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INDUSTRIAL AND AGGREGATE MEASURES OF PRODUCTIVITY GROWTH IN CHINA, 1982–2000

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We estimate productivity growth for 33 industries covering the entire Chinese economy using a time series of input–output tables covering 1982–2000. Capital input is measured using detailed investment data by asset and labor input uses demographic information from household surveys. We find a wide range of productivity performance at the industry level. We then show how these industry growth accounts may be consistently aggregated to deliver a decomposition of aggregate GDP growth. For the 1982–2000 period aggregate TFP growth was 2.5 percent per year; decelerating from a rapid rate in the early 1980s to negative growth during 1994–2000. The main source of growth during the 1982–2000 period was capital accumulation, with a small negative contribution from the reallocation of factors across industries.

1. INTRODUCTION

While it is widely agreed that the Chinese economy has grown rapidly since the reforms started in 1978, there is disagreement about both the magnitude and sources of that growth. Was the dominant factor the accumulation of capital, total factor productivity growth, or the restructuring of the economy from agriculture to manufacturing and services? A question related to the structural transformation of the economy is how estimates of aggregate GDP growth may be reconciled with the estimates at the industry level. These questions are difficult to answer given the quality and quantity of data available. The answers to them, however, are important in understanding the effects of past economic policies and hence to devise future policies.

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This paper estimates the sources of growth of industry output—the growth of capital, labor and intermediate inputs, and total factor productivity (TFP). To do this we introduce newly developed data, including a time series of input–output tables and estimates from a survey of the labor force. Our measures account for the changing composition of the labor force and investment. The second aim of the paper is to discuss how these industry measures may be aggregated to GDP. We describe three aggregation approaches to highlight the methodological issues of separating out the roles of factor accumulation, factor reallocation and sectoral total factor productivity growth: (i) aggregate production function; (ii) aggregate production possibility frontier (PPF); and (iii) direct Domar-weighted aggregation. The first approach may be familiar to many readers; the aggregate PPF method relaxes the strict assumptions of that approach and allows us to identify the effects of reallocating value-added across industries. The third method allows us to explicitly trace aggregate growth and input accumulation to the underlying industry sources.

The final aim of the paper is to discuss the various approximations and assumptions that are necessary to construct time series of output and inputs at the industry level that are internally consistent. We hope to lay the groundwork for a systematic and clear framework for sectoral productivity analysis of China, i.e. to sketch out a comprehensive approach, and to point out the missing elements for further research to produce better estimates of growth and productivity change.

We divide our sample into four sub-periods based on the major breaks in economic reform policies. (1) 1982–84, when growth is attributed to the efficiency gains in the agriculture sector by many observers after the rural reforms began in 1978.[1] (2) 1984–88 is the period of reform of state-owned enterprises when they were given greater autonomy in deciding production and prices, including the "contract responsibility system" introduced in 1987 (Chow, 2002, p. 50). The two-tier "plan and market" structure was also introduced, where each commodity carried a price set by the government, and an unregulated market price. The government also scaled up the initial "open door policy" in 1984, and developed 14 additional cities to attract foreign investment and technology transfers. It would thus be interesting to see how manufacturing performance is affected by these reforms. (3) 1988–94, when the government adopted a new "socialist market economy" doctrine and many more "special development zones" were established.[2] (4) 1994–2000 was a period when the role of state owned enterprises was weakened and private ownership was elevated as an "important component of the economy." In addition, tariffs were gradually reduced to be ready for accession to the World Trade Organization.

We estimate aggregate TFP growth at 2.5 percent per year for the whole period, 1982–2000. However, this has been decelerating rapidly, from 9.1 percent during 1982–84 to 3.3 percent (1984–88) to 2.6 percent (1988–94), and even turned

[1]Lin *et al.* (2002, p. 262) note that by 1984, almost all the peasants were in the new "household registration system," and rural income per capita had grown by 14.5 percent per year between 1980 and 1984.

[2]The Tiananmen incident occurred in 1989 and growth was interrupted; however, by the end of 1992 China had resumed its rapid growth path (Chow, 2002, p. 61). After his famous visit to Shenzhen in 1992, the Chinese leader, Deng Xiaoping, reaffirmed and pushed economic liberalization.

negative for 1994–2000 (–0.3 percent). This deceleration occurred in the secondary and tertiary industries; only in agriculture was there a good TFP growth performance during 1994–2000. This average hides a wide range of performance at the sector level; for the 1982–2000 period, TFP growth ranged from 5.6 percent for electrical machinery to ×10 percent for oil and gas mining.

Our three aggregation methods identify the industry role more precisely. Using the aggregate production function approach, aggregate TFP growth is estimated at 1.9 percent; however, the production possibility frontier method puts it at 2.5 percent, the difference being the reallocation of value added. Of the 2.5 percent aggregate TFP growth, TFP growth at the industry level contributes 2.70 percentage points while the reallocation of capital –0.17 points and the reallocation of labor –0.02 points.

The data used in this paper grew out of the International Comparison of Productivity among Asian Countries (ICPA) project sponsored by the Japanese Research Institute of Economy, Trade and Industry (RIETI).[3] The methodology described here for the construction of industry output and inputs is also that used in the project.

This paper is organized as follows. We start with an overview of the literature on estimating TFP growth for China in Section 2. Section 3 presents our methodology for industry productivity and aggregation and Section 4 discusses the construction of industry level output and input indices. Section 5 gives the industry level results and Section 6 gives the aggregation results. Section 7 concludes.

2. Literature Review

There are a number of productivity studies of China at the aggregate level, or using value added for broad (1-digit) industries. There are fewer industry studies focusing on the 2-digit level, and even fewer discussing the aggregation across industries. There is a serious debate in this literature about the magnitude of aggregate TFP growth, and a parallel debate about the future trend of TFP growth. In this section we briefly highlight these studies which are summarized in Table 1.

Chow (1993), using official data prior to 1980 that only included the material sectors (i.e. not including the service sectors that were estimated later), concluded that there was essentially no technical progress in the 1952–80 period. Chow and Li (2002) follow Chow (1993) by estimating a Cobb–Douglas production function, but update the analysis to 1998. They find a positive TFP growth of 3.03 percent in the post-reform period, together with 5.1 percent growth in capital input and 1.2 percent growth in labor input to explain the 9.4 percent overall GDP growth from 1978 to 1998. Holz (2006), however, finds that estimating time series aggregate functions "yields largely insignificant coefficients . . . output elasticities are not constant over time," and thus does not suggest any TFP estimate.

Borensztein and Ostry (1996) get a somewhat similar result; they estimate that TFP growth was –0.7 percent per year during 1953–78, but rose to an average 3.8 percent per year during 1979–94. Fan *et al.* (1999) share a similar optimistic view

[3]RIETI was founded by the Ministry of Economy, Trade and Industry, and the ICPA project was to compare the productivity trends in China, Japan, Korea and Taiwan. This study is reported in Jorgenson *et al.* (2007).

TABLE 1
Summary of China TFP Studies

Literature	Period	TFP Estimate (%)	Estimation Notes
Woo (1998)	1979–93	1.1	Modifies official GDP, decompose value added into factor growth, reallocation and TFP growth
Young (2003)	1978–98	1.4	Modifies GDP using alternative price indices; account for labor composition; estimated only for non-agriculture sector
Wang and Yao (2001)	1978–99	1.9–3.0	Account for labor composition, various assumptions about labor income shares
Chow and Li (2002)	1978–98	3.0	Cobb–Douglas function estimation
Ren and Sun (2005)	1981–2000	3.2	Account for labor compositions; Domar aggregation of industry TFP
Borensztein and Ostry (1996)	1979–94	3.8	1979–90 based on Li's (1992) estimate and the authors estimate for 1991–94
Perkins and Rawski (2008)	1978–2005	3.8	Use official GDP estimate after 1995, slightly revise data before 1995
Hu and Khan (1997)	1979–94	3.9	Authors made own adjustments on the national income statistics, including taxation adjustments
Fan *et al.* (1999)	1978–95	4.2	Examine four sectors: agriculture, urban industrial, urban services, and rural enterprises

of economic growth in China. They divide the Chinese economy in four sectors: agriculture, urban industrial, urban services, and rural enterprises for 1978–95 and estimate that TFP growth contributed 4.2 percentage points to the aggregate annual GDP growth. Hu and Khan (1997) also estimate China's TFP growth at 3.9 percent during 1979–94; this contributed more than 50 percent to output growth, compared to 33 percent from capital formation.

However, many other studies reach a much more pessimistic view of productivity performance. Woo (1998) estimates GDP growth using value added from the primary, secondary and tertiary sectors, but instead of using the official real value added data, he recalculates them using producer price indices. The result is that, for the period 1979–93, the official growth rate of 9.3 percent per annum is revised to 8.0 percent, which is then decomposed to capital accumulation (4.9 percent), labor force growth (1.4 percent, with no adjustment for changes in labor composition), reallocation effect (0.6 percent) and TFP growth (1.1 percent). He also reports a deceleration of TFP growth; from 2.8–3.8 percent per year during 1979–84 to −0.11 to 1.58 percent during 1984–93. In another study that does not use the official GDP data, Ren (1997) estimates GDP growth at 6.0 percent during 1986–94, instead of the official 9.8 percent. That paper does not discuss productivity measurement, but is focused primarily on measurements of real GDP raising data issues that are relevant to our discussions here.

In more recent papers, Young (2003) and Maddison and Wu (2006) also share the same view as Woo (1998) and Ren (1997). They argue that since officials are rewarded for superior performance and punished for failing to meet GDP growth target, local officials tend to overstate the growth of output. Their adjustments to GDP growth are shown in Figure 1. Maddison and Wu's GDP growth (dotted line) is below the official, revised, NBS growth (bold line) for all years except 1995.

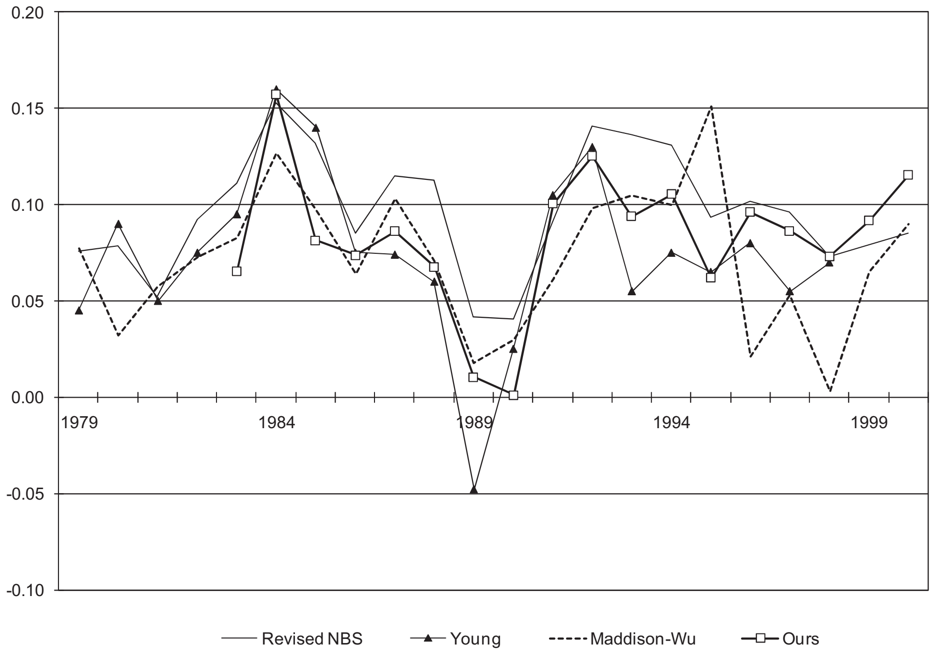

Figure 1. Comparison of the GDP Growth During the Reform Period (1979–2000)

In an earlier paper, Wu (2002) proposed an upward-bias hypothesis that the Chinese official growth index overstates China's real industrial growth performance. Therefore, they conducted a downward correction based on official physical output data. Maddison and Wu estimate that GDP growth is about 8.7 percent for 1992–2003, compared to the official 9.4 percent. Young (2003) makes only small adjustments for the period 1980–86 (line with triangles), but substantially lowers GDP growth for 1987–98, including an estimated negative growth for 1989. Our estimate of aggregate GDP growth (line with squares) is also below the official figures for all years except 1999 and 2000.

Young (2003) discusses the problems with the official estimates of real GDP and uses alternative deflators that Ren (1995) suggested for the primary, secondary, and tertiary sectors.[4] He makes an adjustment for the changing composition of the labor force and estimates that non-agricultural TFP growth was only 1.4 percent per year compared to the 3.0 percent using official numbers for 1978–98. He, however, also points out that ignoring agriculture makes this a misleading estimate since that sector is large (a quarter of GDP in this period) but with rather poor data on inputs (labor, land and capital). He comments that China's post-reform productivity performance of non-agricultural economy is respectable but not outstanding, and concludes that the efficiency gains lie mainly in the agriculture sector.

[4]Young notes that using alternative deflators brings the growth of output per capita from 7.8 percent down to 6.1 percent for the aggregate, and from 6.1 percent to 3.6 percent for the non-agricultural sector.

On the other hand, Perkins and Rawski (2008) accept the official GDP estimates after 1995 (the revised NBS line in Figure 1), and only slightly revise the growth rate down by less than 1 percent for the period before 1995. They estimate aggregate TFP growth at 3.8 percent between 1978 and 2005 and suggest that TFP accounts for 40 percent of overall growth in these three decades of economic reform.

Ren and Sun (2005) use an earlier version of the data described in Section 4 below and calculated a Domar-weighted aggregate of the TFPs for 33 industries. They estimate this aggregate TFP growth to be 3.2 percent per year during 1981–2000. Like Ren and Sun, Wang and Yao (2001) also take into account labor quality distinguishing workers by the number of schooling years. Using various assumptions about labor income shares, they estimate TFP growth to be in the –0.87 to –0.38 percent per year range for the pre-reform period, and in the 1.92 to 2.98 range for 1978–99. That is, the TFP estimates in both Ren and Sun (2005) and Wang and Yao (2001) are somewhere between the low estimates of Woo and Young, and the high estimates of Hu and Khan.

There are also a number of other studies using firm level data rather than economy aggregates, including Jefferson *et al.* (1996, 2000), Groves *et al.* (1994) and Woo *et al.* (1994). These studies seem to agree that collective owned enterprises show much higher TFP growth than state owned ones, but give very different estimates of the actual performance of the state owned enterprises, ranging from positive to negative.[5] While our analysis at the 2-digit level covering the entire economy cannot be compared to these enterprise level studies, we should note that our results also show a wide range of TFP growth, both positive and negative.

3. Methodology

Our preferred approach for estimating industry productivity growth is to use gross output data rather than the more readily available value added that is used in many of the above studies.[6] We use input–output accounts which force the analysis to be consistent across the whole economy; a revision of the output deflator of one sector not only changes the output and productivity growth of that sector, but also changes the real input into some other sector. For example, the service sectors are poorly measured in all countries and especially so in China. Services are also inputs into the manufacturing sector. The IO approach forces us to explicitly confront this issue of poor input measurement for estimating the TFP in manufacturing. We emphasize this since industry level studies have focused on the manufacturing sector.

We summarize our methodology here, which is described in detail in our accounting of U.S. economic growth in Jorgenson *et al.* (2005). The economy is divided into 33 sectors producing 33 different commodities. Each sector of the economy is described by a production function, which uses primary factors and intermediate inputs to produce gross output. This output is used for final demand and intermediate demand, and GDP is the aggregate of final demand. Nominal GDP is also the sum of sectoral value added.

[5]Some of these differences are discussed in Woo (1998), who also surveyed other papers.

[6]Schreyer (2001) discusses the issues of using value added versus gross output. As described below, our methodology derives its own measures of real output and input, and do not rely on the official measures of real value added.

3.1. *Industrial Growth Accounting*

The gross output of sector j in period t is assumed to be produced with a Hicks-neutral production function using various types of capital, labor and intermediate commodities:

$$(1) \qquad Y_{jt} = A_{jt} f\left(K_{1jt}, .. K_{kjt}, L_{1jt}, .. L_{ljt}, Z_{1jt}, .. Z_{njt}\right).$$

The index of productivity is represented by A_{jt}. We assume that the function is separable in such a way that the various types of capital, labor and intermediate inputs may be aggregated into indices K_{jt}, L_{jt} and Z_{jt} respectively, so we may write the production function as:

$$(2) \qquad Y_{jt} = A_{jt} f\left(K_{jt}, L_{jt}, Z_{jt}\right).$$

Industry capital input is derived by aggregating over three types of assets—structures (and land), motor vehicles, and all other equipment—using rental prices as weights. Equation (33) below shows how K_{kjt}, $k = 1, 2, 3$ are aggregated to K_{jt}. Labor input is an aggregate of the number of workers cross classified by sex, age, and educational attainment (L_{ljt}) using wages as weights (equation (36) below). The material input index is aggregated over the 33 commodities. These intermediate goods are produced by the 33 sectors plus imports. The construction of these input aggregates is described in Section 4.

We assume that (2) is described by a translog form:

$$(3) \qquad d\ln Y_{jt} = \bar{v}_{Kjt} d\ln K_{jt} + \bar{v}_{Ljt} d\ln L_{jt} + \bar{v}_{Zjt} d\ln Z_{jt} + d\ln A_{jt}$$

where $d\ln Y_{jt} = \ln Y_{jt} - \ln Y_{jt-1}$ denotes the growth rate, and the $\bar{v}$ weights are averaged shares of the subscripted input in nominal gross output:

$$(4) \qquad \bar{v}_{Kjt} = \frac{1}{2}\left(v_{Kjt} + v_{Kjt-1}\right) \text{ etc}$$

$$v_{Kjt} = \frac{P_{Kjt} K_{jt}}{P_{Yjt} Y_{jt}}$$

$$v_{Ljt} = \frac{P_{Ljt} L_{jt}}{P_{Yjt} Y_{jt}}$$

$$v_{Zjt} = \frac{P_{Zjt} Z_{jt}}{P_{Yjt} Y_{jt}}.$$

The P's denote the prices, P_{Yjt} is the output price to the producer (ex-factory price less taxes), P_{Kjt} is the rental price of capital, and P_{Ljt} is the price of labor input. The value of capital input is defined residually such that the value of total inputs equals the value of output:

$$P_{Yjt}Y_{jt} = P_{Kjt}K_{jt} + P_{Ljt}L_{jt} + P_{Zjt}Z_{jt}. \tag{5}$$

Purchasers buy output at the industry price P_{Ijt}. The difference between the two valuations is the net taxes on production, NT:

$$P_{Ijt}Y_{jt} = P_{Yjt}Y_{jt} + NT_{jt}. \tag{6}$$

For aggregation to GDP we need a concept of industry valued-added. The real value added of sector j, V_{jt}, is defined by writing output as a weighted share of value added and intermediate input:

$$d\ln Y_{jt} = \bar{v}_{Vjt} d\ln V_{jt} + \bar{v}_{Zjt} d\ln Z_{jt}. \tag{7}$$

The following is then implied from equation (3) for the growth of value added:

$$\bar{v}_{Vjt} d\ln V_{jt} = \bar{v}_{Kjt} d\ln K_{jt} + \bar{v}_{Ljt} d\ln L_{jt} + d\ln A_{jt} \tag{8}$$

where $v_{Vjt} = \dfrac{P_{Kjt}K_{jt} + P_{Ljt}L_{jt}}{P_{Yjt}Y_{jt}}$ is the share of value added in gross output. The price of value added is then given by the nominal value of capital and labor input divided by the quantity index:

$$P_{Vjt} = \frac{P_{Kjt}K_{jt} + P_{Ljt}L_{jt}}{V_{jt}}. \tag{9}$$

3.2. *Aggregate Growth Accounting*

The above describes the accounting for each sector. We now turn to the aggregation over all the sectors to derive national output. We present three alternative methodologies to construct economy-wide measures of output growth: aggregate production function, aggregate production possibility frontier, and direct aggregation across industries. The first requires the strongest assumptions about factor mobility and identical value-added functions across industries, while the second does not require the value-added prices to be identical. The third approach relaxes all the restrictions on value-added functions. We give a summary description here; the details are in Jorgenson *et al.* (2005, section 8.2).

3.2.1. Aggregate Production Function

The aggregate production function is the simplest approach and used in many of the studies discussed in Section 2. Four assumptions are required for the existence of such a function: (i) the industry gross output function is separable in value added; (ii) the value-added function is the same across industries (up to a scalar multiple); (iii) the functions that aggregate over capital types and labor types are identical in all industries; and (iv) each type of capital and labor receives the same price in all industries. These assumptions mean that the price of industry value-added is the same across industries:

(10) $$P_V^{PF} = P_{V,j}$$

where the common price, P_V^{PF}, is the price of value-added for the aggregate production function. Aggregate real value added is then the simple sum of sectoral value added:

(11) $$V_t^{PF} = \sum_j V_{jt}.$$

Under the assumption of common capital and labor prices, the aggregate quantity of capital input from asset type k and labor input type l is simply the sum over industry inputs:

(12) $$K_{kt} = \sum_j K_{kjt} \quad \text{and} \quad L_{lt} = \sum_j L_{jlt}.$$

Aggregate capital services (K_t) and labor input (L_t), are defined as translog aggregates of these different types of capital and labor:

(13) $$d\ln K_t = \sum_k \overline{v}_{Kkt} d\ln K_{kt} \quad \text{and} \quad d\ln L_t = \sum_l \overline{v}_{Llt} d\ln L_{lt}$$

where v_{Kkt} is the share of type k capital input in total capital input, and v_{Llt} is the share of type l labor input in total labor input. The prices of aggregate capital input and labor input are then given by the nominal values divided by these quantity indices:

(14) $$P_{Kt} = \sum_k P_{Kkt} K_{kt} / K_t \quad \text{and} \quad P_{Lt} = \sum_l P_{Llt} L_{lt} / L_t.$$

With the above we can write the aggregate production function as:

(15) $$V_t^{PF} = f(K_t, L_t, t),$$

and the corresponding nominal identity for GDP at factor cost, i.e. before indirect taxes:

(16) $$P_V^{PF} V^{PF} = P_{Kt} K_t + P_{Lt} L_t.$$

We can now define aggregate TFP growth from the aggregate production function as:

(17) $$d\ln A_t^{PF} = d\ln V_t^{PF} - \overline{v}_{Kt} d\ln K_t - \overline{v}_{Lt} d\ln L_t$$

where $v_{Kt} = \dfrac{P_{Kt} K_t}{P_{Kt} K_t + P_{Lt} L_t}$ and $v_{Lt} = \dfrac{P_{Lt} L_t}{P_{Kt} K_t + P_{Lt} L_t}$.

3.2.2. Aggregate Production Possibility Frontier

A less restrictive approach is the aggregate production possibility frontier approach used in Jorgenson and Stiroh (2000). Here we relax the assumption that industries have identical value-added functions, which allowed us to write aggregate output a simple sum in equation (11) above. We now define aggregate value-added as a Divisia index of industry value added:

$$d\ln V = \sum_j \overline{w}_j d\ln V_j \tag{18}$$

where $\overline{w}_j$ is the average share of industry value-added in aggregate value-added:

$$\overline{w}_j = \frac{1}{2}\left(w_{jt} + w_{jt-1}\right) \qquad w_j = \frac{P_{Vj}V_j}{\sum_j P_{Vj}V}. \tag{19}$$

Note that V here denotes value-added from the production possibility frontier while V^{PF} denotes that from the aggregate production function.

We maintain the same assumptions for capital and labor input so that aggregate capital and labor are as given in equation (12) above. Aggregate value-added is then written as $V = f(K, L, t)$. We define TFP growth from the aggregate production possibility frontier in the same manner as equation (17) above:

$$d\ln A_t = d\ln V_t - \overline{v}_{Kt} d\ln K_t - \overline{v}_{Lt} d\ln L_t. \tag{20}$$

3.2.3. Direct Aggregation Across Industries

The third approach for measuring the sources of growth for the aggregate economy is direct aggregation across industries, a method developed by Jorgenson *et al.* (1987, chapter 2) using the idea in Domar (1961). Here we need only assume that the value-added function exists for each industry, but impose no restrictions on prices of value-added or factor inputs. This approach allows us to trace the origins of aggregate growth and factor accumulation to the underlying industry sources.

Aggregate output is as defined by the production possibility frontier in equation (18) above. Substituting in the industry value-added from equation (8) we obtain aggregate growth as the weighted contributions of industry capital, labor and TFP:

$$\begin{aligned} d\ln V_t &= \sum_j \overline{w}_{jt} d\ln V_{jt} \\ &= \sum_j \overline{w}_{jt} \frac{\overline{v}_{Kjt}}{\overline{v}_{Vjt}} d\ln K_{jt} + \overline{w}_{jt} \frac{\overline{v}_{Ljt}}{\overline{v}_{Vjt}} d\ln L_{jt} + \overline{w}_{jt} \frac{1}{\overline{v}_{Vjt}} d\ln A_{jt}. \end{aligned} \tag{21}$$

The weights on industry TFP involve two proportions, w_j is j's share of aggregate value added, and v_{Vj} is the share of value-added in industry j's output. In terms of period t's values, this simplifies to the following, before averaging:

$$\frac{w_{jt}}{v_{Vjt}} = \frac{P_{Yjt} Y_{jt}}{\sum_i P_{Vit} V_{it}}. \tag{22}$$

This ratio of industry output to nominal aggregate output is the usual interpretation of the Domar weight (Domar, 1961; Hulten, 1978). Equation (21) employs a two-period average version of it. Note that the sum of the Domar weights is more than one reflecting how industry TFP have two effects: the direct effect on industry output, and an indirect effect via intermediate flows.

Aggregate TFP growth from the production possibility frontier may now be rewritten by substituting (21) into (20):

$$\begin{aligned} d\ln A_t &= \sum_j \bar{w}_{jt} \frac{1}{\bar{v}_{Vjt}} d\ln A_{jt} + \left(\sum_j \bar{w}_{jt} \frac{\bar{v}_{Kjt}}{\bar{v}_{Vjt}} d\ln K_{jt} - \bar{v}_{Kt} d\ln K_t \right) + \\ &\quad \left(\sum_j \bar{w}_{jt} \frac{\bar{v}_{Ljt}}{\bar{v}_{Vjt}} d\ln L_{jt} - \bar{v}_{Lt} d\ln L_t \right) \\ &\equiv \sum_j \frac{\bar{w}_{jt}}{\bar{v}_{Vjt}} d\ln A_{jt} + R_t^K + R_t^L. \end{aligned} \tag{23}$$

This equation shows how the growth of aggregate TFP from the PPF comes from three sources. The first is a Domar-weighted sum of industry TFP growth. The second and third sources reflect the reallocation of factors. These reallocation terms quantify the departure from the assumption of equal input prices in constructing the aggregate measures for K_t and L_t. A positive reallocation term happens when industries with higher capital input prices have faster input growth rates.

We can also quantify the effect of the assumptions required for the existence of the aggregate production function. Recall that the PPF relaxes the assumption of equal value-added prices used for the aggregate production function. We define the reallocation of value-added as the difference in the growth rates of the two definitions of aggregate output:

$$R_t^{VA} = d\ln V_t^{PF} - d\ln V_t = d\ln V_t^{PF} - \sum_j \bar{w}_{jt} \ln V_{jt}. \tag{24}$$

Another way of seeing this is to begin from equation (17) for the growth of TFP from the aggregate production function and combining with (20):

$$\begin{aligned} d\ln A_t^{PF} &= d\ln V_t^{PF} - d\ln V_t + d\ln A_t \\ &= d\ln V_t^{PF} - d\ln V_t + \sum_j \bar{w}_{jt} \frac{1}{\bar{v}_{Vjt}} d\ln A_{jt} + R_t^K + R_t^L \\ &= \sum_j \bar{w}_{jt} \frac{1}{\bar{v}_{Vjt}} d\ln A_{jt} + R_t^{VA} + R_t^K + R_t^L. \end{aligned} \tag{25}$$

This says that TFP growth from the aggregate production function is the Domar-weighted sum of industry TFP growth, the reallocation of value-added due to the assumption of equal value-added prices, and the reallocation of capital and labor due to the assumption of equal factor prices.

4. Constructing Output and Input Indices for Sectors

Equation (3) describes industry gross output as a function of capital, labor, intermediate inputs and technology, which is indexed by time, t. In implementing the system we further divide intermediate input into aggregate energy input and non-energy material input. We now briefly describe the construction of these industry inputs and outputs; details are given in Ren and Sun (2005). They are based on a time series of input–output "Use" or "Activity" tables which consist of the inter-industry section, the value added section, and the final demand section. These tables covering 1981–2000 were constructed in collaboration with the National Bureau of Statistics of China (NBS) and researchers from Beihang University.

The original data set consists of 33 sectors. Here we concentrate on 26 sectors in secondary industry, and the total primary and tertiary industry. Column j of the Use matrix gives the value of each intermediate input, $U_{ij} = P_i^Z Z_{ij},\ i = 1, \ldots n = 33$, and the value of capital input ($P_{Kj}K_j$) and labor input ($P_{Lj}L_j$). The net taxes that are attributable to capital are included in capital input. The column sum gives us the value of gross output as described in (5) and (6) above:

$$P_{Ijt}Y_{jt} = P_{Kjt}K_{jt} + P_{Ljt}L_{jt} + \sum_i P_{it}^Z Z_{ijt}. \tag{26}$$

In Table 2, the values for gross output, capital input, labor input, energy aggregate input, and non-energy material aggregate input, capita stock and employment are given for 2000. The sum of the capital and labor value added columns equals GDP for 2000.

4.1. *Output and Intermediate Input*

The NBS used the Material Product System (MPS) for the input–output tables before 1987 and transformed gradually to the System of National Accounts (SNA) after 1987. The time-series were constructed by us in cooperation with the NBS in the following manner to deal with this and other changes. (1) Annual series for the nominal value of industry input and industry value-added were compiled for each of the 33 sectors for 1981–2000. The final uses for total consumption, investment and net exports were also compiled. (2) Four nominal benchmark Use tables for 1981, 1987, 1992 and 1997 were constructed. Due to differences in accounting systems, industrial classification, statistical coverage and definitions, all the tables were adjusted to conform to the 1997 benchmark conventions. The tables were scaled so that total value added and final use match the latest GDP series that is consistent with the 1997 benchmark. Since the original 1981 table is based on the MPS, the nominal value table for 1981 was constructed using the structure of the 1987 table and estimates of the changes in technical parameters between 1981 and 1987. (3) Using these four comparable benchmark tables and the annual industry output, the nominal Use tables were interpolated for all years between 1982 and 2000. This involves rebalancing the matrices so that the column totals match the industry output.[7]

Row *i* of the Use matrix gives us the intermediate use of commodity *i* by all the industries, and the purchases by final demanders (consumption, investment, government and net exports). The row sum gives us the value of the domestic output of *i*. A separate "Make" matrix gives the value of commodity *i* made by industry *j*. The prices of commodities (P_i^Z, $i = 1, \ldots n$) should ideally be derived by aggregating the price of domestic output with the price of imports (or from surveys covering both items). However, since there is little data on import prices, here we assume that they behaved in the same way as domestic prices.[8] The price of commodities (P_{it}^Z) is derived from the prices of industry output (P_{Ij}) using the Make matrix.[9]

Commodity price indices for the 33 sectors were compiled using the approach used for the estimation of sectoral GDP at constant prices in OECD (2000). The industry price indices were converted from the commodity price indices using the 1981–2000 Make tables. This is described in detail in Xu *et al.* (2005).

These price indices are used to deflate the nominal industry output to give the quantity indices (Y_{jt}), and to deflate the intermediate inputs to give the quantities Z_{ijt}. To do this we assume that all purchasers pay the same price for a given commodity. Given the price and quantity of each input *i* for sector *j* from the above steps, we define the intermediate input aggregate as a Divisia index of all the components:

$$d\ln Z_{jt} = \sum_i \bar{v}_{ijt}^Z d\ln Z_{ijt},\ v_{ijt}^Z = \frac{P_{it}^Z Z_{ijt}}{P_{Zjt} Z_{jt}} \tag{27}$$

where $P_{Zjt} Z_{jt} = \sum_i P_{it}^Z Z_{ijt}$ is the total value of intermediate inputs for sector *j* and P_{Zjt} is the price index for aggregate material input into *j*. These are the terms that enter into equations (3) and (4) in the calculation of the productivity index for *j*.

4.2. *Capital Input*

The flow of capital services is derived by aggregating over three asset classes—structures, motor vehicles and all other equipment. Our method involves distinguishing between the stock of assets and the flow of services derived from them and is described in detail in Jorgenson *et al.* (2005, chapter 5). In this section, we summarize our adaptations to the Chinese data; the detailed description is in Ren

[7]This approach is used in the studies in Jorgenson *et al.* (2007) and involves rebalancing an initial guess matrix based on the benchmark tables. The new matrix is derived by minimizing the sum of squared deviations from the guess.

[8]Young (2003) used Hong Kong trade data to estimate an import price index for China. Expanding approximations like this could provide better estimates in the future.

[9]Details of the relation between industries and commodities, and between domestic and imports, are given in Jorgenson *et al.* (2005, section 4.2).

and Sun (2005). The main sources of investment data used are from the *China Statistical Yearbook on Investment in Fixed Assets* and the *China Statistical Yearbook* (various issues).

The stock of capital of type k in sector j (S_{kjt}) is accumulated from the flow of investment using the perpetual inventory method:

$$S_{kjt} = (1-\delta_k)S_{kjt-1} + I_{kjt},\ k = \text{structures, equipment, motor vehicles} \tag{28}$$

where I_{kjt} is the real investment in asset k, and δ_k is the geometric depreciation rate. There are no systematic surveys of depreciation in China and we turn to estimates from other countries. The depreciation rates are approximated by assuming that the asset life for structures is 40 years, 16 years for equipment, and 8 years for motor vehicles.[10] The asset life for structures is shorter than that used in most U.S. studies given the large differences in buildings between China and the U.S. The asset lives for equipment are taken from studies of capital stock in other countries.[11] The depreciation rates used are 17 percent for equipment, 8 percent for structures and 26 percent for motor vehicles. Real investment is given by the data on value of investment divided by the price of capital goods:

$$I_{kjt} = VI_{kjt} / PI_{kt}. \tag{29}$$

The prices for structures and equipment from 1992 on are taken from the *China Statistical Yearbook*. Prior to that we have to use various proxies: the price of equipment for 1980–91 is the overall industries price index; the prices of motor vehicles and structures for 1980–91 are the output deflators of the motor vehicle and construction industries estimated in Section 4.1. Prior to 1978 the general retail price index was used (details in Ren and Sun, 2005).

The total stock of capital for sector j is the Tornqvist aggregate of the three types:

$$d\ln S_{jt} = \sum_k \bar{v}^S_{kjt} d\ln S_{kjt} \qquad v^S_{kjt} = \frac{PI_{kt}S_{kjt}}{\sum_a PI_{at}S_{ajt}}. \tag{30}$$

Each of the asset types is assumed to generate a flow of services in period t proportional to the stock that was in place at the end of $t-1$ ($K_{kjt} \propto S_{kjt-1}$), at a rental cost P_{Kkjt}. The taxation of capital income has undergone many changes in the 1990s and here we take a highly simplified view of it to express the rental cost (in contrast to the detailed description of the U.S. tax code in Jorgenson *et al.*, 1987). We express the rental cost of one unit of the capital stock S_{kjt-1} used in period t in sector j as:

[10]Maddison (1993) assumes that the service life for structures in national industrial assets is 40 years, and for equipment is 16 years. The service life for manufacturing equipment has been estimated to be 10 years in Japan, 15 years in Germany and 17 years in both the U.S. and France (Melachroinos and Spence, 2000). For manufacturing structures it is 31 years in the U.S., 37 years in France, 41 years in Germany and 43 years in Japan.

[11]Jorgenson *et al.* (2005, table 5.1) gives the depreciation rates used by the U.S. Bureau of Economic Analysis. This includes the 26 percent rate for motor vehicles.

$$P_{Kkjt} = \left[r_{jt} + (1 + \pi_{kt}) \delta_k \right] PI_{kt-1} \tag{31}$$

where r_{jt} is the nominal rate of return in sector j, and $1 + \pi_{kt} = PI_{kt} / PI_{kt-1}$ is the rate of asset inflation.

The total value of capital services is given by the capital row of the Use matrix, as expressed in equation (26) above. The values for 2000 are given in Table 2 in the column marked "Capital Input." The rate of return is calculated such that the sum of the services over all asset types is equal to this capital input value for each industry:

$$P_{Kjt} K_{jt} = \sum_k P_{Kkjt} K_{kjt} = \sum_k P_{Kkjt} S_{kjt-1}. \tag{32}$$

With this we can now give the expression for the quantity of capital services in equations (2) and (3) as the aggregate of all assets:

$$d \ln K_{jt} = \sum_k \bar{v}^K_{kjt} d \ln K_{kjt} = \sum_k \bar{v}^K_{kjt} d \ln S_{kjt-1}, \tag{33}$$

$$v^K_{kjt} = \frac{P_{Kkjt} K_{kjt}}{\sum_a P_{Kajt} K_{ajt}}.$$

That is, the weight for each asset type is the rental cost, which depends on the common rate of return and an asset specific rate of depreciation. This makes our capital input index different from those that use a simple linear sum of asset types.

Due to the lack of data on land valuation and rents, we make no distinction about the types of land, and make a simple estimate for the rental value of land input in the agriculture sector. We ignore land for the other industries which means that we might overestimate the return to capital in the mining and real estate sectors. For the same reason the return to aggregate capital may be overestimated.

4.3. *Labor Input*

The methodology to construct labor input indices by industry is similar to that used in Jorgenson *et al.* (2005, chapter 6). The details are given in Yue *et al.* (2005) and Ren and Sun (2005); here we summarize the implementation procedures. Our approach recognizes that a simple sum of workers is not a good measure of effective labor inputs since there is great heterogeneity in the workforce. The marginal product of different types of workers is very different as reflected by their wages.

We express labor input for each industry as a Divisia aggregate over workers distinguished by sex, age and educational attainment using wages as weights, just as capital input is an aggregate over various asset types. The categories are:

- Sex
  - Male
  - Female

- Educational attainment
  - College
  - High School
  - Junior High School
  - Elementary School
  - No schooling
- Age
  - 16–34
  - 35–54
  - 55+

For each of the 33 industries there are thus $2 \times 5 \times 3 = 30$ groups, giving a total of 990 groups covering the country's 720 million workers.

Let H_{ljt} denotes the annual hours worked by all the workers in group l in industry j. We assume that the effective labor services for each category of labor is proportional to the hours worked:

$$(34) \qquad L_{ljt} = q_l^L H_{ljt}, l = 1, 2, \ldots 30.$$

The proportionality constant is represented by q to denote "quality"; this is assumed to be constant over time. The hours worked is the product of the number of workers, the average hours per week (h_{lj}), and the average weeks per year (w_{lj}):

$$(35) \qquad H_{ljt} = N_{ljt} h_{ljt} w_{ljt}.$$

The growth of effective labor input in industry j is a weighted average of the growth rates of all the categories:

$$(36) \qquad d \ln L_{jt} = \sum_l \bar{v}_{ljt}^L d \ln L_{ljt} = \sum_l \bar{v}_{ljt}^L d \ln H_{ljt},$$

where the weights are the value shares (denoting hourly compensation by P_{Llj}):

$$v_{ljt}^L = \frac{P_{Lljt} L_{ljt}}{\sum_{a=1}^{30} P_{Lajt} L_{ajt}}.$$

The second equality in (36) is given by (34).

The data of the number of workers by demographic groups for the benchmark years is based on the Population Censuses (1982, 1990, 2000), and the Sample Population Surveys (1987, 1995). The number of workers in other years is estimated from the Labor Force of Society series prior to 1990, and since 1990, from the annual Population Change Surveys.[12] There is no good data on work

[12]Yue (2007) notes that there are two sources of employment data in China: the population census and the so-called "three-in-one" employment statistics that are derived from statistics of urban units, registration data of private enterprises, and rural employment. These two sources give different estimates of the total and sector allocation of employment. We have chosen to use the census since it includes demographic information and also covers the informal sector workers which are ignored in the "three-in-one" statistics.

hours, we use the hours data in the 1995 Sample Population Survey, and incorporate the changes in institutional arrangements for working time over the period 1982–2000 (e.g. the change in the work week to 5 days in 1999). The number of workers for each industry in 2000 is given in the last column of Table 2.

The relative costs of the different types of workers are estimated using the Chinese Household Income Project (CHIP) Surveys for the years 1987, 1995 and 2000, conducted by the Chinese Academy of Social Sciences in collaboration with other institutes. The wage rates from the survey are scaled such that the sum over all categories of workers is equal to the total value of labor compensation in j as estimated in the input–output tables described in Section 4.1. That is:

$$P_{Ljt} L_{jt} = \sum_{l} P_{Lljt} L_{ljt}. \tag{37}$$

We interpolate the wage rates in between the three income survey years and scale them according to equation (37) in the same way. The value of industry labor is given in Table 2, in the column marked "Labor input."

The price of total labor in industry j is this nominal value divided by the quantity index given in (36):

$$P_{Ljt} = \frac{\sum_{l} P_{Lljt} L_{ljt}}{L_{jt}}. \tag{38}$$

This price and the labor input index, L_{jt}, are the ones that enter into equations (3) and (4) for the productivity calculation.

5. Chinese Industry Productivity Performance

We begin by describing a snapshot view for year 2000 given in Table 2. We first divide the economy into three industries—primary, secondary and tertiary industries—and then divide the secondary into 20 manufacturing, 3 mining, 1 construction and 2 utility sectors. The total value added produced in the secondary industry is about equal to the sum of the primary and tertiary industries. The largest sector by value added or gross output of the secondary industry is construction, followed by electrical machinery, food products, chemicals, primary metal and non-electrical machinery. The smallest sector by gross output is gas utilities. The sectors with the largest stock of reproducible capital in the secondary group are electric utilities, oil and gas extraction and chemicals, while the sectors with the highest employment are construction and electrical machinery. The primary industry uses 64 percent of the workforce but accounts for only 21 percent of the value of labor input. The sum of capital and labor value-added is GDP, which was 9,116 billion yuan in 2000.

Table 3 gives the growth rates of output and all factor inputs, first averaged over the whole period 1982–2000, and then averaged over 1994–2000. Output growth has been rapid in all sectors of the economy, in particular the secondary industry which averaged 11.4 percent per year. The rapid growth during the first 12

TABLE 2
CHARACTERISTICS OF THE CHINESE ECONOMY OF YEAR 2000

Sector	Output (bil. yuan)	Capital Input (bil. yuan)	Labor Input (bil. yuan)	Energy Input (bil. yuan)	Material Input (bil. yuan)	Capital Stock (bil. yuan)	Employment (million)
Primary industry	2,492	544	969	62	917	7,338	464
Secondary industry	18,131	2,496	2,168	1,825	11,642	7,137	121
Coal mining	253	36	61	31	126	446	4.1
Metal and non-metal mining	336	61	64	37	174	163	2.9
Oil and gas extraction	578	272	69	146	92	923	0.5
Construction	2,202	146	466	168	1,422	264	19.3
Food products	1,613	295	137	29	1,152	309	8.5
Textile mill products	1,045	127	96	19	803	155	8.7
Apparel	448	50	61	5	331	12	8.1
Lumber and wood	101	13	11	5	72	32	2.5
Furniture and fixtures	179	20	22	4	133	6	2.6
Paper and allied	306	32	43	20	212	75	1.9
Printing, publishing	92	13	11	2	66	31	1.5
Chemicals	1,557	212	130	203	1,012	802	5.6
Petroleum, coal prod	818	112	39	488	178	206	0.6
Leather	239	25	31	2	181	14	3.2
Stone, clay, glass	1,000	130	124	131	614	199	7.3
Primary metal	1,277	139	132	179	828	691	3.1
Fabricated metal	536	61	60	30	384	38	4.8
Machinery, non-elect	1,055	137	133	45	740	278	7.7
Electrical machinery	2,037	208	213	32	1,583	181	7.8
Motor vehicles	453	61	42	14	336	107	2.2
Transportation equip	268	24	27	6	211	145	3.3
Instruments	107	13	15	2	77	27	1.1
Rubber and plastics	565	65	49	20	431	43	3.4
Misc. manufacturing	421	59	56	14	293	160	5.8
Electric utilities	607	178	69	176	184	1,761	4.2
Gas utilities	37	6	5	17	9	69	0.3
Tertiary industry	6,153	1,385	1,555	331	2,883	9,585	136
Total	26,776	4,424	4,692	2,219	15,442	24,061	721

TABLE 3

Growth of Sector Output and Inputs (% per annum)

Sector	Output		Capital Input		Labor Input		Energy Input		Material Input	
	82–00	94–00	82–00	94–00	82–00	94–00	82–00	94–00	82–00	94–00
Primary industry	6.9	8.9	3.0	5.9	2.2	0.8	6.3	11.5	7.9	5.4
Secondary industry	11.4	10.2	6.7	9.2	3.3	2.6	9.7	12.0	13.3	11.5
Coal mining	7.2	6.7	5.7	6.9	0.5	–4.6	5.1	3.2	11.2	9.0
Metal and non-metal mining	10.3	8.3	7.4	5.0	0.2	–3.5	9.4	5.2	13.8	7.4
Oil and gas extraction	1.4	6.2	11.6	9.7	3.2	–0.8	10.6	18.5	11.7	13.3
Construction	9.2	9.1	8.8	15.7	4.5	8.9	11.8	29.0	10.8	11.8
Food products	9.8	7.1	8.5	7.8	4.3	3.4	11.5	6.7	10.3	10.1
Textile mill products	8.9	6.7	3.7	0.3	2.5	–4.0	7.7	3.0	8.6	6.5
Apparel	14.6	4.6	1.6	10.2	6.4	10.4	17.5	12.6	15.3	5.6
Lumber and wood	15.9	10.2	6.6	18.3	7.5	11.3	8.4	1.2	17.1	8.7
Furniture and fixtures	15.7	10.7	0.5	6.3	3.1	7.2	9.9	7.8	17.0	9.7
Paper and allied	18.9	11.4	6.7	13.0	2.7	–0.3	15.7	8.7	18.7	12.8
Printing, publishing	12.9	4.2	6.3	6.8	4.1	0.4	10.3	12.4	13.2	4.6
Chemicals	12.3	10.3	8.1	12.1	2.6	–1.9	6.9	9.0	13.6	12.5
Petroleum, coal prod	6.6	16.1	9.6	8.3	3.6	0.5	3.9	8.7	15.4	17.9
Leather	15.5	5.8	1.3	–3.1	7.5	13.9	14.6	8.0	16.5	7.0
Stone, clay, glass	14.2	9.8	8.7	6.4	0.9	–1.1	9.8	4.3	17.3	8.0
Primary metal	10.8	15.7	6.4	8.3	2.7	–1.6	5.9	9.6	11.8	10.9
Fabricated metal	12.9	8.8	2.2	5.0	1.9	4.0	10.1	10.0	13.5	8.9
Machinery, non-elect	13.3	9.7	0.4	2.5	0.4	–4.8	8.5	8.5	13.8	10.5
Electrical machinery	23.0	24.2	9.3	11.3	5.4	6.3	14.3	15.8	21.2	23.7
Motor vehicles	13.6	9.6	6.9	11.6	4.4	5.3	10.1	14.1	13.0	9.5
Transportation equip	14.4	9.9	5.0	13.2	4.8	3.5	4.1	6.6	14.4	12.3
Instruments	14.1	16.0	1.4	2.4	–0.9	–2.8	8.9	14.1	15.7	17.2
Rubber and plastics	10.9	9.8	–2.0	6.6	4.2	3.2	10.7	13.3	12.4	11.9
Misc. manufacturing	10.3	8.9	8.7	13.1	2.0	8.8	12.2	14.9	11.4	8.8
Electric utilities	9.4	9.3	11.2	17.9	7.3	9.8	8.4	11.4	17.7	15.6
Gas utilities	12.7	10.1	16.7	11.0	12.7	13.9	13.8	13.1	18.8	10.0
Tertiary industry	10.5	7.2	13.9	15.3	6.8	8.6	5.5	8.9	12.0	9.9

years of the sample period decelerated in 1994–2000 for the secondary and tertiary industries but accelerated for primary industry. For the whole period 1982–2000, the most rapid growth rates are in electrical machinery (23 percent), paper and allied products (19 percent) and lumber & wood (16 percent). Other industries with growth rates exceeding 14 percent are furniture and fixtures, apparel, transportation equipment, and instruments.

Capital and labor input grew at very different rates in this period. Recall that our factor inputs are aggregate indices of the components, as given in equations (33) and (36). The growth rates for capital are mostly less than 10 percent for the whole period 1982–2000, much lower than the growth rate of gross output for primary and secondary sectors. In the tertiary industry, however, capital input grew at 13.9 percent per year, compared to the output growth of 10.5 percent.

The behavior in the 1994–2000 period is quite different; capital input accelerated even when output growth slowed down in the secondary and tertiary industries. In construction, lumber and wood, electric utilities, paper and allied products, and transportation equipment, capital input growth exceeded 13.0 percent per year during 1994–2000, compared to output growth rates that are mostly much less than 10 percent. In the primary industry, capital input and output both accelerated during 1994–2000.

The change in labor input is as expected, with a larger growth in labor intensive manufacturing, such as apparel, lumber and wood, leather, lumber and wood, as well as the energy sectors—electric utilities and gas utilities. For the sub-period 1994–2000, labor input fell for the mining sectors and seven manufacturing sectors including machinery and textile mills. This may due to the weak performance or restructuring of the state owned enterprises (SOEs), resulting in worker layoffs. However, we should note again that capital input was very rapid in this period for these sectors.

The last four columns in Table 3 show the growth rates of energy and material inputs. We can see that for most of the sectors, there is substantial energy conservation for the period as a whole; for example, in the tertiary industry which includes transportation, the energy input growth was only 5.5 percent per year compared to the 10.5 percent output growth. However, for the 1994–2000 period the growth in energy use actually exceeds output growth for the three industry groups, including 7 of the 20 manufacturing sectors. The growth rate of material input is similar to that of output in the secondary and tertiary industries. In the primary industry material input decelerated in 1994–2000 when output accelerated.

We now turn to changes in total factor productivity as defined in equation (3). The TFP results, averaged over 1982–2000 and four sub-periods, are reported in Table 4. We can see that TFP growth is quite varied—many energy industries (utilities, oil extraction and petroleum refining) show negative TFP growth rates while electrical machinery (which includes computers), paper and allied products, and machinery see very high rates exceeding 4 percent per year. Sectors with TFP growth exceeding 3 percent for the whole period include furniture and fixtures, transportation equipment, and instruments.

The puzzling phenomenon of negative TFP growth is a much discussed issue with commentators trying to identify the main sources of mismeasurement. We

TABLE 4
Sectoral Total Factor Productivity Growth (% per annum)

Sector	Total Factor Productivity				
	1982–2000	1982–84	1984–88	1988–94	1994–2000
Primary industry	2.6	4.1	–1.4	2.2	5.0
Secondary industry	1.4	3.0	2.1	1.3	0.7
Coal mining	0.8	4.9	1.8	–3.1	2.6
Metal and non-metal mining	1.2	–1.9	0.8	–0.2	3.7
Oil and gas extraction	–10.0	–7.6	–18.1	–10.7	–4.6
Construction	–0.2	0.2	2.8	0.5	–3.2
Food products	0.2	0.8	0.8	1.9	–2.0
Textile mill products	1.6	0.9	4.0	–0.4	2.3
Apparel	2.7	5.6	6.4	3.9	–2.1
Lumber and wood	2.4	–2.7	4.2	5.0	0.1
Furniture and fixtures	3.4	1.3	3.3	5.8	1.9
Paper and allied	4.8	9.5	10.3	3.7	0.8
Printing, publishing	2.4	5.1	5.1	2.3	–0.2
Chemicals	1.6	4.7	2.2	2.2	–0.5
Petroleum, coal prod	–1.5	4.9	–15.7	–1.1	5.4
Leather	2.2	8.2	4.5	1.9	–0.9
Stone, clay, glass	2.2	1.3	2.7	0.8	3.7
Primary metal	1.6	3.2	–1.6	–1.8	6.5
Fabricated metal	2.9	4.4	4.1	3.5	0.9
Machinery, non-elect	4.1	9.1	6.9	2.3	2.5
Electrical machinery	5.6	6.4	8.6	4.9	4.0
Motor vehicles	2.9	10.0	5.4	1.8	0.0
Transportation equip	3.1	9.6	5.4	3.9	–1.3
Instruments	3.9	4.1	3.9	3.8	3.8
Rubber and plastics	2.4	8.1	3.4	2.8	–0.5
Misc. manufacturing	0.6	0.8	2.4	0.7	–0.7
Electric utilities	–2.0	2.0	0.0	–1.4	–5.1
Gas utilities	–2.7	–1.0	–5.2	–2.5	–1.8
Tertiary industry	–0.6	4.5	1.2	0.1	–3.5

cannot address these issues in detail here, but note the following. We have assumed that all industries pay the same price for a given commodity input. This is, of course, not very accurate in the period of controlled prices and favored sectors; however, improvements will have to wait for more detailed price data. Secondly, the capital stock that has been growing so rapidly in these sectors may not have been fully utilized. Finally, our assumption of the same depreciation rate in 1982 as in 2000 may be very poor given the rapid changes in the quality of investment goods.[13]

Apparel is a major export sector in post-reform China, and it has moderate TFP growth for the whole period 1982–2000; however, for the late 1990s TFP growth is estimated to be negative (–2.1 percent). Other sectors with negative estimated TFP growth during 1994–2000 include oil and gas mining, construction, food, and electric utilities. On the other hand some sectors had very high TFP growth during the most recent sub-period—primary industry (5.0 percent), primary metals (6.5 percent), petroleum and coal products (5.4 percent), electrical

[13]One may add another source of mismeasurement: environmental regulation often results in more inputs being used to make the production process cleaner; the inputs (e.g. desulfurization equipment) are counted but official output is the same.

machinery (4.0 percent), and stone, clay and glass (3.7 percent). The tertiary industry had a continuous deceleration of TFP growth, from 4.5 percent during 1982–84, to 1.2 percent during 1984–88 and to −3.5 percent for 1994–2000. It should be noted that Jorgenson *et al.* (2005) also find negative TFP growth in many U.S. service sectors and construction.

Overall, comparing the different sub-periods, we find that productivity growth is very high for many sectors in the 1982–88 period, with a slowdown in 1988–94, and really poor performance during 1994–2000 outside of agriculture. This deceleration does not augur well for the future if sustained.

We should note some additional caveats here. The gross output of a sector at the 2-digit level includes a large intra-sector transaction, which some analysts exclude from both the input and output measures. Excluding it gives a somewhat different picture of productivity growth.

Secondly, we find that the oil and gas mining, electric utilities sector and other energy sectors had a large negative estimated TFP growth. As we noted, we do not have estimates of land input for the mining sectors and this exaggerates the price of capital. If there is a trend in this effect this may contribute to such an implausible estimate. Another point to note is the large effect of the economic reforms during this period on prices of this sector. Before these sectors were deregulated, their input prices were highly subsidized; that is, they were buying at lower prices than other sectors, in contrast to our equal-price assumption. After deregulation, the input prices for these sectors converged to the average price and thus we may have overestimated the growth rate of intermediate inputs. Deregulation also raises the output price of these energy sectors, to the extent that these were not correctly captured in the price indices the growth rate of the gross output is also underestimated. All these give a downward bias to TFP growth.

6. Aggregate Productivity Change and Decomposition of GDP Growth

We now describe the results of applying our three aggregation methods. First we report the contribution of each industry to value-added growth and to TFP growth using Domar weights as given in equations (21) and (23). Table 5 gives the results for the whole sample period 1982–2000 and Table 6 for 1994–2000. The column "V-A weight" gives the value added share $\bar{w}_j$, "Growth" gives the growth rate, $\Delta\ln V_j$, and "Contribution to aggregate growth" gives the product $\bar{w}_j \cdot \Delta\ln V_j$, all averaged over the sample period. In the four columns under "Total Factor Productivity," we report the Domar weight ($D_j = \bar{w}_j \big/ \bar{v}_{V,j}$), the growth rate of TFP ($d\ln A_{jt}$), the Domar-weighted contributions ($\sum_j \bar{w}_j \big/ \bar{v}_{V,j}\, d\ln A_{jt}$), and finally, the share contribution to aggregate TFP growth which sums to 1.0.

For the whole period 1982–2000 the weighted sum of industry TFP growth (the first term on the right side of equation (23) is 2.7 percent per year. Of this 2.7 percent, primary industry (agriculture) with its large share of GDP is the biggest contributor with 0.91 percentage points. This is followed by sectors that are small, but with rapid TFP growth: electrical machinery with 0.51 points, and non-electronic machinery with 0.43 points. The dampers are those with negative TFP

TABLE 5

Contributions to Aggregate Value Added Growth and Productivity Growth (1982–2000)

Sector	Value-Added: V-A Weight	Value-Added: Growth (% p.a.)	Value-Added: Contribution to Aggregate Growth	Total Factor Productivity: Domar Weight	Total Factor Productivity: TFP Growth (% p.a.)	Total Factor Productivity: Contribution to Agg. TFP Growth	Total Factor Productivity: Share of Agg. TFP Growth
Primary industry	0.240	6.5	1.52	0.363	2.56	0.91	0.337
Secondary industry	0.467	10.0	4.66	1.547	1.36	2.10	0.779
Coal mining	0.014	3.6	0.05	0.030	0.76	0.02	0.008
Metal and non-metal mining	0.014	7.8	0.11	0.032	1.15	0.05	0.018
Oil and gas extraction	0.019	–5.1	–0.10	0.030	–9.95	–0.30	–0.111
Construction	0.058	5.1	0.30	0.206	–0.24	–0.06	–0.022
Food products	0.045	8.5	0.35	0.162	0.22	0.02	0.006
Textile mill products	0.033	9.6	0.32	0.131	1.62	0.19	0.072
Apparel	0.010	13.1	0.12	0.038	2.66	0.08	0.028
Lumber and wood	0.002	15.3	0.04	0.008	2.35	0.02	0.007
Furniture and fixtures	0.004	13.8	0.05	0.013	3.43	0.05	0.017
Paper and allied	0.006	20.4	0.11	0.023	4.84	0.07	0.027
Printing, publishing	0.003	12.6	0.04	0.011	2.40	0.02	0.008
Chemicals	0.037	11.7	0.41	0.124	1.59	0.18	0.067
Petroleum, coal prod	0.013	10.0	0.11	0.042	–1.49	0.01	0.005
Leather	0.005	12.4	0.04	0.019	2.22	0.02	0.008
Stone, clay, glass	0.030	12.4	0.38	0.090	2.23	0.22	0.082
Primary metal	0.032	11.7	0.37	0.116	1.57	0.22	0.082
Fabricated metal	0.014	12.3	0.17	0.050	2.88	0.14	0.051
Machinery, non-elect	0.036	12.5	0.44	0.113	4.14	0.43	0.158
Electrical machinery	0.027	28.0	0.75	0.106	5.58	0.51	0.191
Motor vehicles	0.012	14.7	0.18	0.041	2.90	0.11	0.040
Transportation equip	0.006	14.1	0.08	0.022	3.14	0.05	0.020
Instruments	0.003	11.7	0.03	0.008	3.86	0.03	0.011
Rubber and plastics	0.013	7.6	0.09	0.049	2.42	0.11	0.039
Misc. manufacturing	0.012	7.7	0.10	0.042	0.61	0.02	0.008
Electric utilities	0.020	5.6	0.40	0.042	–1.96	–0.11	–0.039
Gas utilities	0.001	7.1	0.18	0.002	–2.72	–0.01	–0.002
	0.294	9.3	2.72	0.555	–0.56	–0.31	–0.116
Tertiary industry	1.000		8.91			2.70	1.000

Note: "Contribution to aggregate TFP growth" is the last term of equation (21).

TABLE 6

CONTRIBUTIONS TO AGGREGATE VALUE ADDED GROWTH AND PRODUCTIVITY GROWTH (1994–2000)

	Value-Added			Total Factor Productivity			
Sector	V-A Weight	Growth (% p.a.)	Contribution to Aggregate Growth	Domar Weight	TFP Growth	Contribution to Agg. TFP Growth	Share of Agg. TFP Growth
Primary industry	0.194	10.9	2.11	0.315	5.04	1.59	1.904
Secondary industry	0.506	9.0	4.54	1.816	0.73	1.33	1.602
Coal mining	0.013	5.7	0.07	0.031	2.59	0.08	0.093
Metal and non-metal mining	0.015	10.4	0.15	0.038	3.72	0.14	0.168
Oil and gas extraction	0.022	0.1	–0.03	0.036	–4.60	–0.20	–0.245
Construction	0.068	0.1	0.00	0.233	–3.16	–0.73	–0.879
Food products	0.050	–1.0	–0.04	0.183	–2.02	–0.37	–0.441
Textile mill products	0.028	7.5	0.22	0.114	2.31	0.26	0.317
Apparel	0.014	2.8	0.03	0.052	–2.11	–0.11	–0.129
Lumber and wood	0.003	15.4	0.05	0.011	0.14	0.00	0.004
Furniture and fixtures	0.005	13.5	0.07	0.019	1.91	0.04	0.043
Paper and allied	0.009	8.8	0.07	0.032	0.84	0.02	0.029
Printing, publishing	0.004	2.4	0.01	0.012	–0.21	0.00	0.000
Chemicals	0.038	5.5	0.24	0.147	–0.46	–0.03	–0.035
Petroleum, coal prod	0.012	33.0	0.42	0.052	5.42	0.35	0.417
Leather	0.008	2.4	0.02	0.029	–0.93	–0.03	–0.033
Stone, clay, glass	0.034	15.2	0.55	0.117	3.74	0.45	0.543
Primary metal	0.029	30.6	0.96	0.127	6.46	0.84	1.008
Fabricated metal	0.015	8.4	0.12	0.062	0.94	0.05	0.065
Machinery, non-elect	0.034	8.0	0.27	0.120	2.53	0.30	0.366
Electrical machinery	0.034	26.7	0.94	0.156	4.04	0.60	0.725
Motor vehicles	0.012	9.3	0.11	0.047	–0.03	0.00	0.002
Transportation equip	0.007	2.7	0.02	0.030	–1.31	–0.04	–0.050
Instruments	0.003	12.9	0.03	0.009	3.80	0.03	0.041
Rubber and plastics	0.013	3.0	0.04	0.057	–0.45	–0.03	–0.030
Misc. manufacturing	0.013	8.7	0.11	0.045	–0.69	–0.03	–0.038
Electric utilities	0.023	3.6	0.10	0.055	–5.14	–0.28	–0.333
Gas utilities	0.001	6.7	0.01	0.003	–1.84	–0.00	–0.005
Tertiary industry	0.300	4.3	1.29	0.601	–3.47	–2.09	–2.505
Total	1.000		7.94	2.732		0.83	1.000

Note: "Contribution to aggregate TFP growth" is the last term of equation (21).

TABLE 7
Growth in Aggregate Value-Added and its Sources; Using Production Possibility Frontier

	1982–2000	1982–84	1984–88	1988–94	1994–2000
Value added (% p.a.)	8.91	12.50	10.2	7.81	7.96
Capital input (% p.a.)	8.75	3.11	8.84	6.73	12.58
Labor input (% p.a.)	3.89	3.73	4.66	3.41	3.91
Contribution to aggregate growth (equation 20)					
Capital	4.57	1.72	4.83	3.58	6.33
Labor	1.83	1.66	2.11	1.59	1.94
Aggregate TFP	2.51	9.12	3.26	2.64	–0.31

growth: tertiary industry with –0.31 points, and oil and gas extraction with –0.30 points. For the 1994–2000 sub-period, the Domar-weighted sum of industry TFP is only 0.83 percent; the large positive contribution from primary industry (1.59 points) is offset by the large negative contribution from the tertiary industry (–2.09 points). The other sectors with large positive contributions are primary metals with 0.84 points, electrical machinery with 0.60, and stone, clay and glass with 0.45. The other negative contributions come from electric utilities, construction, and food products.

We next turn to the production possibility frontier which defines GDP as an index over industry value added (equation 18). Table 7 gives the growth rate of aggregate output, aggregate capital and labor for the various sub-periods in the first three lines. Over the entire sample period aggregate value added grew at 8.91 percent per year with the fastest growth in the first sub-period and the slowest during 1988–94.

The last three lines of Table 7 give the contributions to this aggregate output growth (equation 20). Of the 8.9 percent growth, capital contributed 4.6 percentage points, labor 1.8 and aggregate TFP 2.5. Compared to the post-War U.S. this is a large TFP growth, but like the U.S., the greatest source is capital input growth. There is a great deal of variation among the various sub-periods; aggregate TFP during the agricultural reforms of 1982–84 was the fastest at 9.1 percent, while it was –0.3 percent during 1994–2000. TFP growth was about 3 percent during 1984–94. Labor input contribution was roughly stable at about 2 percentage points in all sub-periods, but capital contribution was small in the first sub-period. Except for 1982–84, in the other periods, capital input was the largest source of aggregate growth.

In our third approach, the aggregate production function defines GDP as the simple sum of industry value added (equation 11); this is not exactly equal to the official real GDP. Recall that this imposes the assumption of identical value added price for all sectors. The first two lines in Table 8 show how growth rates of output using the aggregation production function method differ from the PPF method. For the entire sample 1982–2000, the difference is modest, the aggregate PPF method estimates aggregate value added growth at 8.91 percent per year, whereas the aggregate production function method gives 8.29 percent, with the –0.62 percentage points difference due to the reallocation of value added.

TABLE 8

Aggregate Reallocation Effects (% per year)

	1982–2000	1982–84	1984–88	1988–94	1994–2000
Agg. production possibility frontier vs. agg. production function					
Agg prod. func. value added	8.29	11.12	7.73	7.28	8.74
Agg. PPF value added	8.91	12.50	10.2	7.81	7.96
Reallocation of value added	–0.62	–1.38	–2.47	–0.53	0.78
Agg. production possibility frontier vs. direct aggregation across industries					
Aggregate TFP	2.51	9.12	3.26	2.64	–0.31
Domar weighted productivity	2.70	7.48	2.78	2.92	0.83
Primary industry	0.91	1.84	–0.55	0.89	1.59
Secondary industry	2.10	3.67	2.71	1.94	1.33
Tertiary industry	–0.31	1.96	0.62	0.08	–2.09
Reallocation of capital	–0.17	1.80	0.48	–0.28	–1.15
Reallocation of labor	–0.02	–0.15	0.00	0.00	0.00

The difference of growth rates between these two methods is, however, much bigger and volatile over the shorter sub-periods. For the 1984–88 period, the difference is 2.5 percentage points out of the 10.2 percent growth rate. For the first three sub-periods, the PPF gives a higher growth rate, whereas for 1994–2000 the aggregate production function method is faster. The comparisons for the U.S. given in Jorgenson *et al.* (2005, table 8.4) also show a similar volatility over short periods.

The bottom section of Table 8 compares the PPF to the direct aggregation across industries using the TFP decomposition (equation 23). This decomposition links aggregate TFP growth to the Domar-weighted sum of industry TFP growth and the reallocation of capital and labor. For the whole period 1982–2000, of the 2.51 percent aggregate TFP growth, 2.7 percent is due to the industry TFP growth, –0.17 percent to reallocation of capital input, and –0.02 percent to reallocation of labor. That is, the individual sectors of the economy performed well, but the sectors that expanded relatively more included the poor performers. The movement of labor contributed little to the reallocation effects; most of the negative contribution is due to the reallocation of capital. The reallocation of capital has a positive effect for most of the 1980s, but a negative effect after 1988.

Table 8 also shows the contributions of the TFP growth from primary, secondary and tertiary industries. Of the 2.70 percent annual Domar-weighted TFP growth during 1982–2000, the secondary industry contributed 2.1 percentage points, while the primary industry contributed 0.9 points and the tertiary industry contributed –0.3 points. Over the various sub-periods, the Domar-weighted sum was decelerating, from 7.5 percent during 1982–84, to 2.9 percent during 1988–94, and to 0.8 percent during 1994–2000. As we noted earlier, this pattern is dominated by the rapid deceleration of TFP growth in the secondary and tertiary industries. In the tertiary industry it fell from 2.0 percent per year during 1982–84 to 0.6 percent during 1984–88, and to 0.1 percent during 1988–94; it even registered a negative –2.1 percent for 1994–2000. The primary industry was different with a steadier TFP growth except for 1984–88.

Sensitivity Analysis

In Section 4.2, we noted how we had to turn to international estimates of depreciation rates given the lack of Chinese estimates. These rates are higher than those used, for example, in Jorgenson *et al.*'s (2005) estimates of U.S. capital input. To see how lower depreciation rates would affect the sources of growth estimates, we compute an alternative index of capital input using a 4 percent rate for structures and a 12 percent rate for equipment. The result is that the capital contribution to aggregate growth rises from 4.57 percentage points (Table 7) to 4.99 points, and the TFP contribution falls from 2.51 to 2.10 percentage points. The industry contribution to aggregate TFP growth also changes by a similar magnitude; for example, the share of aggregate TFP growth for 1982–2000 due to agriculture changes from 0.337 (Table 5) to 0.401. These are not trivial changes but do not change our basic conclusions.

7. Conclusion

We have laid out a methodology to account for Chinese economic growth, both at the sectoral level and at the aggregate level. We implemented this to estimate the productivity performance for China during the post-reform period using a time-series of input–output tables that is part of a consistent set of National Accounts, and using detailed labor data from the micro-level surveys.

Aggregate TFP growth for the post-reform period 1982–2000 is estimated at 2.5 percent, which is between the low estimates of 1.1–1.4 percent from Woo (1998) and Young (2003), and the high estimates of 4–5 percent from Hu and Khan (1997). This is similar to the estimates in Wang and Yao (2001). By dividing the whole period into four sub-periods, we find a very high TFP growth of 9.1 percent during 1982–84, a high growth during 1984–88 and 1988–94, but a negative TFP growth for 1994–2000.Whether this trend is due to secular forces or to unusual changes that are not going to be repeated would be a subject of interesting future research.

Unlike the other previous studies, we also decomposed the aggregate TFP growth into contributions from industry TFP, reallocation of value added, as well as reallocation of capital and labor inputs. Our results suggest that the main contribution comes from the Domar-weighted industry TFP, while the reallocation of labor is negligible. The efficiency improvement due to the reallocation of capital is positive in the 1980s, but negative in the 1990s. GDP growth was driven by technical progress and efficiency improvements in the 1982–94 sub-period; in other periods it is mainly driven by the accumulation of capital. Aggregate TFP was moderate and even negative for some years during the late 1990s.

Looking at the industry TFP contribution to aggregate TFP growth, we find that the tertiary industry contributed 20–30 percent in the 1980s, but only a fairly small share in the early 1990s and was negative in the late 1990s. The agriculture sector showed good productivity gains, as did many manufacturing sectors including the computer related sector, averaged over the whole 1982–2000 period. However, a good number of sectors in secondary industry, especially the energy related ones, showed negative productivity growth. Both secondary and tertiary industries show a declining TFP growth over the sub-periods examined.

As the other studies of productivity have noted, the quality of data leaves much to be desired. We believe that our dataset is an improvement over those used in previous studies. However, we should summarize here some the weaknesses discussed above. The difficulties of estimating capital input include: the lack of good deflators for the different assets in the earlier periods, the lack of good data on land input, and the lack of China-specific depreciation rates. The measurement of labor suffers from the lack of a good annual industry estimate especially in the years prior to 1990, the lack of hours worked data, and the lack of information about the self-employed. The measurement of output and intermediate input suffers from the lack of good import prices and a good distinction of market and regulated prices. The gradual deregulation of prices in the energy-intensive sectors, and other regulated sectors, may have overstated the rate of inflation. Finally, as Holz (2006) has emphasized, the assumption of prices equaling marginal products may not be valid during the earlier periods when there is no functioning labor market and many prices are fixed by the Plan.

These shortcomings point to a full agenda for future research, but we believe the methods laid out here will prove useful in measuring the sources of growth in this dynamic economy.

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