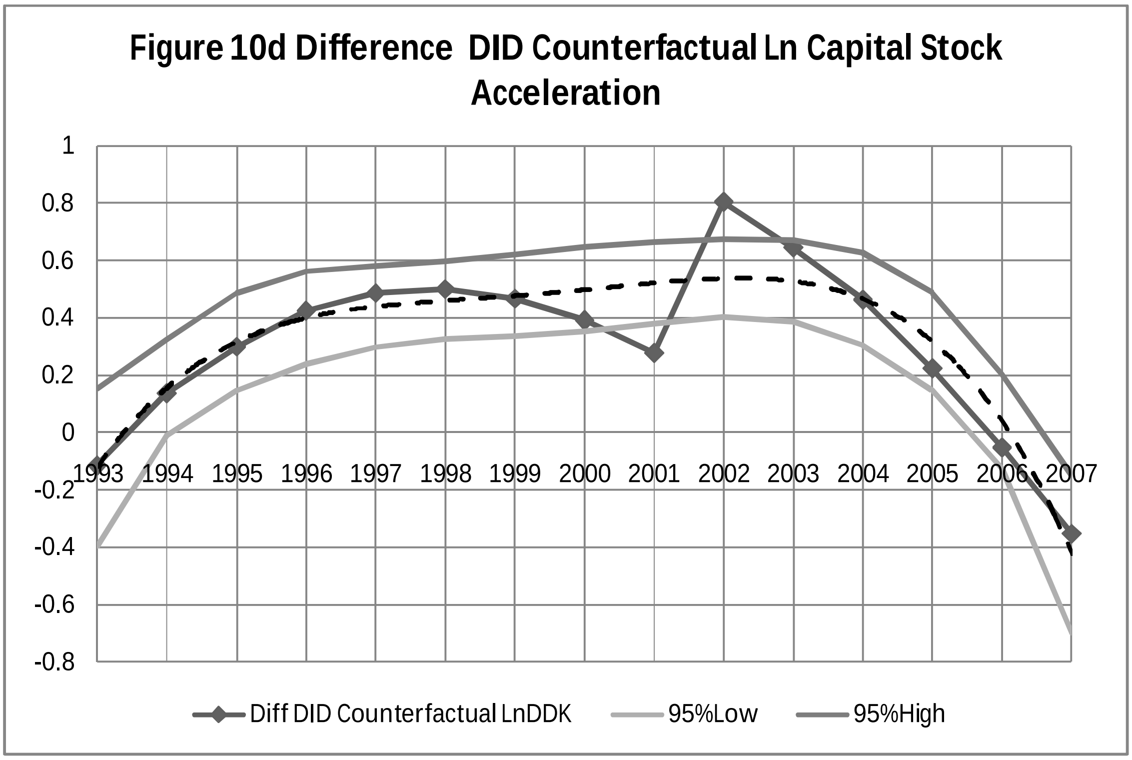


Figure 10d Difference DID Counterfactual Ln Capital Stock Acceleration
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Diff DID Counterfactual LnDDK
95%Low
95%High

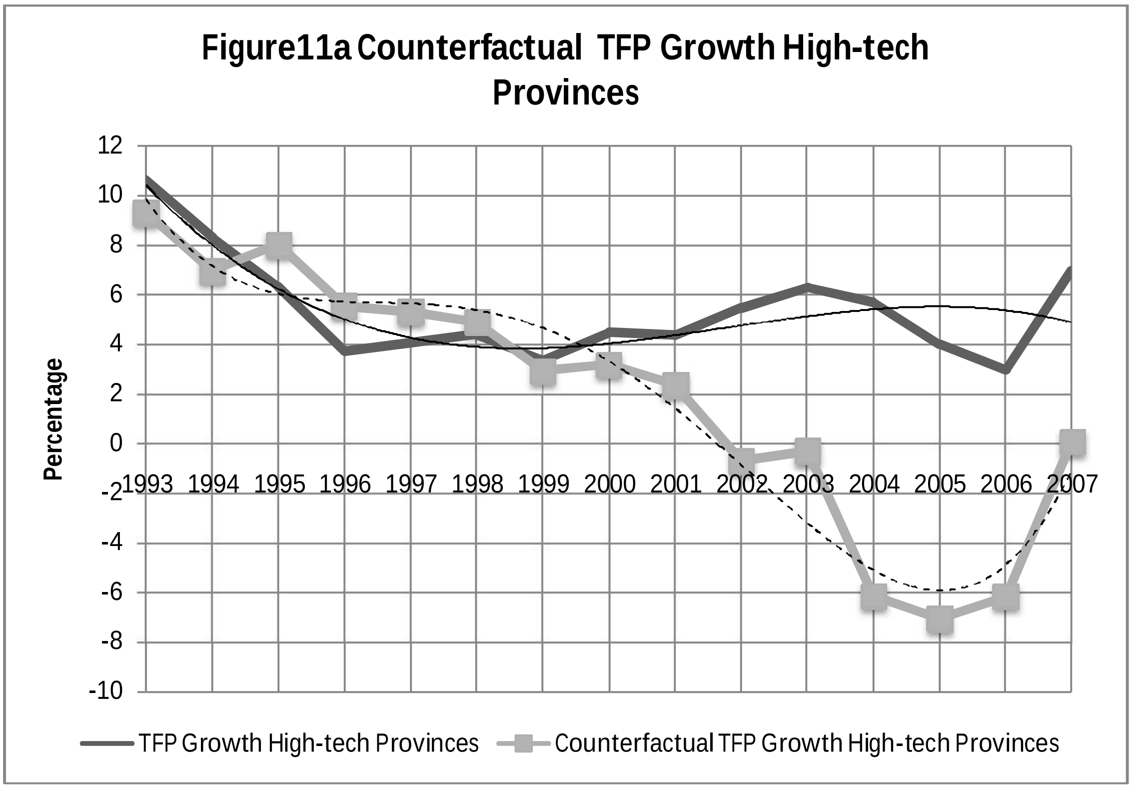


Figure11a Counterfactual TFP Growth High-tech Provinces
Percentage
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
TFP Growth High-tech Provinces
Counterfactual TFP Growth High-tech Provinces

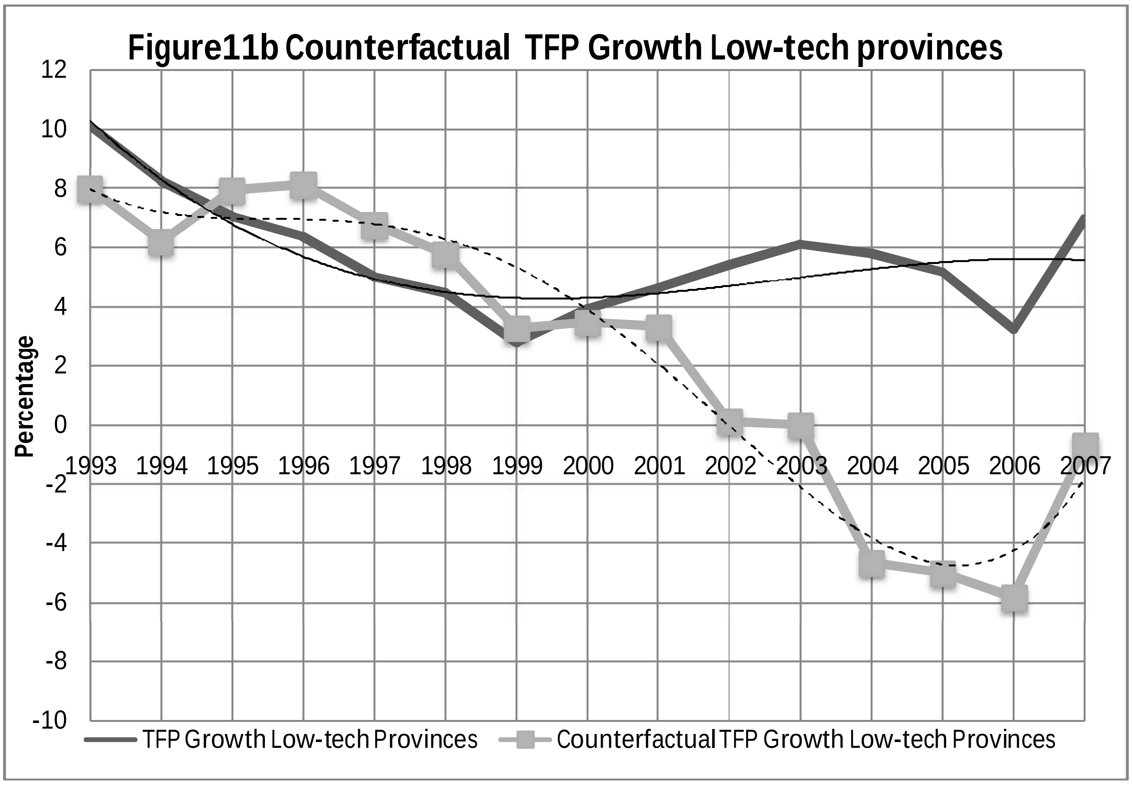


Figure11b Counterfactual TFP Growth Low-tech provinces
Percentage
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
TFP Growth Low-tech Provinces
Counterfactual TFP Growth Low-tech Provinces

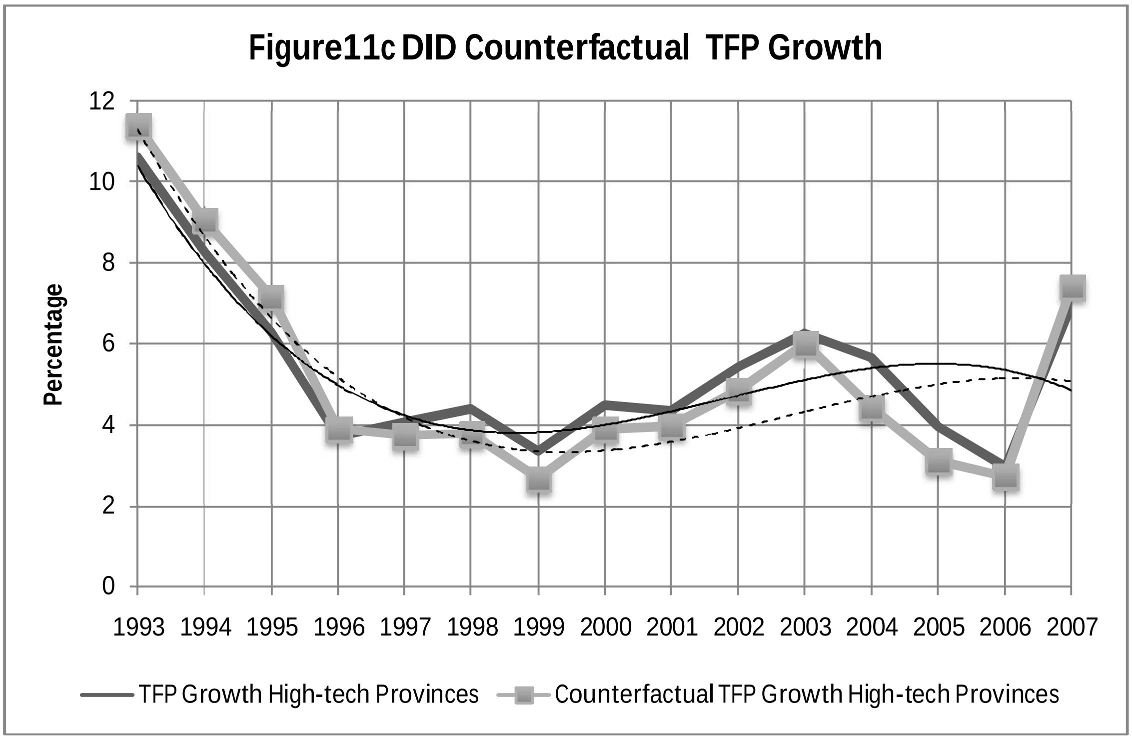


Figure11c DID Counterfactual TFP Growth
Percentage
12
10
8
6
4
2
0
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
TFP Growth High-tech Provinces
Counterfactual TFP Growth High-tech Provinces

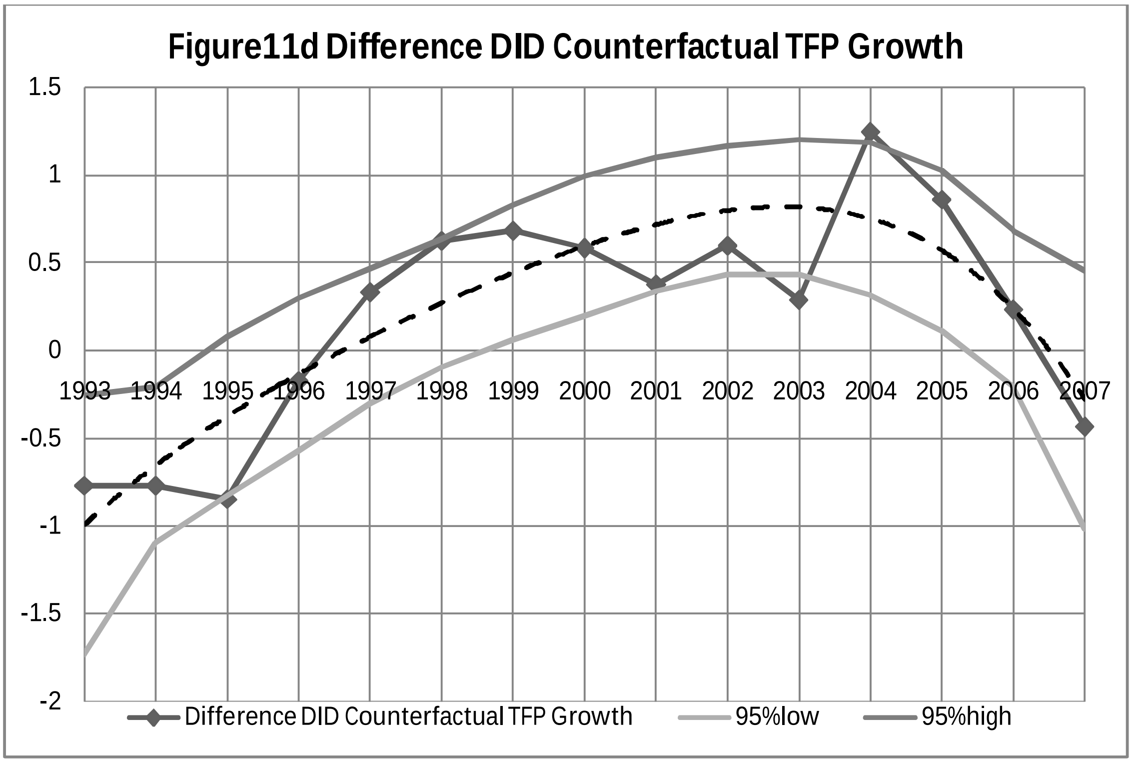


Figure11d Difference DID Counterfactual TFP Growth
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Difference DID Counterfactual TFP Growth
95%low
95%high