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Explaining Industrial Growth in Coastal China: Economic Reforms . . . and What Else?

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In the 1980s China experienced "an explosion of pent-up entrepreneurship" facilitated by wide-ranging, although often unorthodox, economic reforms. This article uses data on the output of 23 industrial sectors in seven coastal regions (provinces and counties) over the period 1985 to 1989 to study the correlates of growth. Although industry-specific features—the degree of specialization and competition—had some influence on growth, much of the action came from region-specific influences and regional spillovers. Regional influences included the open-door policies and special economic zones that successfully attracted investments from overseas Chinese to particular locations. Existing regional strengths, especially high-quality human capital and infrastructure, also contributed to growth. The results illuminate the interplay between conditions conducive for growth—for example, the contribution of foreign expertise is greatly enhanced by available human capital. China made judicious use of the advantages of backwardness by targeting areas that were less developed and less encumbered by the legacy of existing institutions, although it was fortunate in this regard that the backward regions were in close proximity to Hong Kong and Taiwan (China). Important also was the transmission of growth impulses across the provinces and counties, possibly through prereform cadre and administrative networks.

In the 1980s China experienced an explosion of pent-up entrepreneurship facilitated by wide-ranging, although often unorthodox, economic reforms. Walker's (1993) apt metaphor rightly focuses the spotlight on China's entrepreneurs who include not just factory managers but also local government officials, especially mayors of cities and counties. Growth in gross domestic product (GDP) jumped from 6.4 percent a year between 1965 and 1980 to 10.1 percent between 1980 and 1989. From 1985 to 1989, the years on which we focus, the pace of economic reforms was stepped up and performance was especially outstanding: GDP grew at 11.5 percent a year, and industrial output, the principal engine of growth, grew at a yearly rate of 14.4 percent. Moreover, factor productivity—which made virtually no contribution to growth in the three decades before 1980—

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grew at an annual rate of 2.4 percent for state-owned enterprises and 4.6 percent for collectively owned enterprises and accounted for 27 percent of growth between 1980 and 1988 (Chow 1993; Jefferson, Rawski, and Zheng 1990). At the same time China's share of world markets jumped dramatically between 1985 and 1989, particularly (but not exclusively) in light manufactured goods, such as shoes, clothing, toys, and small electrical appliances.

Gains in industrial output were especially marked in the coastal region, where growth during 1985–89 was significantly higher than that in other regions and was also substantially above its own growth rate in the previous five years (see table 1). Five coastal provinces (Fujian, Guangdong, Jiangsu, Shandong, and Zhejiang) were at the center of the "miracle," registering growth rates of about 20 percent a year between 1985 and 1989. The performance of the three coastal counties (Beijing, Shanghai, and Tianjin) was less impressive. Throughout China, but especially in the coastal provinces, enterprises in the nonstate sector were the star performers. In the Chinese context, the nonstate sector includes collective enterprises, which are typically owned by local governments—that is, by governments below the provincial or county level—whose officials have been a key source of domestic entrepreneurship (see Bateman and Mody 1991 and Oi 1992). Table 2 provides the share of industry by ownership for the eight coastal provinces and counties.

To examine China's exceptional growth experience, this article attempts to explain the variation in the growth of 23 industrial sectors in each of seven provinces and counties along the east coast of China during the period 1985 to 1989. The unit of analysis is the growth rate of an industrial sector in a specific

Table 1. *Growth in Industrial Output by Ownership in Coastal China, 1980–89*
(average annual percent)

	Total		*State-owned*		*Collectively owned*		*Others*[a]	
Region	*1980–85*	*1985–89*	*1980–85*	*1985–89*	*1980–85*	*1985–89*	*1980–85*	*1985–89*
Coastal counties								
Beijing	8.7	12.9	6.2	8.3	12.0	12.1	37.9	36.2
Tianjin	9.1	11.4	7.2	4.9	11.6	12.0	24.5	35.8
Shanghai	7.3	6.6	5.1	2.2	15.7	8.8	23.3	30.8
Coastal provinces								
Jiangsu	15.1	17.3	8.6	9.9	19.3	18.4	27.5	26.6
Zhejiang	18.7	17.8	10.4	8.2	23.4	18.0	33.0	28.6
Fujian	13.5	20.5	9.2	11.4	13.8	16.6	33.7	37.5
Shandong	11.2	21.5	6.8	10.2	15.6	21.9	26.8	55.3
Guangdong	14.4	23.5	11.2	15.1	16.6	22.2	23.4	40.7
Total	12.0	16.5	7.4	8.0	17.6	18.0	27.7	34.6
China	11.3	14.4	7.9	8.7	17.9	19.0	—	—

— Not available.
a. Includes mainly collectively owned enterprises below the township level, private enterprises, partnerships, individuals, and joint ventures with foreigners.
Source: China, State Statistical Bureau (1990).

Table 2. *The Share of Industry by Ownership in Coastal China, 1980, 1985, and 1989*
(percent)

Region	State-owned			Collectively owned			Others[a]		
	1980	1985	1989	1980	1985	1989	1980	1985	1989
Coastal counties									
Beijing	80.6	71.1	59.6	17.4	20.5	19.6	2.1	8.4	20.8
Tianjin	80.1	72.1	55.8	15.6	17.7	18.4	4.4	10.2	25.8
Shanghai	87.5	77.5	65.8	9.6	15.4	16.3	2.9	7.1	18.0
Coastal provinces									
Jiangsu	57.2	40.5	30.6	33.4	40.6	42.4	9.4	18.9	27.1
Zhejiang	56.1	35.5	24.6	34.5	44.4	44.6	9.4	20.1	30.9
Fujian	71.2	56.8	40.1	21.1	21.8	18.7	7.7	21.4	41.2
Shandong	67.6	54.6	38.5	26.6	32.4	32.6	5.9	13.0	28.9
Guangdong	63.0	52.5	37.6	27.1	30.6	28.6	9.9	17.0	33.9
Total	71.4	55.7	40.8	22.5	29.9	31.4	6.1	14.3	27.8

a. Includes mainly collectively owned enterprises below the township level, private enterprises, partnerships, individuals, and joint ventures with foreigners.

Source: China, State Statistical Bureau (1990).

region in a specific year. Three sets of influences on the growth rate are examined:

- *Industry-specific features:* the degree of specialization and competition
- *Regional growth factors:* the availability of infrastructure, educational levels, and direct foreign investment; also, the initial per capita income of the province or county measures the extent of backwardness and hence the catch-up potential
- *Regional spillover effects*: the relationship between growth in a region and growth in other regions.

Certain distinguishing features of this analysis, as well as its limitations, are worth noting. First, by comparing growth rates within a relatively homogeneous region (the Chinese east coast), the study overcomes some concerns in interpreting cross-country growth regressions, where it is difficult to control for widely different economic, social, and political regimes.[1] Second, studies of developing-country growth focus principally on a country's GDP (Mankiw 1995 surveys that literature); our focus on individual industrial sectors is likely to yield more reliable estimates. In this respect, we follow Glaeser and others (1992) and Henderson, Kuncoro, and Turner (1995) who study industrial growth within the United States. Third, we build on the analysis of Glaeser and others (1992) by including the possibility of regional spillovers along with regional influences. Fourth, although covering only a short time span of four years, we are able to exploit the panel features of the data to examine factors influencing growth

1. Islam (1995) uses country dummies to control for country-specific features but finds them correlated with the traditional explanatory variables.

within and across the provinces and counties. Finally, we also study whether heavy and light industries have been subject to different growth impulses.

The main limitation of the study arises from the concern that the industrial output data used may have built-in biases. We are reassured, however, by the significant variation in growth rates across sectors, regions, and time, suggesting that measured growth rates are not merely a reflection of some bureaucratic data-recording process. Moreover, we conduct a number of sensitivity analyses running regressions for different samples, checking for the presence of influential observations, and testing the robustness of important explanatory variables. However, we have attempted to interpret the results conservatively, highlighting the most quantitatively and statistically significant findings.

Section I decomposes output growth into time-dependent, regionwide, and industry-specific components, as well as their interactions, to identify the proximate sources of growth. Section II describes the approach to studying the correlates of growth used and our explanatory variables. Section III presents and interprets our findings. Section IV summarizes our major findings and also draws some lessons for other countries.

I. A Decomposition of Growth of Output

Did growth occur across the board or only in certain regions or industries? Within regions or industries, did growth vary substantially from year to year? Variance analysis allows us to quantitatively decompose output growth into time, region, and industry-specific effects and their interactions. Identifying the main sources of variance in the data through decomposition analysis helps in a preliminary quantitative assessment of the different sources of growth. The finding of significant time and regional differences in growth rates after controlling for sectoral growth patterns also provides some reassurance that the industrial output data are not being generated in a bureaucratically mechanical manner.

Growth in time period t, region r, and industry i, G_{tri}, is assumed to be the additive result of main and interaction effects.

$$G_{tri} = m + \alpha_t + \beta_r + \tau_i + a_{tr} + b_{ti} + c_{ri} + \varepsilon_{tri} \qquad (1)$$

where m is a constant, α_t, β_r, and τ_i are the main time, region, and industry effects, respectively, a_{tr}, b_{ti}, and c_{ri} are the second-order interaction terms between two main effects, and ε_{tri} is the interaction term for the three main effects.

Following Schankerman (1991), the variance of output growth can therefore be expressed as:

$$\text{Var}(G_{tri}) = \underset{4.98}{\text{Var}(\alpha_t)} + \underset{5.72}{\text{Var}(\beta_r)} + \underset{2.88}{\text{Var}(\tau_i)} + \underset{1.33}{\text{Var}(a_{tr})} + \underset{48.14}{\text{Var}(b_{ti})} + \underset{2.18}{\text{Var}(c_{ri})} + \underset{34.78}{\text{Var}(\varepsilon_{tri})}. \qquad (2)$$

The numbers below the variables in equation 2 are the results derived by equating the expected values of the variance components with their observed values (see the appendix for the derivation). Because this is a decomposition, the values add up to 100 percent. The small variance of α_t—4.98 percent—implies that during 1985 to 1989, time-varying factors had only a minor effect on growth. Thus, although the overall pace of reforms accelerated, the effect was not felt uniformly in all regions and industries.

Purely regional effects, β_r, were also small—5.72 percent—implying that across years and industrial sectors, there was no consistent ranking of regional growth. Together with their interaction, time, and region effects, α_t, β_r, and a_{tr} explain 12 percent of the variation in growth. Thus reforms did not manifest themselves primarily through general coastal expansion or through growth in specific coastal provinces or counties.

Industry-specific factors, τ_i, were small as well, accounting for 2.88 percent of the variation in growth. Hence, no industrial group grew uniformly rapidly or slowly throughout the period. For example, the electronics and telecommunications sector grew only 5.6 percent in 1985–86, whereas in 1987–88, it rose a remarkable 19.3 percent.

The dominant source of variation in the data comes from the interaction of time and industry (b_{ti}), which explains 48.14 percent of the total variance in growth. Thus output growth rates for specific sectors varied from year to year, but within a year they were strongly correlated across regions. This effect captures an industry-specific wave phenomenon evident from a visual examination of the time pattern of sectoral growth rates for miscellaneous light industries in table 3. The term wave is used here not to suggest any predictable sequence of industries experiencing successive surges in growth, but only to indicate that specific industries achieved high rates of growth across regions at the same time. Different industries led in different years; some of the most labor-intensive sectors, such as garments, achieved their biggest spurt only very late. The wave phenomenon was not restricted to light industries. In 1985–86 rapid growth was evident in leather products, pharmaceutical products, chemical fibers, and metallic products in most of the coastal region. In 1986–87 electronics and chemicals replaced leather and metallic products. In 1987–88 paper products, transportation equipment, electronics, and pharmaceutical products expanded rapidly, only to lose their position to the apparel industry in 1988–89.

Such synchronization could be accounted for by shifts in buyers' preferences for goods, industry-specific technological improvements rapidly transmitted along the coast, or coordinated strategies among decisionmakers to promote growth of specific industries at specific times. Also formal and informal interactions among firms and labor turnover, particularly of highly skilled managers and engineers, may have extended technology and skills learned in the open areas to the rest of the coastal region (Ho and Huenemann 1984, p. 55). Another intriguing possibility is that decisionmakers (whether in the communist party or industrial administration) maintained close ties that led to the rapid diffusion of development strategies along the coast (see Yusuf 1993 and the literature he cites). This network of decisionmakers could provide a grid for information flows leading to replication of sectoral targeting strategies, among other things.

Table 3. *Growth in Output of Light Industries in Coastal China, 1985–89*
(average annual percent)

Years and industries	*Guangdong*	*Fujian*	*Jiangsu*	*Zhejiang*	*Shandong*	*Beijing*	*Tianjin*	*Shanghai*
1985–86								
Apparel	27.0	20.6	11.8	1.1	12.7	–5.6	6.7	–14.7
Leather products	31.2	28.8	22.7	15.0	26.3	5.7	9.8	8.3
Wood products	3.1	9.3	13.1	17.5	5.0	–0.7	–7.4	0.5
Furniture	4.4	–1.9	11.2	11.0	18.6	3.3	–4.3	2.1
Paper products	15.8	11.8	18.8	15.8	18.0	8.8	5.4	2.4
Art products	14.9	39.5	–7.6	11.8	25.6	–36.7	–3.0	–16.6
Plastic	17.3	17.5	8.4	11.3	19.7	3.6	6.7	5.1
1986–87								
Apparel	36.1	19.1	14.5	17.6	13.8	4.3	–0.1	11.3
Leather products	54.5	13.5	24.1	13.0	18.7	–2.3	–2.8	3.9
Wood products	15.3	16.2	24.1	1.1	16.3	–3.0	–15.7	–0.7
Furniture	26.1	12.6	19.8	14.6	21.0	13.1	0.4	5.8
Paper products	28.1	16.8	27.8	20.2	20.8	10.2	6.2	15.5
Art products	20.8	12.1	21.1	20.4	41.1	14.4	8.6	2.1
Plastic	27.3	13.4	18.7	17.6	21.6	–8.7	6.5	4.0
1987–88								
Apparel	15.4	21.0	12.7	17.4	20.1	13.2	–8.9	7.1
Leather products	17.2	17.0	9.1	9.1	9.7	–22.2	–3.4	–2.2
Wood products	25.1	20.0	–7.1	8.8	16.3	–7.6	–27.2	–16.0
Furniture	10.5	6.0	6.6	14.2	17.5	1.9	–2.7	0.5
Paper products	95.7	56.0	79.5	64.3	60.7	155.6	66.4	103.2
Art products	0.8	21.2	13.2	18.5	28.7	18.0	11.9	6.2
Plastic	14.8	18.4	6.8	16.7	26.5	–1.4	–3.2	–4.6
1988–89								
Apparel	28.2	49.8	13.1	16.9	15.2	12.4	14.5	7.3
Leather products	26.6	5.0	–1.8	10.7	10.4	–3.0	–4.0	–3.5
Wood products	5.1	13.4	–5.5	5.0	23.6	–10.0	–12.0	–3.7
Furniture	6.9	1.7	–11.1	–7.0	10.3	3.8	–6.6	–1.3
Paper products	5.7	11.1	–0.4	4.7	10.4	2.5	–5.2	–2.3
Art products	10.7	8.7	11.5	20.8	27.0	–3.6	8.9	18.4
Plastic	15.5	14.2	2.6	4.0	17.5	0.8	–8.9	0.9

Note: The underlined values indicate an industry-specific wave phenomenon evident from a visual examination of the time pattern of sectoral growth rates for miscellaneous light industries. Although output growth rates for specific sectors varied from year to year, certain sectors achieved high rates of growth across regions.

Source: China, State Statistical Bureau, *China Statistical Yearbook* (various years).

In a field study of major decisionmakers, Oi (1995) found considerable support for this hypothesis.

But the synchronization could also reflect data limitations. If price deflators for particular industrial groups are biased in different directions in different years, then high synchronization would be built into the data, making it *appear* that certain sectors grew more rapidly than others in a given year when, in fact, they did not. Such biases in industrial price deflators would exaggerate the extent of synchronization. Here, in this variance decomposition, the limited objective is to describe the variance in the data, whether it arises from data artifacts or from interesting economic forces. In the regression results reported below, however, interpretation is more critical. A conditioning term—growth of the same industry outside the region—could be viewed as a control variable for this deficiency in the quality of data. But in this case, we would have to downplay its interpretation as a measure of regional spillovers. The continued plausibility of the regional spillover hypothesis arises from the differences in degree of the cross-regional synchronization for heavy and light industries and the findings of a field study (Oi 1995). Such synchronization is also evident in the study by Glaeser and others (1992).

The remaining 34.78 percent of the variance in output growth is attributable to the third-order interaction between time, region, and industry (ε_{tri}). We interpret this as a regional effect conditional on time-varying industry-specific factors. Although the changing identity of high-growth sectors is a major source of variation in growth, this third-order interaction indicates that growth in an industrial sector during a particular year is not uniform in every region. Regional differences in initial conditions, human capital endowment, and infrastructure availability, among others, may cause industries in some regions to grow faster than those in others. Thus even though the own effect of regional differences (β_r), and its interactions with time (a_{tr}) or industry (c_{ri}), do not explain much of the variation in growth, after adjusting for time-varying *and* industry-specific factors, significant regional effects remain.

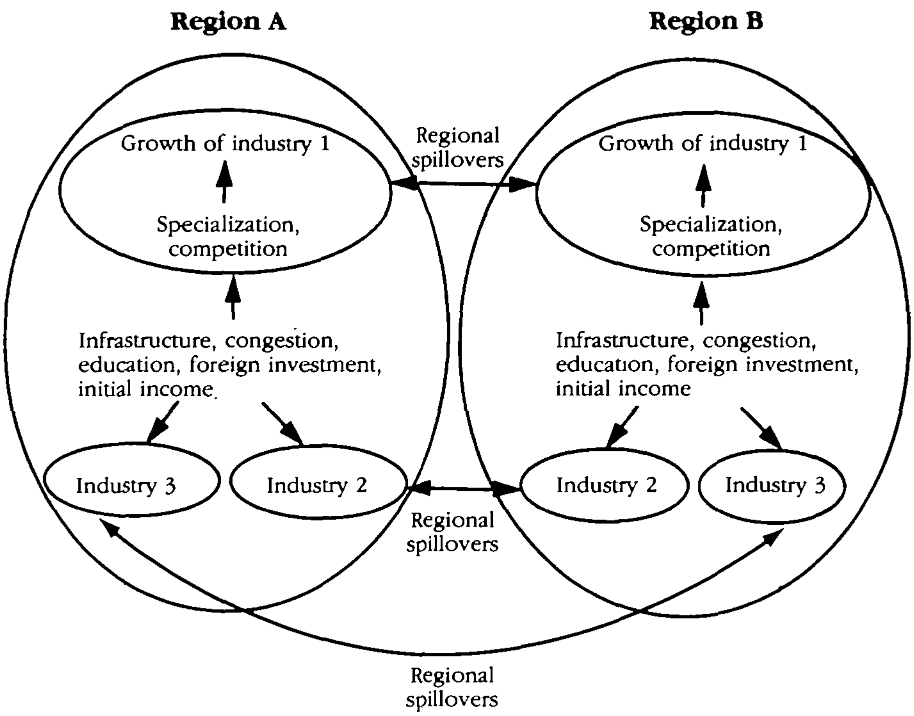
Unconditional time, industry, and regional factors do not carry significant explanatory power for variation in growth. Instead, about half the variation in growth during 1985–89 is associated with time-varying sectoral growth differences (b_{ti}). Regional effects, by contrast, emerge only after controlling for the time *and* industry effects.

II. Investigating the Correlates of Growth

The annual growth rate of output in an industrial sector in a given region is our dependent variable. Various industry-specific, regionwide, and cross-regional factors are the independent variables whose correlation with growth we seek to examine. The goal here is not to test any specific model of growth but to describe its most robust partial correlates.

Following Glaeser and others (1992), we focus on growth itself rather than on increases in productivity. (Their dependent variable was employment growth; we use output growth.) Although it may be more appropriate to use increases in labor or total factor productivity as the dependent variable, this is not possible in our case because consistent labor force data by industrial sector are not consistently available. We find, however, that the data on growth of industrial output are so rich that considerable insights can be obtained even in the absence of information on labor and capital inputs. Indeed, if we believe that enterprise-level decisions to acquire or invest in labor or capital inputs are influenced by

Figure 1. *A Framework for Industrial Growth in Coastal China*



available knowledge, infrastructure, human capital, and industrial organization, then not only productivity but also a considerable amount of output growth can be attributed to these factors.

The basic framework of analysis is described in figure 1 for two regions (A and B) and three industrial sectors (1, 2, and 3). The most proximate influences on an industry's growth rate are industry-specific variables that condition the extent of knowledge flows within an industry and the incentives to invest in the development and appropriation of knowledge. The variables we use—the degree of industry specialization and entrepreneurship—are the same as those used by Glaeser and others (1992). We add a set of regional variables to the regressions. The assumption is that having controlled for industry-specific characteristics, the effect of region-specific variables (such as infrastructure) will be similarly felt by all industries (for a similar assumption, see Waldmann and De Long 1990, who analyze growth across industries in different countries, and Stockman 1988). Finally, if there are regional spillovers, an industry in a particular region will be influenced by growth in other regions.

Table 4 provides descriptive statistics for the seven provinces and counties used in the regression analysis below for 1986–89. The regression analysis, un-

Table 4. *Descriptive Statistics for the Data on Industry in Coastal China, 1986–89*

Variable	*Mean*	*Standard deviation*	*Minimum value*	*Maximum value*
Industry specific				
Specialization index[a], *S*	1.028	0.466	0.000	4.347
Entrepreneurship index[b], *E*	1.203	0.839	0.018	5.292
Region specific				
Secondary school enrollment rate	0.444	0.125	0.300	0.731
Accumulated foreign direct investment per person (thousands of dollars)	0.015	0.019	0.000	0.067
Roads[c] (kilometers)	0.434	0.174	0.262	0.882
Interaction between roads and congestion (population per square kilometer)	389.543	532.696	75.648	1,797.400
Telephones per 1,000 persons	13.462	9.473	4.712	36.194
GDP per capita (current yuans)	1,845.360	1,188.910	708.000	5,161.000
Regional spillover				
Growth in industry in region, *G* (percent)	0.112	0.151	−0.423	1.032
Growth in industry outside region (percent)	0.104	0.119	−0.195	0.886

Note: Statistics are for beginning-of-period values, based on annual data for 1985–86 to 1988–89 for seven provinces and counties: Fujian, Guangdong, Jiangsu, Shandong, Shanghai, Tianjin, and Zhejiang.

a. The specialization index for industry *i* in region *r*, at time *t* is S_{irt} = (output in industry *i* / total output) for region *r* / (output in industry *i* / total output) for all regions.

b. The entrepreneurship index for industry *i*, in region *r*, at time *t* is E_{irt} = [(number of firms/total output) for industry *i* in region *r*] / [(number of firms / total output) for industry *i* in all regions].

c. Length of road routes (kilometers) is normalized by area (square kilometers).

Source: Authors' calculations based on data from China, State Statistical Bureau (1990); *China Statistical Yearbook* (various years); Hayase and Kawamata (1990); *Statistical Yearbook of Fujian* (various years); *Statistical Yearbook of Guangdong* (various years).

like the variance decomposition, is based on data only for seven regions (the five coastal provinces and two counties—Shanghai and Tianjin); foreign investment data for Beijing are not available.

Industry-Specific Variables

An important structural feature of an industry is its degree of regional specialization. Presumably greater specialization is good if the relevant knowledge is best acquired within the industry, but deleterious when diverse skills and information from other industries are important. Another important industry characteristic is the degree of entrepreneurship and competition that can spur investment, although too much competition can lead to diminished investible surpluses. With the data at hand, the existence of entrepreneurship or competition is inferred only indirectly from the size of firms in industry *i* in region *r* relative to its average in all seven regions.

As in Glaeser and others (1992), we calculate the following measures of specialization, S_{irt}, and entrepreneurship, E_{irt}.

S_{irt} = [(output in industry *i* / total output) for region *r*] / [(output in industry *i* / total output) for all regions]

E_{irt} = [(number of firms / total output) for industry i in region r] / [(number of firms / total output) for industry i in all regions].
The time subscript indicates that these measures are different for each year.

S_{irt} is the ratio of the share of industry i in region r to its average share across the seven regions. S greater than 1 implies that the industry commands a larger share of the region's output than the average share that industry enjoys in the seven regions. We interpret a rising S_{irt} for a region-industry as an indication of increasing specialization of that industry in that region. As S increases, knowledge flows will be increasingly restricted to sources within that industry. Learning from other industrial sectors is likely to be greater when S is low. Jacobs (1969), who contends that exchanges of information between different sectors are more productive than exchanges within a sector, predicts that high-S industries will grow more slowly than low-S industries. Porter (1990) makes the opposite prediction. Interpretations other than knowledge flows can also be used to explain the link between S and growth. For example, suitability of regional factor endowments to the sector may contribute to a positive relationship between S and growth.

We interpret E_{irt} as a possible measure of entrepreneurial strength, but it could also measure the degree of competition. If small firms are synonymous with more competition, and more firms imply the existence of entrepreneurship, then the interpretations of the variable will be indistinguishable. A high E for a region-industry implies more firms for a given output in that region relative to the average number of firms divided by output in the industry across all seven regions. A high E could, therefore, be interpreted as more entrepreneurship or greater competition. In any case a high E indicates smaller average firm size. In terms of effects on growth, an unresolved debate centers around whether competition or monopoly is more effective in encouraging innovation. Similarly, the effect of size on growth remains controversial.

Region-Specific Variables

The region-specific variables are the beginning-of-year values for GDP per capita, secondary school enrollment rate, foreign direct investment per person, road network (the length of roads in the region divided by the region's area), telecommunications availability (telephone lines per capita), and congestion (population density).

These regional growth-related factors not only are important in their own right but also can have important spillover effects. Lucas (1988) notes that human capital is twice blessed: first because it is inherently productive and second because interactions among well-educated people further increase efficiency. Shleifer (1990) suggests that good infrastructure provides the focal point for the development of agglomerations, which in turn create the environment for knowledge spillovers. Foreign investors bring knowledge on international best practices in production technologies but also provide links to international markets.

Regional Spillovers

A control variable, growth of the industry outside the province or county (that is, growth of the industry in the other six counties and provinces), is also included in the regressions. By construction, it is a time-varying region- and industry-specific variable. However, as a practical matter, because it captures across-the-board industrial growth, it is close to being a time-varying industry-specific factor with little regional variation in a given time period. In view of the discussion above that cross-regional correlation may be built into the data on account of biases in price indexes, the interpretation of the coefficients on this variable requires some care.

Before reporting our growth regression results, it is important to note the difficulty of identifying causality in these regressions (Mankiw 1995 has an extended discussion). Our goal, as a first step, is to identify the bundle of influences that coexist through a growth process. However, certain techniques are used that bear on the issue of endogeneity. The potential endogeneity of the industry-specific variables, competition and specialization, is addressed by using their lagged (beginning-of-period) values. The endogeneity of regional variables poses a less serious problem. First, beginning-of-period values are used in the regression, and second, our dependent variable is not growth in a region, but rather growth of a specific industry within the region. Infrastructure, education, and flows of foreign investment are likely to be influenced by overall regional growth rather than by the expansion of a particular industry.

III. Correlates of Growth

The regressions are run for 23 industrial sectors: food processing, textiles, apparel, leather products, wood products, furniture, paper products, art products, plastic products, electronics, petroleum, chemicals, pharmaceutical products, chemical fibers, electricity, rubber products, nonmetal products, ferrous products, nonferrous products, metallic products, transportation equipment, electrical machinery, and other machinery. The eight regions for which industrial output data are available include the three coastal counties—Beijing, Shanghai, and Tianjin—and five coastal provinces—Fujian, Guangdong, Jiangsu, Shandong, and Zhejiang. However, Beijing, although considered in our output decomposition analysis, cannot be included in the regression analysis because of incomplete availability of explanatory variables.

Limited degrees of freedom prevent running separate regressions for each industrial sector. This poses a problem because growth has not been uniform across sectors, raising the possibility that independent variables have very different influences on the different sectors. Because a significant feature of China's recent growth has been the rapidly growing share of light industrial sectors, our intermediate solution to this problem is to group sectors into light and heavy industries and to reestimate the basic regression. Although the coefficients show interesting differences in magnitudes, we find the basic results unchanged and hence focus on the pooled results, noting the differences that do arise when light and heavy industries are considered separately.

Pooling Time Series and Cross-Sectional Data

Because we are pooling time series and cross-sectional data, we first test for serial correlation in growth rates. If observations in growth rates in four adjoining years in a specific industry in a particular region are not independent of one another, the standard errors will be biased and the inferences drawn will be stronger than warranted. Recall that we have three dimensions in our data: industry, region, and year. Our interest is in the correlation over time. We can, therefore, sort the data by region, then by industry, and finally by year; alternatively, we can sort by industry, followed by region and year. Both procedures ensure that the adjoining observations are for four successive years. In either case, the Durbin-Watson statistic for the base regression is 1.87, implying that the autocorrelation problem is not serious.

The base regression is estimated with time and industry dummies, but without regional dummies. When dummy variables for regions are added to the regression, we, in effect, remove from the data the variation due to differences in the levels of variables across regions. The coefficients thus obtained are weighted averages of within-region relationships, which are sometimes described as short-run effects. When region dummies are not included, we are able to compare across regions. Because interregional differences occur over a longer period of time than do variations within a region, dropping regional dummies, as we do in our principal regressions, captures the long-run effects. We also report the more interesting short-run estimates.

The time, region, and industry dummies are not reported in the tables that present our regression results. But the main patterns of the results for the time and regional dummy variables are worth noting. Table 5 presents the results for the time dummies. The size of the coefficients for the time dummies in the first column in table 5 shows an upward trend through the period under consideration, and the coefficients are significantly different from the constant term for the base year. However, excluding the time dummies only reduces the R^2 marginally, indicating their limited explanatory power. The statistical significance of the time dummies is sensitive to whether the observations are weighted by the population of the region; when observations are not weighted by population, the influence of the two counties, Shanghai and Tianjin, increases and the time dummies are not significantly different from 0, suggesting that the time effects were felt primarily in the five coastal provinces.

The inference we draw from the increasing coefficients on the time dummies, consistent with the variance decomposition analysis, is that there were independent, though limited, time effects during this period. In other words, the gradual move toward a more market-oriented economy appears to have had some secular effects independent of the region and industrial sector. The second column in

Table 5. *Time Dummy Coefficients, 1986–88*

Year	*Base regression*[a]	*Regression without regional explanatory variables*[b]
1986	–0.08	0.02
	(–3.2)	(1.80)
1987	–0.05	0.05
	(–1.89)	(4.15)
1988	–0.04	0.03
	(–1.97)	(2.41)

Note: Results are relative to the base year 1989. The t-statistics are in parentheses.
a. Overall regression results for the base case are given in column 4 in table 7.
b. Overall regression results are not reported for the regression without regional explanatory variables. It is the model reported in column 4 in table 7 excluding the following variables: secondary school enrollment, foreign direct investment, roads, population density, telephones, and GDP per capita.
Source: Authors' calculations.

table 5 gives the results for the time dummies after dropping the region-specific variables (secondary school enrollment, foreign direct investment, roads, population density, telephones, and GDP per capita). Again, the estimated coefficients on the time dummies are statistically different from the base year.

Table 6 presents the coefficients for the regional dummy variables, using Shanghai as the base for comparison. The coefficients in the first column are positive but not significantly different from 0 (even at the 10 percent level of confidence). The second column gives the results when we drop the region-specific variables from the regression. The pattern of regional dummies in the second column mirrors more closely the statistics of regional growth presented in table 1, with the regional coefficient higher for Guangdong than for Fujian, followed by Jiangsu, Zhejiang, and Tianjin. The exception in the regional order of growth is

Table 6. *Regional Dummy Coefficients, 1986–89*

Region	*Base regression*[a]	*Regression without regional explanatory variables*[b]
Guangdong	1.8	0.11
	(1.1)	(6.4)
Fujian	1.8	0.08
	(1.0)	(3.8)
Jiangsu	1.6	0.07
	(1.1)	(3.7)
Zhejiang	2.0	0.05
	(1.2)	(2.2)
Shandong	1.7	0.12
	(1.1)	(7.4)
Tianjin	2.4	–0.02
	(1.8)	(–0.6)

Note: Results are relative to the base region Shanghai. The t-statistics are in parentheses.
a. Overall regression results for the base case are given in column 1 in table 7.
b. Overall regression results are not reported for the regression without regional explanatory variables. It is the model reported in column 1 in table 7 excluding the following variables: secondary school enrollment, foreign direct investment, roads, population density, telephones, and GDP per capita.
Source: Authors' calculations.

Shandong, whose coefficient indicates a higher growth rate than Guangdong's, although the F-test shows that the two coefficients are not significantly different from each other. These results give some confidence that the regional variables, such as foreign investment (and accompanying know-how), domestic investment (especially in infrastructure), human capital, and initial per capita income levels are good explanatory variables for differences in regional growth. Industry dummies show no interesting pattern, and including or excluding them makes little difference to the results.

The Principal Results

Because results in this type of analysis are sensitive to the variables included (Levine and Renelt 1992), table 7 reports those results that appear robust to various specifications based on sensitivity tests (described at the end of this section).

INDUSTRY-SPECIFIC VARIABLES. After controlling for other variables, industrial specialization has a largely negative effect on growth. This result suggests that the flow of knowledge across industries is more conducive to growth than is the flow within an industrial sector (Jacobs 1969). Less-specialized industrial sectors gain from knowledge spillovers from other sectors. The short- and long-run effects are not very different (table 7). Recall that at S equal to 1, the output share of industry i in region r equals the average output share of industry i in the seven regions. A decline in S to 0.9 increases the growth rate 0.5 percentage points (for example, from 6 to 6.5 percent). However, the relationship between industrial specialization and growth does not appear to be linear. Beyond S equal to about 2, specialization enhances growth.[2] The evidence, therefore, is also consistent with Porter's (1990) hypothesis on the benefits of knowledge flows within the same industry, although the degree of specialization must be large enough. We report below that specialization promotes growth in the heavy industrial sectors.

The statistical significance of the coefficients for E and E^2 is weak. The general thrust of the results is similar across various specifications and hence worth noting: increasing relative firm size has a deleterious effect on growth. The values of the coefficients, however, also suggest that when the average size of firms in an industrial sector in a particular region is smaller than a third of the average firm size in all regions, growth in that region-industry suffers (possibly through excessive competition and/or diminished investible surpluses).

FOREIGN DIRECT INVESTMENT. We begin the discussion of the regional influences with the role of foreign investment. A key element of economic reform in China has been the open door to foreign investment. Although triggered by government policy, growth in foreign investment has taken on a life of its own, reaching close to $20 billion in 1993. Many overseas Chinese have invested large amounts

2. The nonlinear specification includes the squared term. The relation is summarized with the elasticity at the mean values of the variables (see table 4).

Table 7. *Determinants of Industrial Growth in Coastal China, 1986–89*

	Short run			*Long run*		
Variable	*1*	*2*	*3*	*4*	*5*	*6*
Industry specific						
Specialization index, S	−0.061	−0.060	−0.060	−0.061	−0.061	−0.057
	(−2.477)	(−2.462)	(−2.416)	(−2.470)	(−2.501)	(−2.326)
Specialization index squared, S^2	0.014	0.014	0.014	0.014	0.015	0.013
	(1.899)	(1.864)	(1.855)	(1.902)	(2.015)	(1.788)
Entrepreneurship index, E	0.035	0.038	0.034	0.033	0.031	0.042
	(1.683)	(1.863)	(1.638)	(1.714)	(1.646)	(2.199)
Entrepreneurship index squared, E^2	−0.006	−0.007	−0.005	−0.006	−0.005	−0.007
	(−1.267)	(−1.432)	(−1.188)	(−1.244)	(−1.117)	(−1.507)
Region specific						
Secondary school enrollment rate	−3.617		−1.449	0.779	1.373	1.121
	(−3.496)		(−1.366)	(2.962)	(2.371)	(2.219)
Secondary school enrollment rate squared					−0.663	−0.281
					(−1.151)	(−0.552)
Foreign direct investment	7.815	4.130	6.068	1.628	1.655	1.946
	(4.360)	(2.822)	(3.502)	(4.747)	(4.816)	(6.199)
Roads	6.647	5.089		−0.489	−0.587	
	(3.087)	(2.393)		(−2.657)	(−2.896)	
Roads squared	−13.569	−10.532		0.688	0.832	
	(−3.335)	(−2.625)		(3.530)	(3.593)	
Interaction between roads and congestion	0.006	0.005				
	(3.302)	(2.803)				
Telephones			−0.015			−0.017
			(−1.513)			(−4.248)
Telephones squared			0.0005			0.0003
			(2.169)			(3.078)
GDP per capita	−0.0006	−0.0003	−0.0006	−0.0002	−0.0002	−0.0001
	(−5.003)	(−3.548)	(−3.897)	(−5.005)	(−4.969)	(−2.136)
Regional spillover						
Growth in industry outside region	0.785	0.782	0.783	0.777	0.778	0.780
	(20.033)	(19.776)	(19.923)	(19.492)	(19.519)	(19.675)
Regional dummy variables included?	Yes	Yes	Yes	No	No	No
Adjusted R^2	0.617	0.610	0.615	0.604	0.604	0.609
Number of observations	640	640	640	640	640	640

Note: The dependent variable is growth of industry i in region r at time t (G_{irt}). All regressions include time and industry dummy variables and observations are weighted by regional population. Short-run regressions report within-region relationships; long-run regressions drop regional dummies and report interregional relationships. The t-statistics are in parentheses. See table 4 for more complete definitions of variables and descriptive statistics.

Source: Authors' calculations.

of capital and know-how, despite what, by Western standards, would be considered a great deal of uncertainty regarding property rights and enforcement of contractual obligations (see Yusuf 1993).

Our results show that foreign direct investment has a strong impact on growth, particularly in the short run (column 1 in table 7). The short-run elasticity of growth with respect to foreign direct investment, calculated at the mean value of the foreign direct investment variable, is 0.10, indicating that a 10 percent increase in foreign investment can raise the growth rate 1 percent. However, the apparent effect of foreign investment is influenced by trends in secondary school enrollment rates, which, as noted below, fell during this period of rapid growth. Hence human capital is seen to have a perverse effect on growth in the short run (see column 1, table 7). Because a change in school enrollment rates is not a good measure of change in the stock of human capital, the perverse effect is overstated, and to that extent, the positive effect of foreign investment is probably exaggerated in the short-run estimates.

When the secondary school enrollment rate is dropped, the coefficient for foreign investment falls by about half (see column 2, table 7). If we assume that there was little change in human capital within any region during the period under consideration, then the new estimate for foreign investment is closer to being right, and hence the elasticity of the growth rate with respect to foreign investment is closer to 0.06. When the secondary enrollment rates are dropped from the equation, the coefficient on foreign investment declines, but other coefficients remain essentially unchanged (see column 2, table 7). The effect of foreign investment declines in the long run (and hence is a less potent source of differences in growth between regions), but still remains statistically significant and quantitatively important. The foreign investment coefficient decreases from about 4 to about 2, and the growth elasticity falls from 0.06 to 0.03.

One interpretation of these results is that in the short run, foreign investment is the most mobile factor and hence is a dominant driver of growth. In the longer run, such variables as education and infrastructure respond to increased demand for complementary assets, and the contribution of foreign investment declines. There is also a complementary relationship between domestic human capital formation and foreign investment flows, as discussed below.

HUMAN CAPITAL: EDUCATION AND FOREIGN KNOWLEDGE. Measurement of the stock of knowledge available for productive use is a complex task even under normal conditions and is especially difficult in a dynamic situation when knowledge from many different sources is being utilized. Traditionally, secondary school enrollment rates have been used as proxies for the domestic stock of knowledge, or domestic human capital, and serve well as long-run approximations. Using data for the only year available—1987—we compare enrollment rates with the more appropriate proxy, average years of schooling in the labor force, and find a very high correlation coefficient (0.965, significant at 99 percent) between the two indicators.[3] If this finding applies to the whole

3. The labor force includes population in the age group 15 to 54. The average length of education is calculated as $(16U + 12H + 9M + 6E + 0I) / T$, where U, H, M, and E are the number of persons with university, high school, middle high, and elementary school education, respectively. I stands for illiterate. T is the total population in the working age group. The relevant data were obtained from the 1987 population census. Data are available for seven provinces and counties in the coastal region—Beijing, Fujian, Guangdong, Jiangsu, Shandong, Tianjin, and Zhejiang.

period between 1985 and 1989, then secondary school enrollment is a good surrogate for at least the part of human capital endowment due to years of formal education, and our long-run estimates can be considered reasonably reliable.

However, short-run changes in human capital are more difficult to measure. The extensive reforms that began in 1984 were accompanied by an actual fall in school enrollment rates in most of the coastal provinces and counties. This is not altogether surprising during a period of rapid growth accompanied by increases in the demand for labor. Many of the new entrants to the labor force were young women who probably dropped out of school to take up newly available jobs. Over the short period under consideration, the stock of domestic human capital is unlikely to have changed as a consequence of such labor force responses, although unless the trend is reversed, human capital will deplete over time.

The short-run, or within, estimate shows a negative coefficient for secondary education (first column in table 7), reflecting the cyclical shift out of education described above. The finding tells us little about the relationship between domestic human capital and growth in the short run, because, as noted, changes in secondary enrollment rates greatly overstate the depletion of human capital. In the long run, that is, when the comparison is across regions, education has the expected positive effect on growth. However, returns to secondary education diminish beyond a point.[4] Similar results have been obtained for cross-country regressions; see Pritchett (1996) for a recent review. The coefficients for the education variables in column 5 show that when enrollment increases from 30 to 35 percent (that is, approximately from the Fujian enrollment rate to the Guangdong enrollment rate), growth rises 5 percentage points. However, when enrollment increases from 55 to 60 percent, the increase in growth is only 3 percentage points. Thus Tianjin gets a smaller effect from raising its enrollment rate than does Fujian; Shanghai, with an enrollment rate in the mid-60 percent range, gains even less.

Education becomes even more effective when it is associated with foreign knowledge. Column 1 in table 8 shows that the interaction between school enrollment rates and foreign investment is significantly positive, suggesting mutual reinforcement between domestic human capital and foreign knowledge that accompanies the investment. Also, the coefficient on foreign investment becomes negative when the interaction term is introduced, implying that much of the power of foreign knowledge may come through the local base of human capital. Perhaps exposure to foreign knowledge breaks the isolation of the local economy and brings experience-based practices that are rarely available in textbooks and are best communicated in a hands-on manner in a production setting (Romer 1993).

4. The coefficient of the square of secondary enrollment rate in column 5 of table 7 is negative but not statistically significant; however, we find that this result is sensitive to the specification and, in certain cases, the squared term is statistically significant. Thus we believe that the nonlinearity needs to be taken seriously.

Table 8. *The Interaction of Foreign Investment with Infrastructure and Education in Explaining Growth in Coastal China, 1986–89*

Variable	*1*	*2*	*3*
Industry specific			
Specialization index, S	-0.061	-0.061	-0.056
	(-2.480)	(-2.517)	(-2.309)
Specialization index squared, S^2	0.015	0.016	0.013
	(1.976)	(1.999)	(1.764)
Entrepreneurship index, E	0.033	0.033	0.042
	(1.757)	(1.737)	(2.162)
Entrepreneurship index squared, E^2	-0.005	-0.005	-0.007
	(-1.209)	(-1.199)	(-1.508)
Region specific			
Secondary school enrollment rate	1.021	1.076	0.879
	(3.546)	(3.619)	(4.229)
Interaction between secondary school enrollment rate and foreign direct investment	8.631 (2.041)		
Foreign direct investment	-1.373	0.241	1.660
	(-0.910)	(0.328)	(2.688)
Roads	-0.152	-0.118	
	(-0.617)	(-0.465)	
Roads squared	0.325	0.249	
	(1.233)	(0.878)	
Interaction between roads and foreign direct investment		4.608	
		(2.121)	
Telephones			-0.016
			(-3.961)
Telephones squared			0.0003
			(1.798)
Interaction between telephones and foreign direct investment			0.023 (0.494)
GDP per capita	-0.0002	-0.0002	-0.0001
	(-5.374)	(-5.448)	(-2.413)
Regional spillover			
Growth in industry outside region	0.779	0.779	0.779
	(19.591)	(19.594)	(19.671)
Adjusted R^2	0.606	0.606	0.609
Number of observations	640	640	640

Note: The dependent variable is growth of industry i in region r at time t (G_{irt}). All regressions include time and industry dummy variables but no regional dummy variables and observations are weighted by regional population. t-statistics are in parentheses. See table 4 for more complete definitions of variables and descriptive statistics.

Source: Authors' calculations.

INFRASTRUCTURE. Good infrastructure not only facilitates the flow of information but also provides the focal point for the development of agglomerations (Shleifer 1990). We consider two types of infrastructure: roads and telecommunications. Roads represent the traditional infrastructure, and their stock has grown only slowly to date. Phone lines, in contrast, have grown rapidly to meet the needs of the international trading community—much, possibly all, of the new telecommunications investment uses modern digital technology.

The results show that a network of roads has a positive effect on growth but is subject to diminishing returns in the short run (column 1, table 7), possibly reflecting indivisibilities in infrastructure investment (Weitzman 1970). Roads are more productive in high-density areas (as reflected in the positive coefficient on the interaction term between roads and population density). The long-run increasing returns are possibly related to network effects: gains from an increase in the length of a route rise as the route interconnects new areas and multiplies the connections possible. The effectiveness of foreign investment flows also appears to depend on the availability of infrastructure, as is shown in the strong positive interaction between foreign investment and the roads network (column 2, table 8).

Telecommunications growth has an even stronger effect; telephones per 1,000 residents show increasing returns both in the short run and in the long run (columns 3 and 6, table 7). The short- and long-run elasticities are both approximately 0.10.

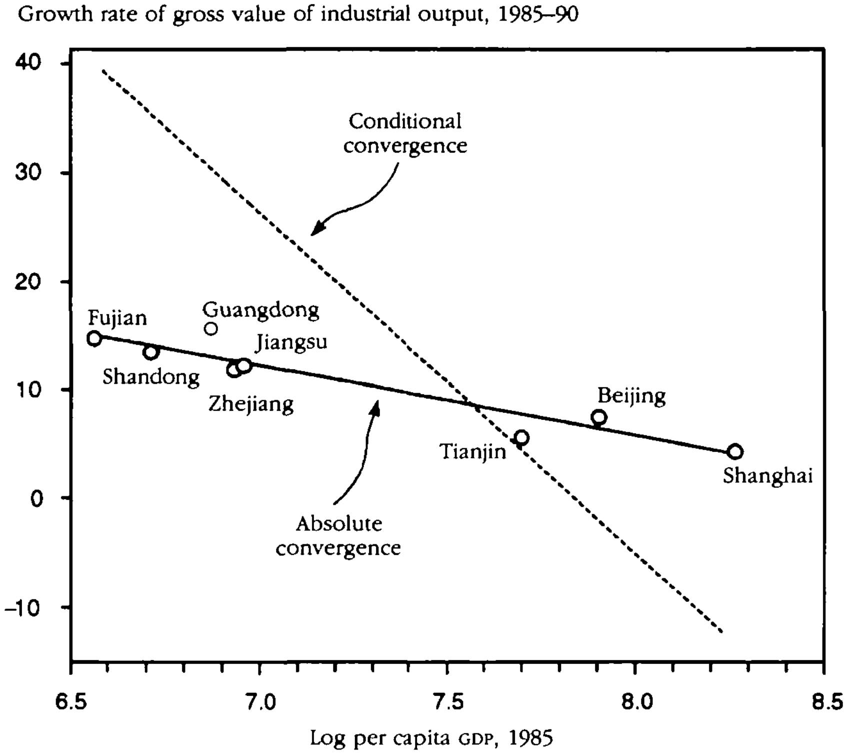
INITIAL CONDITIONS. The initial per capita income of a region turns out to be an important variable in explaining subsequent growth. When initial per capita income is not included in the regressions, the partial correlations between growth and the other variables change significantly; as noted below in our discussion of sensitivity tests, variables other than per capita income do not have a similar influence when added or dropped from the analysis.

The strongly negative relationship between industrial growth rates in a region and the initial per capita income of the region suggests that growth is being influenced not just by steady-state factors but also by transitory influences. If steady-state growth had been achieved in the different industrial sectors and regions, both neoclassical and endogenous growth models predict that the initial levels of backwardness will have no influence on subsequent growth (Mankiw, Romer, and Weil 1992). Only when an economy is moving to a new steady state will initial levels of backwardness provide an additional impetus to growth. This seems particularly appropriate for coastal China, which has indeed been shaken up and put on a new growth trajectory.

Figure 2 shows a strong inverse relationship between the rate of growth of industrial output during 1985–89 and the log of per capita GDP in 1985. In the terminology suggested by Mankiw, Romer, and Weil (1992) and by Barro and Sala-i-Martin (1992), there is evidence of absolute convergence. In other words, even without controlling for other variables that may affect steady-state growth, the relatively backward provinces grew faster than the more advanced regions. For example, initial backwardness partly explains why Fujian grew so fast despite low educational attainment and limited infrastructure.

Absolute convergence applies not only to industrial growth (as described in figure 2) but also to per capita GDP. Over the 1980s the per capita GDP of the five, relatively poor, coastal provinces increased relative to that of the three richer counties (the ratio of GDP per capita in the five provinces to that in the three

Figure 2. *Absolute Convergence versus Conditional Convergence*



Note. Absolute convergence is plotted by fitting the observed values of the five provinces and three counties Conditional convergence is plotted according to table 6, equation 4. Its slope is based on the coefficient of per capita GDP, *Y/N*. Its intercept is the sum of the products of the mean values of the independent variables (except *Y/N*) and their respective coefficients.

Source: Authors' calculations.

counties rose from 0.23 in 1980 to 0.38 in 1988, see China, State Statistical Bureau, 1990). But while there was convergence *within* the coastal region, there was divergence between the coast and the rest of China. The per capita income was higher in the coastal region than in the rest of China when the reforms were launched, and the gap has increased over time. The region's GDP per capita was 50 percent higher than the average in the rest of the nation in 1980; it was 74 percent higher in 1988.

These observations point to an interesting international parallel. In cross-country comparisons, absolute convergence is observed among advanced industrial countries but not among poor economies. Poor economies converge conditionally, that is, after controlling for education and investment rates. Within the group of industrial nations, the rate of conditional convergence is higher than the rate of absolute convergence, because the richer ones typically also have higher education and investment rates (see Mankiw, Romer, and Weil 1992).

We have not investigated the possibility of conditional convergence outside the coastal region. However, not surprisingly, conditional convergence within the coastal region, as within the industrial economies, is more rapid than absolute convergence. The richer coastal regions also tend to have better education and infrastructure, and thus it may be supposed that they have higher steady-state growth rates. The fact that the poorer regions are growing faster despite their lack of endowment indicates that they are benefiting from their backwardness.

The common interpretation of this catching-up phenomenon is that regions with low per capita income also have low capital per worker and so have a higher marginal product of capital than regions that are well endowed with capital. Thus the poorer regions potentially attract new capital (along with new ideas). Our evidence certainly supports this view: the poorer regions have attracted huge amounts of foreign capital and knowledge. But in addition, as discussed above, the more advanced regions have been burdened by an institutional setup that has been a drag on growth. But the Chinese are also fortunate in this regard that the backward regions are in proximity to Hong Kong and Taiwan (China), both major centers of knowledge and capital.

GROWTH OF THE INDUSTRY OUTSIDE THE REGION. Results show that the growth of an industrial sector in any region is powerfully influenced by the growth of the same industry in other regions during the same year. On average, a 1 percent increase in the growth rate of an industrial sector outside the region is associated with a 0.78 percent increase in the growth rate of that industry within the region. Unlike other variables, this variable not only passes the test of significance but also accounts for 49 percent of the total sum of squares. This is another way of capturing the wave phenomenon noted in the variance decomposition exercise. The high *t*-statistics for the coefficient for growth outside the region are also obtained by Glaeser and others (1992), who interpret the result as a demand effect—exogenous growth in demand, in this view, conditions the growth of specific sectors irrespective of the region. As noted above in the discussion on variance decomposition, synchronization across regions can also occur as a result of technology diffusion or networking among decisionmakers. A concern arises, however, because there may be biases in the data-gathering process, which build in cross-regional correlations. To that extent, this variable conditions for these correlations.[5]

We try two extensions of the basic regression to gain further insight into the cross-regional influences at work. First, we interact growth outside the region with the specialization variable. The results indicate that growth outside the region has a stronger effect in conditions lacking industrial specialization (table 9, column 1). In other words, the more a sector is specialized within a region, the

5. Coe and Helpman (1995) find large international research and development (R&D) spillovers. However, Jaffe and Trajtenberg (1996), examining patent data, find limited cross-national citations, which they interpret as evidence of limited geographical spillovers.

Table 9. *Cross-Regional Influences on Industrial Growth in Coastal China, 1986–89*

Variable	*1*	*2*	*3*
Industry specific			
Specialization index, S	–0.028	–0.069	–0.042
	(–1.092)	(–2.834)	(–1.622)
Specialization index squared, S^2	0.010	0.016	0.010
	(1.328)	(2.152)	(1.303)
Entrepreneurship index, E	0.030	0.032	0.032
	(1.634)	(1.694)	(1.571)
Entrepreneurship index squared, E^2	–0.005	–0.005	–0.003
	(–1.214)	(–1.172)	(–0.724)
Region specific			
Secondary school enrollment rate	0.728	0.638	1.311
	(2.785)	(2.206)	(3.464)
Foreign direct investment	1.616	0.994	4.053
	(4.750)	(2.478)	(3.020)
Roads	–0.475	–0.919	–0.132
	(–2.605)	(–4.121)	(–0.546)
Roads squared	0.678	0.982	0.355
	(3.510)	(4.106)	(1.493)
GDP per capita	–0.0001	–0.0001	–0.0002
	(–4.914)	(–3.619)	(–4.674)
Growth in Guangdong			0.458
			(13.302)
Regional spillover			
Growth in industry outside region	1.009		
	(12.136)		
Interaction between growth in industry outside region and specialization index	–0.211		
	(–3.179)		
Interaction between growth in industry outside region and regional dummy variable			
Guangdong		0.969	
		(13.714)	
Fujian		0.797	
		(8.751)	
Zhejiang		0.700	
		(9.297)	
Jiangsu		0.902	
		(13.271)	
Shandong		0.607	
		(9.908)	
Tianjin		0.750	
		(4.471)	
Shanghai		0.714	
		(4.840)	
Adjusted R^2	0.610	0.613	0.550
Number of observations	640	640	548

Note: The dependent variable is growth of industry i in region r at time t (G_{irt}). All regressions include time and industry dummy variables but no regional dummy variables, and observations are weighted by regional population. The t-statistics are in parentheses. See table 4 for more complete definitions of variables and descriptive statistics.

Source: Authors' calculations.

less it is affected by growth of that same industry outside the region. This is not surprising. With scale economies, certain industries will be concentrated in particular regions. At the same time, they will also develop certain technical specializations or market niches that limit the usefulness of the experience of firms in the same industrial sector but located in other regions. Also, intellectual property is likely to be more protected in such specialized sectors. In general, light industrial sectors, with lower capital intensity and less specialization than the heavier sectors, are likely to be more able to absorb external influences rapidly, as discussed below.

Second, in view of the policy attention accorded to Guangdong (and more recently to Fujian), and also given their physical proximity to Hong Kong and Taiwan (China), a question of interest is whether these regions are conduits of growth impulses. For the time span studied, no evidence to this effect is found. When growth outside the region is interacted with region dummies, the coefficients show that Guangdong benefited most from growth outside the province and Fujian was third on the list, with Jiangsu in between (table 9, column 2). This indicates that Guangdong, Jiangsu, and Fujian are most responsive to macro influences, such as changes in buyer perceptions and changes in government policies. We then replace growth outside the region (which is growth in *all* outside regions) with growth in Guangdong as an independent variable to isolate the effects that Guangdong may have had on growth in other regions (Guangdong itself is not included in this regression). Guangdong's growth does have a statistically significant impact on other regions, but the magnitude of the effect is much smaller than when growth in all other regions is considered (table 9, column 3). Similar conclusions apply to Fujian.

It is, however, likely that spillovers from Guangdong and Fujian to the other provinces will be significant in the long run. Within the coastal region, these provinces have the greatest flexibility to respond to external stimuli. As other regions become more receptive to change, Guangdong and Fujian can be expected to have greater spillover effects. Field surveys in Guangdong and Fujian show unambiguously that modern production techniques, including sophisticated methods of quality control, are being rapidly adopted in these provinces. As such experience accumulates, increasing labor mobility will complement existing administrative communication networks to diffuse the knowledge gained to other parts of China.

Light and Heavy Industries

Thus far we have assumed that all industrial sectors respond to the explanatory variables in the same manner. Here we note some differences between light and heavy industrial sectors (table 10). Although the differences are of interest, the exercise also gives us confidence in the results reported so far—the signs of the coefficients are similar, and the key variables (barring education) continue to be statistically significant for both light and heavy industries.

Table 10. *Growth in Light and Heavy Industries in Coastal China, 1986–89*

	All industries		Light industries[a]		Heavy industries[b]	
Variable	*1*	2	*3*	*4*	*5*	6
Industry specific						
Specialization index, S	–0.061	–0.061	–0.109	–0.109	–0.112	–0.117
	(–2.470)	(–2.501)	(–2.936)	(–2.939)	(–1.687)	(–1.765)
Specialization index squared, S^2	0.014	0.015	0.022	0.022	0.043	0.046
	(1.902)	(2.015)	(2.267)	(2.240)	(1.497)	(1.583)
Entrepreneurship index, E	0.033	0.031	0.142	0.143	0.017	0.015
	(1.714)	(1.646)	(1.924)	(1.933)	(0.859)	(0.761)
Entrepreneurship index squared, E^2	–0.006	–0.005	–0.034	–0.035	–0.002	–0.002
	(–1.244)	(–1.117)	(–1.483)	(–1.496)	(–0.514)	(–0.343)
Region specific						
Secondary school enrollment rate	0.779	1.373	0.813	0.611	0.778	1.654
	(2.962)	(2.371)	(1.800)	(0.622)	(2.454)	(2.368)
Secondary school enrollment rate squared		–0.663		0.223		–0.981
		(–1.151)		(0.231)		(–1.406)
Foreign direct investment	1.628	1.655	2.234	2.225	1.254	1.296
	(4.747)	(4.816)	(3.843)	(3.816)	(3.004)	(3.101)
Roads	–0.489	–0.587	–1.084	–1.053	–0.097	–0.241
	(–2.657)	(–2.896)	(–3.528)	(–3.132)	(–0.422)	(–0.961)
Roads squared	0.688	0.832	1.269	1.223	0.295	0.507
	(3.530)	(3.593)	(3.925)	(3.195)	(1.218)	(1.779)
GDP per capita	–0.0002	–0.0002	–0.0002	–0.0002	–0.0002	–0.0001
	(–5.005)	(–4.969)	(–3.184)	(–3.181)	(–3.775)	(–3.730)
Regional spillover						
Growth in industry outside region	0.777	0.778	0.827	0.827	0.583	0.590
	(19.492)	(19.519)	(16.898)	(16.864)	(6.260)	(6.339)
Adjusted R^2	0.604	0.604	0.671	0.670	0.493	0.491
Number of observations	640	640	280	280	360	360

Note: The dependent variable is growth of industry i in region r at time t (G_{irt}). All regressions include time and industry dummy variables but no regional dummy variables, and observations are weighted by regional population. The t-statistics are in parentheses. See table 4 for more complete definitions of variables and descriptive statistics.

a. The light industry group includes food processing, textiles, apparel, leather products, wood products, furniture, paper products, art products, plastic products, and electronics.

b. The heavy industry group includes petroleum, chemicals, pharmaceutical products, chemical fibers, electricity, rubber products, nonmetal products, ferrous products, nonferrous products, metallic products, transportation equipment, electrical machinery, and other machinery.

Source: Authors' calculations.

The estimated equation does a better job of explaining growth in light industries (R^2 = 0.67) than in heavy industries (R^2 = 0.49). Of special interest is the finding that growth outside the region, which measures the degree of synchronization or diffusion across regions, has a higher coefficient for light industries. This is to be expected given the lower capital intensity and hence higher mobility of light industrial sectors. Guangdong, Fujian, and Jiangsu benefit especially from growth outside the region in both heavy and light industries; this difference is measured by interacting growth outside the region with regional dummies.[6] In light industries, other regions also benefit strongly from the diffusion process, whereas the effect for heavy industries falls off in other regions and is not statistically different from 0 for Shanghai and Tianjin. In both light and heavy industries, when growth in Guangdong is used as an explanatory variable, the partial correlation is positive and significant, but smaller in magnitude than the coefficient obtained for growth outside the region, implying again that Guangdong is more an imitator than a leader.

Foreign investment provides a bigger effect in light industries, although it has a significant coefficient for heavy industries. Similarly, infrastructure does more for light than for heavy industries. In contrast, education has a positive effect on growth in light industries, but the effect is not statistically different from 0. Thus, although formal education is important, its relationship with growth is imprecise, and tacit knowledge based on experience (and channeled through foreign sources) appears to be a somewhat firmer predictor of growth. For heavy industries, we observe diminishing returns to education, as was seen above for all industries; within the range of observed secondary school enrollment rates, this implies a positive, though declining, effect of education on growth of heavy industries.

The lack of specialization has a stronger association with growth among light industries, which is not surprising; skills are likely to be more mobile in such sectors. When all observations are pooled, we note that specialization is an aid to growth only beyond S = 2. For light industries, the positive effects of specialization are felt at even higher levels of specialization (beyond S = 2.5); in comparison, for heavy industries, specialization is conducive to growth after S = 1.3. The implication is that specialized sectors, which have also grown rapidly, are principally in the heavy industry group. Although an exact correspondence cannot be easily made, our results bear some similarity to those of Henderson, Kuncoro, and Turner (1995). They find that for the mature sectors, specialization promotes growth (in the Chinese case, heavy industry has been the more traditional focus of state investment); in contrast, they find that a diverse industrial environment fosters new industrial sectors (while the light industries studied here are not new in the sense of being high-technology, they have required many new skills to meet the exacting demands of the international market).

6. These results are not presented to conserve space but can be provided on request.

Table 11. *Sensitivity Analysis of Growth Determinants for Coastal China, 1986–89*

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Industry specific							
Specialization index, S	–0.061	–0.052	–0.066	–0.062		–0.049	–0.079
	(–2.501)	(–2.093)	(–2.688)	(–2.530)		(–1.860)	(–3.540)
Specialization index squared, S^2	0.015	0.012	0.016	0.013		0.014	0.018
	(2.015)	(1.559)	(2.096)	(1.750)		(1.723)	(2.981)
Entrepreneurship index, E	0.031	0.017	0.030	0.020		0.059	0.022
	(1.646)	(0.885)	(1.564)	(1.086)		(3.351)	(1.205)
Entrepreneurship index squared, E^2	–0.005	–0.004	–0.006	–0.004		–0.012	–0.003
	(–1.117)	(–0.820)	(–1.211)	(–0.979)		(–2.756)	(–0.662)
Region specific							
Secondary school enrollment rate	1.373		0.301		0.821		1.301
	(2.371)		(0.633)		(1.190)		(2.556)
Secondary school enrollment rate squared	–0.663		0.577		–0.407		–0.888
	(–1.151)		(1.213)		(–0.570)		(–2.081)
Foreign direct investment	1.655		1.486	0.837	1.115		1.432
	(4.816)		(5.222)	(3.866)	(2.729)		(4.004)
Roads	–0.587	–0.684		–0.741	–0.551		–0.620
	(–2.896)	(–4.145)		(–4.521)	(–2.130)		(–3.435)
Roads squared	0.832	0.698		0.834	0.759		0.818
	(3.593)	(3.702)		(4.395)	(2.573)		(4.995)
GDP per capita	–0.0002	–0.0001	–0.0001	–0.0001	–0.0001		–0.0001
	(–4.969)	(–4.319)	(–6.275)	(–5.452)	(–3.176)		(–4.458)
Regional spillover							
Growth in industry outside region	0.778	0.771	0.775	0.774		0.754	0.818
	(19.519)	(19.022)	(19.262)	(19.297)		(17.496)	(20.161)
Adjusted R^2	0.604	0.590	0.596	0.599	0.351	0.535	0.616
Number of observations	640	640	640	640	640	640	640

Note: The dependent variable is growth of industry i in region r at time t (G_{irt}). All regressions include time and industry dummy variables but no regional dummy variables and observations are weighted by regional population. Observations are weighted by the population in the region for the regressions reported in columns 1–6. No weights are used for the regression reported in column 7. The t-statistics are in parentheses. See table 4 for more complete definitions of variables and descriptive statistics.

Source: Authors' calculations.

Sensitivity and Misspecification

Our sensitivity analysis uses the methods of Belsley, Kuh, and Welsch (1980). We first drop one observation at a time and find that no single observation influences the coefficients significantly. This result could have been expected, given the large sample of 640 observations. We then drop specific sets of observations, excluding from regressions a province, a year, an industry, a region-industry, a year-industry, and a year-region. The distributions of the coefficients show a very strong concentration around the mean value. We can therefore rule out the possibility of outliers driving our regression results.

In the regressions reported, we weight the observations by the population of the region, which gives more weight to the provinces and less to the counties, reducing the influence of the counties in the regression results. To see how much the results are influenced by this weighting procedure, we also run our basic regression by treating every observation equally (column 7, table 11). The results do not change qualitatively, except that diminishing returns to education are now more evident: this is as expected because the more educated counties that recorded relatively modest economic performance now have *greater* weight in the regression.

Another type of sensitivity analysis is done by adding or dropping independent variables (table 11). Omitting secondary school enrollment rates has little effect on the sign and magnitude of the remaining coefficients (column 4). Similarly, the regression results are not sensitive to specifications that exclude an entire set of industry- or region-specific variables, as columns 5 and 6 demonstrate.

If there is no serious misspecification problem, regional factors other than initial per capita income predict that the counties (Shanghai and Tianjin) should have done especially well because they had better than average access to foreign investment, education, and infrastructure. But instead, growth in these counties was slow, possibly because of the significant presence of state-owned enterprises, which is not captured in the regressions. When we include the share of state-owned enterprises as an independent variable, it does not generate significant results because the share of these enterprises is correlated with per capita income (and also with the variable E, which is the inverse of average firm size). Thus the relatively slow growth in recent years of the two richer regions reflects diminishing returns, which arise not merely from a technological source but also from the constraining effects of the institutional structure within which past industrialization occurred.

IV. CONCLUSIONS

We have examined three sets of influences on industrial growth along the eastern coast of China: factors specific to an industrial sector, regional influences, and regional spillovers.

Overall, industry-specific influences explain only a small portion of variance in growth. A low level of specialization, perhaps allowing for absorption of influences from other industrial sectors, seems to promote more rapid growth for light industries, whereas specialization seems to be conducive to growth in heavy industries. Our findings on the role of competition are statistically weak, possibly because of the very crude statistical proxy used for competition.

A number of regional influences are important. Higher levels of education differentiate good performers from poor performers over the long haul: gains of even a few percentage points in secondary school enrollment rates have an important effect on growth. When only light industries are considered, however, the relationship between growth and secondary school enrollment is potentially influential but imprecise. For heavy industries, education has diminishing returns, although the positive effects continue well into the range observed in the sample (as well as the range spanned by most middle-income countries).

The role of secondary school education, however, cannot be considered separately from knowledge acquired through international links. Foreign investment showed consistently as a spur to growth, especially in the short run and in light industries. Moreover, we found that foreign investment and education interact positively. It is worth noting that secondary school enrollment rates in Fujian province at 31 percent are close to the average for low-income countries (World Bank 1991). Our results suggest that China's coastal provinces were able to exploit their educational attainment better than other low-income regions because the complementary effects of foreign knowledge enhanced the educational level of the work force.

Infrastructure investment, particularly in telecommunications but also in roads, yields increasing returns. There is some question whether infrastructure is a true enabling factor; although it accelerates output growth, it also responds to growth. Large infrastructure investments are occurring along the coast in the wake of the huge growth of the past several years. Thus although good infrastructure is valuable, conditions that enable externality-generating infrastructure investments to be put in place as demand emerges are equally important.

Almost half of the variation in industrial growth along the coast is attributable to the synchronization in growth of particular industries across provincial and county boundaries. The identity of the most rapidly growing sectors changed from year to year across the entire region. Such synchronization was more pronounced in light than in heavy industries. Although many substantive possibilities exist to explain the synchronization—and a recent field study documents that the perception of synchronization exists among decisionmakers on the Chinese coast (Oi 1995)—we have noted that, on account of data construction and reporting, the extent of regional spillovers is likely to be less than the statistical analysis may suggest.

China has pursued a decentralized economic reform program. Particular reforms have been tried in specific regions—sometimes with and sometimes without the blessing of the central government. To complement reforms for increasing allocative efficiency, China has pursued a long-term strategy for encouraging investments by specific new entrepreneurs. The open-door policies and special economic zones have successfully attracted investments from overseas Chinese to the southeastern coast. At the same time, local governments have been given greater autonomy to invest in new business ventures (for example, the so-called collectively owned enterprises) and in infrastructure. Although many of the experiments are considered innovative, the lack of coordination and wasteful regional competition have resulted in damaging macroeconomic effects.

In any case, synchronization across regions has been quite strong. The source of this synchronization cannot be discerned from the data at hand, but it is clear that a network of communication channels exists across the country. Such a network could reflect the links between the cadres of the communist party or could even predate the party, reflecting much older economic and social ties (Yusuf 1993 and Oi 1995). Success has, thus, required a combination of centrally approved local experiments, local government entrepreneurship, and an effective network for diffusing success across different regions.

An interesting aspect of the decentralization has been that regions with relatively low per capita income and hence a large catch-up potential were targeted early on. These regions were relatively unencumbered by state-owned enterprises, planning bureaucracies, and other mechanisms that guided output in the prereform era. Indeed, some of the counties in Guangdong province that experienced the most spectacular growth rates, such as Shenzen and the neighboring areas, were essentially agricultural communities (or even wastelands) 15 or 20 years ago.

Although the successes of the strategy have been evident, questions have been raised about policy reversals and setbacks and the consequent lack of government credibility (see Sung 1991 and Chen, Jefferson, and Singh 1992). Such credibility lapses are generally viewed as expensive, inasmuch as they create investor uncertainty and reduce investment. Yet investors, especially foreign investors, have rarely been deterred. Foreign investment has been almost an exogenous force, dampened only occasionally by policy conditions. At the same time, locally financed infrastructure and human capital investments plus job training within enterprises have proceeded with vigor, fueling growth.

We suggest two related possibilities. First, the credibility of government policies as a determinant of investment is overrated; it is likely that credibility and certainty derive from overall economic performance rather than from government actions per se. Second, investors may accept contradictions and reversals as a reflection of the government's response to evolving conditions.

If this analysis of China's recent experience is in any respect correct, what lessons does it hold for other countries? Decentralized experiments are valuable, but they may well require local governments that are entrepreneurial. Human capital and infrastructure aid the process of transformation but in more complex interactive modes than usually assumed. A steady flow of foreign investment and skills provides a strong advantage. For wider impact, the lessons from decentralized experiments must flow to other regions. Mechanisms to ensure information transfers are essential, but difficult to establish. In a complex reform process, credible commitments may be desirable, but governments also need to stay flexible.

Appendix. Details of the Decomposition of Growth of Output

The standard variance components method assumes as the first approximation a growth equation of additive main and interaction effects with zero means and covariances. Let G_{tri} denote growth in industry i in region r at time t. Variance of G_{tri} can be decomposed to the main effects of time (α_t), region (β_r), industry (τ_i), and their respective interaction effects (a_{tr}, b_{ti}, c_{ri}, and e_{tri}). Formally,

$$G_{tri} = m + \alpha_t + \beta_r + \tau_i + a_{tr} + b_{ti} + c_{ri} + e_{tri}$$

where m is a constant, $t = 1, \ldots, n_t$, $r = 1, \ldots, n_r$, $i = 1, \ldots, n_i$.

With the assumption of zero covariance, Var_G can be expressed as follows:

$$\mathrm{Var}(G) = \mathrm{Var}(\alpha) + \mathrm{Var}(\beta) + \mathrm{Var}(\tau) + \mathrm{Var}(a) + \mathrm{Var}(b) + \mathrm{Var}(c) + \mathrm{Var}(e)$$

or

$$s^2(G) = s^2_\alpha + s^2_\beta + s^2_\tau + s^2_a + s^2_b + s^2_c + s^2_e.$$

Variance components are estimated by equating observed values of variances to their expected values (Searle 1971). Let $N = n_i n_r n_t$.

Define

$$\begin{aligned}
T_0 &= S_t S_r S_i\, G^2_{tri} \\
E(T_0) &= n_t n_r n_t\, (m^2 + s^2_\alpha + s^2_\beta + s^2_\tau + s^2_a + s^2_b + s^2_c + s^2_e) \\
&= N(m^2 + s^2_\alpha + s^2_\beta + s^2_\tau + s^2_a + s^2_b + s^2_c + s^2_e) \\
T_1 &= G^2 / n_i n_r n_t = (S_t S_r S_i G)^2 / n_i n_r n_t \\
&= (n_i n_r n_t m + S_t n_i n_r \alpha + S_r n_i n_t \beta + S_i n_t n_r \tau \\
&\quad + S_t S_r a + S_t S_i b + S_r S_i c + S_t S_r S_i e)^2 / n_i n_r n_t
\end{aligned}$$

$$E(T_1) = Nm^2 + n_i n_r s^2_\alpha + n_i n_t s^2_\beta + n_t n_r s^2_\tau + n_i s^2_a + n_r s^2_b + n_t s^2_c + s^2_e$$

$$\begin{aligned}
T_2 &= S_t G_t^2 / n_i n_r = S_t (S_r S_i G)^2 / n_i n_r \\
&= S_t (n_i n_r m + n_i n_r \alpha + S_r n_i \beta + S_i n_r \tau + n_i S_r a + n_r S_i b + S_r S_i c + S_r S_i e)^2 / n_i n_r
\end{aligned}$$

$$E(T_2) = Nm^2 + Ns^2_\alpha + n_i n_t s^2_\beta + n_t n_r s^2_\tau + n_t n_i s^2_a + n_t n_r s^2_b + n_t s^2_c + n_t s^2_e.$$

Similarly, let

$$\begin{aligned}
T_3 &= S_r G_r^2 / n_t n_i = S_r (S_t S_i G)^2 / n_t n_i \\
E(T_3) &= Nm^2 + n_r n_i s^2_\alpha + Ns^2_\beta + n_t n_r s^2_\tau + n_r n_i s^2_a + n_r s^2_b + n_t n_r s^2_c + n_r s^2_e
\end{aligned}$$

$$\begin{aligned}
T_4 &= S_i G_i^2 / n_t n_r = S_i (S_t S_r G)^2 / n_t n_r \\
E(T_4) &= Nm^2 + n_r n_i s^2_\alpha + n_t n_i s^2_\beta + Ns^2_\tau + n_i s^2_a + n_r n_i s^2_b + n_t n_i s^2_c + n_i s^2_e
\end{aligned}$$

$$\begin{aligned}
T_5 &= S_t S_i G_{ti}^2 / n_r = S_t S_i (S_r G)^2 / n_r \\
E(T_5) &= Nm^2 + Ns^2_\alpha + n_t n_r s^2_\beta + Ns^2_\tau + n_t n_i s^2_a + Ns^2_b + n_t n_i s^2_c + n_t n_i s^2_e
\end{aligned}$$

$$T_6 = S_t S_r G_{tr}^2 / n_i = S_t S_r (S_i G)^2 / n_i$$
$$E(T_6) = Nm^2 + Ns^2_\alpha + Ns^2_\beta + n_t n_r s^2_\tau + Ns^2_a + n_t n_r s^2_b + n_t n_r s^2_c + n_t n_r s^2_e$$

$$T_7 = S_r S_i G_{ri}^2 / n_t = S_r S_i (S_t G)^2 / n_t$$
$$E(T_7) = Nm^2 + n_r n_i s^2_\alpha + Ns^2_\beta + Ns^2_\tau + n_r n_i s^2_a + n_r n_i s^2_b + Ns^2_c + n_r n_i s^2_e.$$

The system therefore contains eight equations with eight unknowns. The eight equations refer to the expressions of $E(T_0), \ldots, E(T_7)$ and the eight unknowns are m^2, s^2_α, s^2_β, s^2_τ, s^2_a, s^2_b, s^2_c, and s^2_e. We can solve the system by equating sample values of $T_0, \ldots, T_7$ to their expected values, $E(T_0), \ldots, E(T_7)$. The solutions are the following:

$$s^2_a = \{n_i[(T_1 - T_2) - (T_3 - T_6)] - [(T_0 - T_5) + (T_4 - T_7)]\} / [n_i(n_i - 1)(n_t - 1)(n_r - 1)]$$

$$s^2_b = \{n_r[(T_1 - T_4) - (T_2 - T_5)] - [(T_0 - T_7) + (T_3 - T_6)]\} / [n_r(n_r - 1)(n_t - 1)(n_i - 1)]$$

$$s^2_c = \{n_t[(T_1 - T_3) - (T_4 - T_7)] - [(T_0 - T_6) + (T_2 - T_5)]\} / [n_t(n_t - 1)(n_r - 1)(n_i - 1)]$$

$$s^2_e = (T_0 - T_1 + T_2 + T_3 + T_4 - T_5 - T_6 - T_7) / [(n_t - 1)(n_r - 1)(n_i - 1)]$$

$$s^2_\alpha = [(T_3 - T_6) - (n_r n_i - N)s^2_a - (n_r - n_t n_r)s^2_b - (n_r - n_t n_r)s^2_e] / (n_r n_i - N)$$

$$s^2_\beta = [(T_4 - T_7) - (n_i - n_r n_i)s^2_a - (n_t n_i - N)s^2_c - (n_i - n_r n_i)s^2_e] / (n_r n_i - N)$$

$$s^2_\tau = [(T_2 - T_5) - (n_t n_r - N)s^2_b - (n_t - n_t n_i)s^2_c - (n_t - n_t n_i)s^2_e] / (n_t n_r - N).$$

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