TCER Working Paper Series

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February 2023

Working Paper E-178
https://www.tcer.or.jp/wp/pdf/e178.pdf

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Abstract

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Improving the SNA: Alternative Measures of Output, Input, Income and Productivity for China*

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February 5, 2023

Abstract

The paper defines and computes alternative measures of output, input and Total Factor Productivity (TFP) for the production sector of the Chinese economy. The current System of National Accounts (SNA) input measure that corresponds to Gross Domestic Product (GDP) does not measure the *income* generated by the production sector since it includes depreciation and excludes capital gains and losses on assets used in the production sector. The paper suggests an accounting framework that addresses these problems with the existing SNA gross income measure and implements a net income measure using the Augmented Productivity Database (APDB) developed by Asian Productivity Organization and Keio University for China over the years 1970-2020. Real gross and real net income generated by the Chinese production sector is decomposed into explanatory factors including TFP growth using the framework suggested by Jorgenson and Diewert and Morrison. TFP growth is further decomposed into technical progress and inefficiency components using the nonparametric approach developed by Diewert and Fox. The APDB has estimates for the price and quantity of agricultural, industrial, commercial and residential land used in China. The paper argues that changes in land use should be treated in the same manner as inventory change and added to the alternative output measures. It turns out that Jorgensonian user costs for land are frequently negative. The problems associated with negative user costs are discussed in the paper.

Journal of Economic Literature Classification System Numbers

C43, C82, D24, D31, F14, I3

Key Words

Total Factor Productivity growth, terms of trade, GDP functions, land input, exact index numbers, nonparametric estimation of technology, gross versus net output, measurement of real income.

* The authors gratefully acknowledge financial support from the JSPS KAKEN Grant (A): 20H00082.

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1 Introduction

The production accounts in the current international System of National Accounts (SNA) serve many useful purposes but the Gross Domestic Product (GDP) concept in these accounts does not measure the *income generated by the country's production sector* for two main reasons:

- The GDP concept includes depreciation as part of output and
- The GDP concept excludes capital gains or losses that accrue to productive assets held over the accounting period.

It is obvious that depreciation is not part of "income" as conceived by the public. However, including capital gains or losses on assets used by the production sector as part of the income generated by domestic producers is more controversial and has been resisted by national income accountants due to the volatility of capital gains and losses on assets used in production. However, the inclusion of capital gains in income measures has a long history in economics, dating back to Marshall:

> "When a man is engaged in business, his profits for the year are the excess of his receipts from his business during the year over his outlay for his business. The difference between the value of his stock of plant, material, etc. at the end and at the beginning of the year is taken as part of his receipts or as part of his outlay, according as there has been an increase or decrease of value. What remains of his profits after deducting interest on his capital at the current rate (allowing, where necessary, for insurance) is generally called his earnings of undertaking or management. The ratio in which his profits for the year stand to his capital is spoken of as his rate of profits. But this phrase, like the corresponding phrase with regard to interest, assumes that the money value of the things which constitute his capital has been estimated: and such an estimate is often found to involve great difficulties." Alfred Marshall (1920; 62)[54].

Marshall essentially defined the nominal income generated by a production unit over the accounting period as the period's cash flow plus the end of the period capital stock minus the beginning of the period capital stock. This residual is decomposed into interest payments plus pure profits. To this residual, we add payments to labour plus tax payments to governments to obtain a useful measure of the nominal income generated by the production unit over the accounting period. In section 6 of the paper, we will essentially use this definition of nominal income to measure the nominal income generated by the production sector of the Chinese economy.

Haig's net income concept was similar to Marshall's concept:

> "More simply stated, the definition of income which the economist offers is this: Income is the *money value of the net accretion to one's economic power between two points of time*. It will be observed that this definition departs in only one important respect from the fundamental economic conception of income as a flow of satisfactions. It defines income in terms of power to satisfy economic wants rather than in terms of the satisfactions themselves. It has the effect of taxing the recipient of income when he receives the power to attain satisfactions rather than when he elects to exercise that power." Robert Haig (1921; 7)[33].

However, Haig took Marshall's definition one step further by recognizing that income received at two points in time may not have the same purchasing power. He recognized that finding the "right" deflator to convert nominal income into real income was not a trivial task:

> "The prospect for a complete solution of the difficulty pointed out, however, is identical with the prospect for a perfect monetary standard. But an approximate solution might be realized if we were able to evolve a satisfactory index of the level of prices. If it were accurately known what the change in price level in a given year had been, it might be possible to qualify the results shown by a comparison of the balance sheets for the beginning and the end of the period in such a way as to eliminate the influence of the changing standard. But even this refinement is not likely to be introduced soon. Indeed, the desirability and urgency of its introduction is dependent largely upon the complete solution of the accounting problem, which solution is certainly not imminent." Robert Haig (1921; 17)[33].

The "accounting problem" Haig referred to is the problem of valuing production unit assets (in current market values) at the beginning and end of the accounting period. Indeed Marshall also noted this problem in the above quotation. Because capital stocks are not bought and sold at the end of every accounting period, current values for produced assets at a point in time must be estimated and these estimates rest on assumptions about the form of depreciation. For non-produced assets in production, like land, transactions are typically sparse for commercial and industrial properties and, as an added complication, sales of land are usually bundled with structures on the land and so again, beginning- and end-of-period current values for land assets used in production will generally be imputations rather than market transactions.

The fact that nominal measures of gross domestic output (or value added) can be produced (largely) without the use of imputations is the reason why the GDP concept has become the measure of output that is largely used around the world. Thus while Hicks favoured the use of a net measure of output and the corresponding measure of input or income, he recognized that the above argument for the use of GDP or GNP had some validity:[*1]

> "There are items, of which Depreciation and Stock Appreciation are the most important, which do not reflect actual transactions, but are estimates of the changes in the value of assets which have not yet been sold. These are estimates in a different sense from that previously mentioned. They are not estimates of a statistician's true figure, which happens to be unavailable; there is no true figure to which they correspond. They are estimates relative to a purpose; for different purposes they may be made in different ways. This is of course the basic reason why it has become customary to express the National Accounts in terms of Gross National Product (before deduction of Depreciation) so as to clear them of contamination with the 'arbitrary' depreciation item; though it should be noticed that even with GNP another arbitrary element remains, in stock accumulation." John R. Hicks (1973; 155)[39].

Hicks noted that including the change in inventory stocks in the definition of GNP was an imputation. Basically, the value of inventory stocks held by the production unit at the beginning and end of the accounting period had to be estimated and then deflated by a suitable price index and then differenced to form real inventory change.

The above discussion can be summarized as follows:

[*1] This point of view is also expressed in the *1993 SNA*: "As value added is intended to measure the additional value created by a process of production, it ought to be measured net, since consumption of fixed capital is a cost of production. However, as explained later, consumption of fixed capital can be difficult to measure in practice and it may not always be possible to make a satisfactory estimate of its value and hence of net value added." Eurostat, IMF, OECD, UN and World Bank (1993; 121)[25].

- GDP is favoured over a net measure of output (NDP) because it can be produced largely without using imputations.*2
- NDP is favoured over GDP because NDP best approximates a measure of the *income* generated by the production unit.

Measures of nominal income have to be converted into real income measures to be meaningful. Following Haig, we could choose a consumer price index to deflate nominal gross or net income into real gross or net income. However, a consumer price index is not the only choice for the deflator. Consider the following quotation:

> "At once we run into the difficulty that if Net Investment is interpreted as the difference between the value of the Capital Stock at the beginning and end of the year, the transformation would not be possible. It is only in the special case when the prices of all sorts of capital instruments are the same (if their condition is the same) at the end of the year as at the beginning, that we should be able to measure the money value of Real Net Investment by the increase in the Money value of the Capital stock. In all probability these prices will have changed during the year, so that we have a kind of index number problem, parallel to the index number problem of comparing real income in different years. The characteristics of that other problem are generally appreciated; what is not so generally appreciated is the fact that before we can begin to compare real income in different years, we have to solve a similar problem within the single year—we have to reduce the Capital stock at the beginning and end of the years into comparable real terms." John R. Hicks (1942; 175-176)[36].

When we move from the gross output model of production to the net output model, gross investment is replaced by some measure of net investment or by some measure of the difference between the end of the period capital stock minus the beginning of the period capital stock. In the above quotation, Hicks recognized that there was a "kind of index number problem" in comparing capital stocks at the beginning and end of the period. Thus instead of deflating capital stock values by a consumer price index, a capital stock price index could be used as the deflator. *Real financial capital is held constant* (or increased) if the end-of-period nominal value of the capital stock employed divided by an end of the period consumer price index minus the beginning of the period value of the capital stock employed by the production unit divided by the beginning of the period consumer price index is equal to (or greater than) zero. *Real physical capital is held constant* (or increased) if the end-of-period nominal value of the capital stock employed divided by an end of the period capital stock price index minus the beginning of the period value of the capital stock divided by the beginning of the period capital stock price index is equal to (or greater than) zero. Pigou (1941; 273-274)[57] favored the second approach which is called the *maintenance of physical capital approach* while Haig (1921)[33] and Hayek (1941; 276-277)[34] favored the first approach, the *maintenance of real financial capital approach* to the measurement of income. In this paper, we will take the approach which can be traced back to Haig. However, we will provide indexes of real physical capital input for the Chinese economy in passing. The details of our approach to measuring the net income generated by an economy will be spelled out in section 6 below.*3 We note that our chosen measure of national net income is not the only measure that could be used to measure the income generated by the production sector of an economy. There is a huge

*2 However, when Gross Operating Surplus (and a part of Mixed Income) is transformed into Jorgensonian capital services, imputations are also necessary.

*3 For additional details on alternative economic approaches to the measurement of net income, see Samuelson (1961)[61] and Diewert and Fox (2022)[16].

inflation accounting literature on the measurement of income for a business enterprise which could be adapted to measure real national income.*4

We will illustrate the difference between our theoretical gross and net measures of national income by using the Asian Productivity Organization (APO) data on the People's Republic of China for the years 1970-2020. Due to the efforts of the APO and the work of Koji Nomura at Keio University, a national accounts Augmented Productivity Database (APDB) that has price and quantity (or volume) information on 16 capital stock components has been developed. This APDB has national annual price and quantity estimates for four types of land: agricultural, industrial, commercial and residential. We will use this data base to construct estimates of China's gross output Total Factor Productivity (TFP) for these years in section 3 below.*5

In section 4, the Chinese *real gross income* over the years 1970-2020 will be decomposed into explanatory factors using the decomposition suggested by Diewert and Morrison (1986)[18], Kohli (1990)[47] and Diewert and Lawrence (2006)[17].

In section 5, an alternative (nonparametric) decomposition of the Chinese real gross income into explanatory factors due to Diewert and Fox (2018)[15] is implemented using our Chinese data. This alternative framework further decomposes TFP growth into technical progress and inefficiency terms. We typically think of TFP growth as a measure of technical progress but when a recession occurs in a country, TFP invariably becomes negative due to the existence of fixed factors that cannot be sold easily. Using the Diewert and Fox methodology, technical progress never becomes negative but inefficiency can cause TFP to become negative.

Section 6 presents the *real net income* TFP estimates for China. The theory we use in this section is primarily due to Hicks (1961)[38] and Edwards and Bell (1961)[24].*6 Instead of using user costs and gross investment as our measurement concepts, we use waiting services *7 in place of capital services and we use the capital stock in place of gross investment. An alternative measure of TFP emerges in this section. The decompositions explained in sections 4 and 5 are also adapted to the net product context.

Section 7 concludes.

National estimates of TFP when land is an input are fairly scarce due to the lack of national data on the price and quantity of land. This lack of data on land is perhaps partly due to the belief that land is not a very important input into production and partly due to the difficulties in decomposing market property prices into land and structure components. Thus the APDB on land input by type of use for 25 countries fills an important gap in the international statistical system.*8

With the availability of land data by type of land, a new problem with traditional measures of GDP arises. At present, changes in land use do not appear in the GDP measure as currently compiled by countries. But using the APDB, we can see that agricultural land is being converted into commercial and residential land; i.e., the quantity of land in the different categories is changing over time (even if the total land area remains constant). We think that

*4 See Middleditch (1918)[55], Sweeney (1934)[63] (1935)[64], Edwards and Bell (1961)[24], Baxter (1975)[3], Sterling (1975)[62], Whittington (1980)[66], Carsberg (1982)[6] and Tweedie and Whittington (1984)[65].

*5 The APDB has similar data for 25 Asian countries. We chose China to illustrate the differences between gross and net income measures because the Chinese economy is now the largest economy in Asia and hence "explaining" its tremendous growth is of some interest.

*6 It is further developed in Diewert and Fox (2022)[16].

*7 This term is due to Rymes (1968)[58] (1983)[59].

*8 For a summary of land shares in total asset value by country for 25 Asian countries, see APO (2022; 179)[2].

these changes in land use should appear in the GDP measures produced by countries; these changes are entirely analogous to changes in inventories, which do appear in GDP measures. Thus our Chinese measures of gross output include changes in land use.

Adding land use changes to GDP did not materially change our estimates of Chinese GDP. However, adding capital gains on land stocks used by the production sector did lead to Chinese estimates of Net Domestic Product (NDP) or Net Income that did materially differ from the corresponding GDP estimates. Many advanced countries have experienced huge increases in land prices over the past 20 years. These increases translate into increased income generated by the production sector of the economy but these increases do not show up in country estimates of GDP. This is why supplementary measures of NDP should be constructed by National Statistical Offices.

However, the increased availability of data on land use by country does lead to some additional problems. It turns out that land prices are very volatile. Thus at times, increases in land prices will cause Jorgensonian user costs to become negative. Negative user costs create some conceptual problems: if they are anticipated, investors should immediately buy the asset because the asset will generate a one-period return which exceeds the cost of capital. Moreover, user costs are supposed to approximate rental prices for the underlying assets. We do not observe negative rental prices in the real world. Section 2 below explains and discusses the negative user cost problem. Section 2 also discusses the construction of the productivity data for China. An Appendix has more detail on the problems associated with the data construction.

2 User Cost Theory and Data Construction

In this section and the following section, we use the APDB to construct estimates of China's gross output TFP for the years 1970-2020 using the methodology developed by Jorgenson and his coworkers.[*9] A key aspect of this methodology is the construction of a *user cost of capital* to measure the services provided by the use of a capital stock asset over the course of a year. Below, we explain how a user cost can be constructed from the APDB.

Suppose the beginning of the year t price of a new unit of capital stock n is P_{Kn}^t and the production unit faces an annual cost of capital at the beginning of year t of r^t. Suppose further that asset n in year t has a geometric depreciation rate equal to δ_n^t. Then the net discounted (to the beginning of year t) cost of purchasing a new unit of asset n, using it during year t and then selling it at the end of year t (most likely to the same production unit) is equal to:[*10]

$$\begin{aligned} P_{Kn}^t - (1-\delta_n^t)P_{Kn}^{t+1}/(1+r^t) &= P_{Kn}^t - (1-\delta_n^t)(1+i_n^t)P_{Kn}^t/(1+r^t) \\ &= (1+r^t)^{-1}[(1+r^t) - (1-\delta_n^t)(1+i_n^t)]P_{Kn}^t \\ &= (1+r^t)^{-1}[r^t - i_n^t + \delta_n^t(1+i_n^t)]P_{Kn}^t. \end{aligned} \quad (1)$$

The *asset n year t inflation rate* i_n^t which appears in (1) is defined by the following equation:

$$1 + i_n^t \equiv P_{Kn}^{t+1}/P_{Kn}^t. \quad (2)$$

*9 See Jorgenson (1963)[40], Jorgenson and Griliches (1967)[43] (1972)[44], Christiansen and Jorgenson (1969)[7] and Jorgenson (1989)[41].

*10 This is the method used by Diewert (1974; 504)[8] (1980; 472-473)[10] to derive a user cost formula. Note that the price P_{Kn}^{t+1} is the price of a new unit of the capital stock at the end of year t.

The *user cost of capital* defined by the right hand side of (1) discounts costs (the purchase price P^t_{Kn}) and benefits (the selling price of the used asset at the end of year $(1-\delta^t_n)P^{t+1}_{Kn}$ equal to $(1-\delta^t_n)(1+i^t_n)P^t_{Kn}$) to the beginning of year t. This is a beginning of the year perspective. If we take an end of the year perspective, then the end of the year benefits are no longer discounted and the beginning of the year costs are anti-discounted to their end of the period equivalents by multiplying P^t_{Kn} by $(1+r^t)$.*11 The resulting *end-of-year user cost of capital* for asset n, U^t_n, is defined as follows:*12

$$\begin{aligned} U^t_n &\equiv (1+r^t)P^t_{Kn} - (1+i^t_n)(1-\delta^t_n)P^t_{Kn} \\ &= [r^t - i^t_n + \delta^t_n(1+i^t_n)]P^t_{Kn}. \end{aligned} \tag{3}$$

The user cost formula defined by (3) makes sense from the viewpoint of accounting theory: if a production unit purchases a unit of capital stock n at the beginning of year t, it has to raise capital from investors to finance the purchase so the all inclusive cost of the purchase is not only the purchase price but the implicit or explicit interest that the unit has to pay to investors to tie up their financial capital for a year. Thus, the total cost associated with the purchase of a capital input is not P^t_{Kn} but $(1+r^t)P^t_{Kn}$.

In many countries, land and structure assets are taxed. These property taxes need to be added to the corresponding user costs. Thus let τ^t_n be the year t property tax rate that applies to asset n. The *new end-of-period user cost of capital for asset n* is defined as follows:

$$\begin{aligned} U^t_n &\equiv (1+r^t+\tau^t_n)P^t_{Kn} - (1+i^t_n)(1-\delta^t_n)P^t_{Kn} \\ &= [r^t + \tau^t_n - i^t_n + \delta^t_n(1+i^t_n)]P^t_{Kn}. \end{aligned} \tag{4}$$

The Jorgenson methodology uses the *geometric model of depreciation.* This methodology relates the end of the year quantity of capital for asset n in year t, Q^{t+1}_{Kn}, to the corresponding beginning of the year capital stock for asset n, Q^t_{Kn}, as follows:

$$Q^{t+1}_{Kn} = (1-\delta^t_n)Q^t_{Kn} + Q^t_{In} \tag{5}$$

where Q^t_{In} is the production unit's *gross investment* in asset n in year t. Assumption (5) allows us to apply the user cost formula (4) to the aggregate capital stock for asset n (and not just to new units of the capital stock).

We apply the above methodology to the data for the People's Republic of China in the APDB. The data for the years 1970-2020 are explained more fully in the Data Appendix. We have data on the usual macroeconomic variables, $C+G+I+X-M$, which are consumption, government, gross investment, exports and (minus) imports. The year t prices and quantities for these variables are denoted by $P^t_C, P^t_G, P^t_I, P^t_X$ and P^t_M and $Q^t_C, Q^t_G, Q^t_I, Q^t_X$ and Q^t_M respectively. The price indexes have been normalized to equal 1 in 1970 and the quantities or volumes are measured in units of trillions of 1970 yuan. The corresponding values (in trillions of current yuan) are $V^t_C, V^t_G, V^t_I, V^t_X$ and V^t_M where V^t_C equals $P^t_C Q^t_C$ and so on. These output price and quantity indexes for China are listed in Appendix Tables A5 and A6 respectively.*13

*11 The end of year perspective is used in accounting theory where current year revenues and costs are cumulated over the year (or quarter) and regarded as taking place at the end of the accounting period; see Peasnell (1981)[56].

*12 This user cost formula was also derived by Christensen and Jorgenson (1969)[7] using a different method of derivation.

*13 The price and quantity indexes for gross investment in year t, P^t_I and Q^t_I, include land investment which

The APDB has information on quality-adjusted labour input for China (price, quantity and value in year t are P_L^t, Q_L^t and $V_L^t = P_L^t Q_L^t$) and on beginning of the year capital stocks for 16 assets China (price, quantity and value in year t for asset n are P_{Kn}^t, Q_{Kn}^t and $V_{Kn}^t = P_{Kn}^t Q_{Kn}^t$ for $n = 1, \ldots, 16$). The 16 assets are as follows: (1) IT hardware; (2) Communications equipment; (3) Transport equipment; (4) Other machinery and equipment; (5) Dwelling structures; (6) Non-residential buildings; (7) Other structures; (8) Cultivated assets; (9) Research and development; (10) Computer software; (11) Other intangible assets; (12) Net increase in inventory stocks; (13) Agricultural land; (14) Industrial Land; (15) Commercial Land and (16) Residential Land. The price indexes have been normalized to equal 1 in 1970 and the quantities or volumes are measured in units of trillions of 1970 yuan. The APDB also has information on the corresponding gross investments. The price and quantity indexes for investment in asset n and the value of investments in trillions of yuan are denoted by P_{In}^t, Q_{In}^t and $V_{In}^t = P_{In}^t Q_{In}^t$ respectively for $n = 1, \ldots, 12$. The APDB also has estimated depreciation rates δ_n^t for the depreciable assets 1-11 (inventory assets are assumed to have zero depreciation rates) and the Q_{Kn}^t, Q_{In}^t and δ_n^t satisfy equations (5) for $n = 1, \ldots, 11$ and $t = 1970, \ldots, 2020$.

Note that the APDB follows standard SNA conventions by setting investment in land assets equal to zero for each year. We believe that this is a problem with the current SNA methodology which ignores land investments. The reason for this omission may be the assumption that at the national level, the stock of land is fixed and therefore there is no real investment in land where investment is defined as the change in the stock of land. However, as soon as we have information on alternative uses of land (as is available in the APDB, we see that there are considerable changes in the composition of the land subaggregates. In general, agricultural land is converted to commercial and residential land and other uses [*14] as population grows or as economic development proceeds. Since inventory change is accepted as part of gross investment in the SNA, it seems reasonable to also include changes in land use as part of gross investment. Thus, we define *land investment* in year t for the four types of land, Q_{In}^t for $n = 13, 14, 15, 16$, as follows:

$$Q_{In}^t \equiv Q_{Kn}^{t+1} - Q_{Kn}^t; \qquad n = 13, \ldots, 16; t = 1970, \ldots, 2020. \tag{6}$$

The investment prices P_{In}^t for the produced assets are "objective" but the beginning of the year prices for the corresponding stocks could be chosen to be closer to year end prices for the investment goods rather than being an annual average of the year's investment prices. For example, the APDB could have set the beginning of the year price of asset n equal to $P_{Kn}^t \equiv (1/2)[P_{In}^t + P_{In}^{t-1}]$, an average of the year t and $t-1$ investment prices for the nth asset. The choice of the "right" beginning of the year price for an asset is more or less up to the national income accountant. However, in this paper, we follow the APDB conventions and set the beginning of the year t asset prices equal to the corresponding year t investment price

is not included in the APDB because the international SNA does not include land investment as part of gross fixed capital formation (GFCF). The price indexes in table A5 have been adjusted for indirect taxes on consumption and imports; i.e., consumption taxes have been subtracted from the final demand output prices to obtain the prices that producers receive for their outputs and added to import prices because we follow Kohli (1978)[46] in assuming that all imports flow through the country's production sector. The importance of making these indirect tax adjustments was noted by Jorgenson and Griliches (1972)[44].

[*14] We note that our decomposition of land use into four categories omits some addition important categories such as forest land and some forms of government land such as parks. See Eurostat (2017)[27] for a comprehensive description of possible land use categories. Another note is that the land stock value may reflect the accumulated value of land improvements, which are included in GFCF. The issue of such double-counting possibilities is a problem in equation (6) and also in the definition of land stock prices.

for assets 1-11. For assets 13-16, we do not have APDB investment prices so we will simply set the year t investment price equal to the corresponding the end of the year asset price in APDB.[*15] The depreciation rates for inventory stocks and the land assets are set equal to 0; i.e., we have:

$$\delta_n^t \equiv 0; \qquad n = 12, \ldots, 16; t = 1970, \ldots, 2020. \tag{7}$$

To summarize the above relationships between the investment flows Q_{In}^t and the corresponding beginning of the year stocks Q_{Kn}^t and depreciation rates δ_n^t: all 16 assets satisfy equations (5) for years $t = 1970, \ldots, 2020$ and $n = 1, \ldots, 16$. The asset price indexes, P_{Kn}^t, are listed in Table A1 and the corresponding beginning of the year quantities are listed in Table A2 of the Appendix. The depreciation rates for all assets are reported in Table A3 of the Appendix.

In order to reduce the size of our data tables, we will work with a more aggregated model where there are only 5 types of capital: (i) *Aggregate Machinery and Equipment* (M&E as an aggregate of assets 1-4), with year t price, quantity and value indexes equal to P_{KM}^t, Q_{KM}^t and $V_{KM}^t \equiv P_{KM}^t Q_{KM}^t$; (ii) *Aggregate Structures* (an aggregate of assets 5-7) with year t price and quantity indexes equal to P_{KS}^t and Q_{KS}^t; (iii) *Aggregate Other Capital* (an aggregate of assets 8-11) with year t price and quantity indexes equal to P_{KO}^t and Q_{KO}^t; (iv) *Inventory Stocks* (equal to asset 12) which we label as P_{KI}^t, Q_{KI}^t and $V_{KI}^t \equiv P_{KI}^t Q_{KI}^t$ and (v) *Land Assets* (an aggregate of assets 13-16) with price and quantity indexes P_{KL}^t and Q_{KL}^t for $t = 1970, \ldots, 2021$. The aggregation is done using chained Törnqvist price indexes.[*16] Table A4 in the Appendix lists these aggregate beginning of the year capital stocks and their corresponding aggregate price indexes. The values of these five capital stock aggregates, $V_{KM}^t, V_{KS}^t, V_{KO}^t, V_{KI}^t, V_{KL}^t$, along with the total value of the total capital stock V_K^t, are listed in Table 1 below along with the shares of the five subaggregate capital stocks in the total value of the capital stock, $s_{KM}^t, s_{KS}^t, s_{KO}^t, s_{KI}^t, s_{KL}^t$ where $s_{KM}^t \equiv V_{KM}^t / V_K^t$. Note that V_K^t can be defined by summing the V_{Kn}^t or by summing the subaggregate values; i.e., we have the

[*15] In order to account for investment in inventories using Jorgensonian user cost theory, it turns out it is necessary to value inventory investment over the accounting period at end of the period prices for the inventory item; see Diewert and Smith (1994; 338)[19]. The same logic applies to land investments. Thus we use end of the period prices to value investment in assets 12-16.

[*16] The Törnqvist bilateral price index is defined as follows. Let $\boldsymbol{p}^t \equiv [p_1^t, \ldots, p_N^t]$ and $\boldsymbol{q}^t \equiv [q_1^t, \ldots, q_N^t]$ be the period t price and quantity vectors. Denote the inner product of the vectors $\boldsymbol{p}^t$ and $\boldsymbol{q}^t$ as $\boldsymbol{p}^t \cdot \boldsymbol{q}^t \equiv \boldsymbol{v}^t$ where $\boldsymbol{v}^t$ is the period t aggregate value. Define the period t shares as $s_n^t \equiv p_n^t q_n^t / \boldsymbol{p}^t \cdot \boldsymbol{q}^t$ for $n = 1, \ldots, N$. Denote the Törnqvist price index that links the prices of period $t-1$ to the prices of period t by $P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{q}^{t-1}, \boldsymbol{q}^t)$. The logarithm of $P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{q}^{t-1}, \boldsymbol{q}^t)$ is defined as $\sum_{n=1}^N (1/2)(s_n^{t-1} + s_n^t) \ln(p_n^t / p_n^{t-1})$. The sequence of aggregate chained price levels starting at period 1, P_T^t , $t = 1, 2, 3, \ldots$ is defined as follows: $P_T^1 \equiv 1; P_T^2 \equiv P_T(\boldsymbol{p}^1, \boldsymbol{p}^2, \boldsymbol{q}^1, \boldsymbol{q}^2); P_T^3 \equiv P_T(\boldsymbol{p}^1, \boldsymbol{p}^2, \boldsymbol{q}^1, \boldsymbol{q}^2) P_T(\boldsymbol{p}^2, \boldsymbol{p}^3, \boldsymbol{q}^2, \boldsymbol{q}^3)$; and so on. The corresponding sequence of aggregate quantity levels Q_T^t is defined by deflating the period t value by the period t price index; i.e., $Q_T^t \equiv \boldsymbol{v}^t / P_T^t$ for $t = 1, 2, 3, \ldots$. All prices must be positive and the value aggregate must also be positive for each period in order to calculate chained Törnqvist price indexes. Some quantities can be negative. When we are aggregating outputs and capital stocks, we will use chained Törnqvist price indexes. However, when aggregating capital services and labour services, we will use chained Törnqvist quantity indexes because it can happen that some user costs may be negative. The chained Törnqvist quantity indexes are defined in the same manner as their price counterparts but the role of prices and quantities is reversed. Thus price indexes in this case are defined by deflating values by the chained Törnqvist quantity indexes. In order to apply this second method of aggregation, we require that all quantities be positive and the value aggregates must also be positive in each period. For the relationship of the Törnqvist indexes to functional forms for unit cost functions and linearly homogeneous aggregator functions, see Diewert (1976)[12].

following equalities:

$$V_K^t \equiv \sum_{n=1}^{16} V_{Kn}^t$$
$$= V_{KM}^t + V_{KS}^t + V_{KO}^t + V_{KI}^t + V_{KL}^t; \qquad t = 1970, \ldots, 2020. \tag{8}$$

Table 1: Values of Capital Stock Components and their Shares in the Total Value of the Capital Stock

Year	V_K^t	V_{KM}^t	V_{KS}^t	V_{KO}^t	V_{KI}^t	V_{KL}^t	s_{KM}^t	s_{KS}^t	s_{KO}^t	s_{KI}^t	s_{KL}^t
1970	0.5811	0.0916	0.2084	0.0119	0.0482	0.2210	0.1577	0.3586	0.0206	0.0829	0.3802
1971	0.6405	0.1058	0.2299	0.0132	0.0570	0.2346	0.1652	0.3589	0.0206	0.0889	0.3664
1972	0.6935	0.1163	0.2541	0.0150	0.0623	0.2458	0.1677	0.3664	0.0216	0.0898	0.3545
1973	0.7616	0.1294	0.2899	0.0173	0.0672	0.2578	0.1699	0.3806	0.0227	0.0882	0.3386
1974	0.8182	0.1440	0.3146	0.0179	0.0718	0.2698	0.1760	0.3845	0.0219	0.0877	0.3298
1975	0.8751	0.1510	0.3491	0.0210	0.0725	0.2815	0.1725	0.3990	0.0240	0.0828	0.3217
1976	0.9407	0.1666	0.3904	0.0243	0.0695	0.2898	0.1771	0.4150	0.0258	0.0739	0.3081
1977	0.9951	0.1754	0.4281	0.0265	0.0680	0.2970	0.1763	0.4302	0.0267	0.0684	0.2984
1978	1.0777	0.1856	0.4767	0.0279	0.0751	0.3124	0.1722	0.4423	0.0259	0.0697	0.2899
1979	1.1962	0.2020	0.5349	0.0307	0.0879	0.3407	0.1689	0.4472	0.0257	0.0734	0.2849
1980	1.3624	0.2080	0.6329	0.0321	0.1097	0.3798	0.1526	0.4645	0.0236	0.0805	0.2787
1981	1.5181	0.2114	0.7205	0.0344	0.1245	0.4273	0.1392	0.4746	0.0226	0.0820	0.2815
1982	1.6773	0.2075	0.8214	0.0364	0.1331	0.4790	0.1237	0.4897	0.0217	0.0793	0.2856
1983	1.8692	0.2065	0.9503	0.0366	0.1354	0.5404	0.1105	0.5084	0.0196	0.0724	0.2891
1984	2.1208	0.2177	1.1026	0.0406	0.1460	0.6140	0.1026	0.5199	0.0191	0.0688	0.2895
1985	2.4850	0.2476	1.3109	0.0488	0.1833	0.6943	0.0996	0.5275	0.0197	0.0738	0.2794
1986	2.9662	0.3021	1.5786	0.0579	0.2393	0.7883	0.1019	0.5322	0.0195	0.0807	0.2658
1987	3.4690	0.3556	1.8512	0.0659	0.2935	0.9028	0.1025	0.5337	0.0190	0.0846	0.2602
1988	4.1991	0.4640	2.2819	0.0818	0.3294	1.0421	0.1105	0.5434	0.0195	0.0784	0.2482
1989	5.0083	0.5855	2.6744	0.0999	0.4389	1.2097	0.1169	0.5340	0.0199	0.0876	0.2415
1990	5.7975	0.6789	3.0685	0.1160	0.5356	1.3985	0.1171	0.5293	0.0200	0.0924	0.2412
1991	6.7332	0.7545	3.5719	0.1254	0.6255	1.6559	0.1121	0.5305	0.0186	0.0929	0.2459
1992	8.2049	0.8871	4.4395	0.1456	0.7685	1.9642	0.1081	0.5411	0.0177	0.0937	0.2394
1993	11.0068	1.1803	6.3405	0.1824	0.9004	2.4032	0.1072	0.5761	0.0166	0.0818	0.2183
1994	13.3627	1.5184	7.6665	0.2139	1.0767	2.8872	0.1136	0.5737	0.0160	0.0806	0.2161
1995	16.0219	1.8998	8.8370	0.2565	1.4594	3.5693	0.1186	0.5516	0.0160	0.0911	0.2228
1996	18.7998	2.1823	10.3345	0.2960	1.8589	4.1281	0.1161	0.5497	0.0157	0.0989	0.2196
1997	21.3787	2.4417	11.7779	0.3225	2.1593	4.6773	0.1142	0.5509	0.0151	0.1010	0.2188
1998	23.5750	2.7671	12.9809	0.3470	2.2884	5.1916	0.1174	0.5506	0.0147	0.0971	0.2202
1999	25.7377	3.0960	14.2614	0.3729	2.2773	5.7300	0.1203	0.5541	0.0145	0.0885	0.2226
2000	28.4059	3.4596	15.7967	0.4249	2.3477	6.3770	0.1218	0.5561	0.0150	0.0826	0.2245
2001	31.7472	3.9367	17.6007	0.5059	2.5534	7.1504	0.1240	0.5544	0.0159	0.0804	0.2252
2002	35.4737	4.4435	19.7301	0.5468	2.7402	8.0131	0.1253	0.5562	0.0154	0.0772	0.2259
2003	40.3150	5.0654	22.5940	0.6728	2.8941	9.0888	0.1256	0.5604	0.0167	0.0718	0.2254
2004	47.5991	6.0976	27.0001	0.8225	3.2649	10.4141	0.1281	0.5672	0.0173	0.0686	0.2188
2005	56.0656	7.3885	31.5243	0.9820	3.8471	12.3238	0.1318	0.5623	0.0175	0.0686	0.2198
2006	65.3301	9.1275	35.9450	1.1730	4.2169	14.8677	0.1397	0.5502	0.0180	0.0645	0.2276
2007	76.9758	11.0496	41.8271	1.3514	4.8221	17.9256	0.1435	0.5434	0.0176	0.0626	0.2329
2008	92.7340	13.5354	49.8832	1.5680	5.9512	21.7962	0.1460	0.5379	0.0169	0.0642	0.2350
2009	104.8100	16.0945	52.5625	1.8994	7.1838	27.0699	0.1536	0.5015	0.0181	0.0685	0.2583
2010	123.8356	19.8370	61.7046	2.5806	7.5964	32.1170	0.1602	0.4983	0.0208	0.0613	0.2594
2011	149.4490	24.6307	75.2075	3.3944	9.3564	36.8599	0.1648	0.5032	0.0227	0.0626	0.2466
2012	171.2955	28.3675	86.1293	4.0998	11.1808	41.5181	0.1656	0.5028	0.0239	0.0653	0.2424
2013	192.2676	32.7638	96.2340	5.0508	12.2151	46.0039	0.1704	0.5005	0.0263	0.0635	0.2393
2014	216.5690	36.6935	108.4165	6.0768	13.3266	52.0556	0.1694	0.5006	0.0281	0.0615	0.2404
2015	238.2260	39.7188	117.9857	7.0947	14.1375	59.2894	0.1667	0.4953	0.0298	0.0593	0.2489
2016	263.0101	42.0181	130.6605	8.4558	14.2524	67.6233	0.1598	0.4968	0.0322	0.0542	0.2571
2017	301.3895	45.5127	155.8307	9.5757	14.9636	75.5068	0.1510	0.5170	0.0318	0.0496	0.2505
2018	347.1331	49.9408	183.2807	10.7727	16.5813	86.5576	0.1439	0.5280	0.0310	0.0478	0.2493

2019	386.7307	54.2983	206.2558	11.8923	17.7243	96.5599	0.1404	0.5333	0.0308	0.0458	0.2497
2020	416.4968	57.7927	224.3879	13.1110	18.5481	102.6571	0.1388	0.5388	0.0315	0.0445	0.2465
2021	467.3031	61.1467	263.5800	14.5690	19.3840	108.6234	0.1309	0.5640	0.0312	0.0415	0.2324
Mean	77.6740	11.4380	40.8620	2.1104	4.3433	18.9200	0.1386	0.5055	0.0214	0.0746	0.2599

On average, the biggest share of the value of the Chinese capital stock is in Structures with an average share of 50.55%. The next highest share is Land with an average share of 25.99% followed by Inventory Stocks at 7.46%. However, in recent years, the share of inventories has fallen from a peak of 10.10% in 1997 to 4.15% in 2021. This very large drop reflects the growth of just in time delivery of inventories and more efficient management of inventories. The share of M&E has varied between a high of 17.71% in 1976 to a low of 9.96% in 1985 and finished at 13.09% in 2021. The above Table indicates that it is important to include land in the list of productive assets used in production. Figure 1 plots the five shares over time. The share of structures is clearly the dominant share.

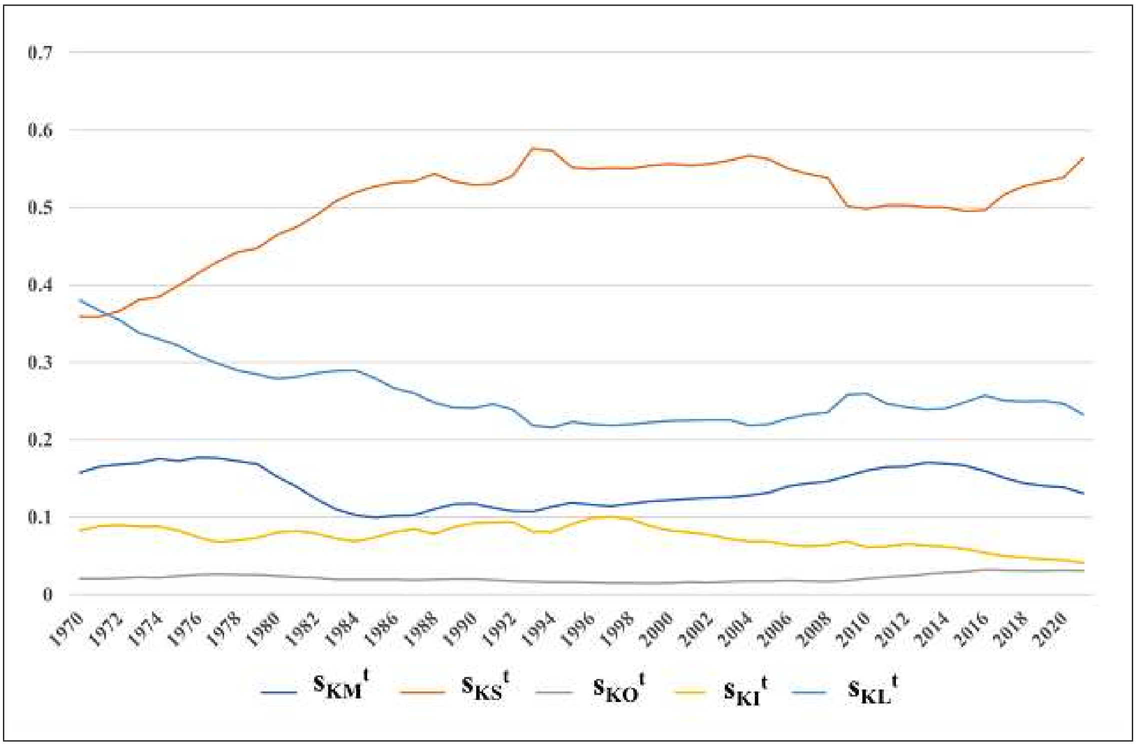

Figure 1 Asset Shares for Five Asset Classes

We use Törrnqvist price aggregation to form price and quantity indexes for the capital stock. Denote these indexes by P_K^t and Q_K^t with $V_K^t = P_K^t Q_K^t$. Use Törrnqvist price aggregation to form price and quantity indexes, P_I^t and Q_I^t, for all 16 investments with the aggregate value of investment defined as $V_I^t = P_I^t Q_I^t$. Finally, use Törrnqvist price aggregation to aggregate over consumption Q_C^t, government Q_G^t, comprehensive aggregate investment Q_I^t, exports Q_X^t and imports $-Q_M^t$ to form price and quantity indexes for GDP at producer prices, P_Y^t and Q_Y^t, with the value of gross output $V_Y^t = P_Y^t Q_Y^t$. Using these estimates for gross output and for the capital stock, we can calculate real and nominal capital output ratios for China for year t, KY^t and VKY^t, defined as follows:

$$KY^t \equiv Q_K^t/Q_Y^t; VKY^t \equiv V_K^t/V_Y^t; \qquad t = 1970, \ldots, 2020. \tag{9}$$

The price and quantity indexes for gross output, labour and the capital stock (and the corresponding values in trillions of current yuan) are listed in Table 2 below along with the real and nominal capital output ratios defined by (9).

Table 2: Output and Labour Aggregates, Capital Stock Aggregates and Capital Output Ratios

Year	P_Y^t	P_I^t	P_L^t	P_K^t	Q_Y^t	Q_I^t	Q_L^t	Q_K^t	V_Y^t	V_I^t	V_L^t	KY^t	VKY^t
1970	1.000	1.000	1.000	1.000	0.236	0.066	0.147	0.581	0.236	0.066	0.147	2.462	2.462
1971	1.024	1.006	1.010	1.027	0.246	0.067	0.155	0.624	0.251	0.068	0.156	2.540	2.548
1972	1.041	1.001	1.062	1.043	0.257	0.070	0.158	0.665	0.268	0.070	0.168	2.586	2.591
1973	1.071	1.028	1.069	1.080	0.265	0.072	0.164	0.705	0.283	0.074	0.175	2.666	2.687
1974	1.092	1.037	1.072	1.098	0.270	0.076	0.170	0.745	0.295	0.079	0.182	2.762	2.779
1975	1.113	1.039	1.084	1.113	0.285	0.086	0.176	0.786	0.317	0.089	0.191	2.763	2.763
1976	1.125	1.049	1.092	1.129	0.286	0.085	0.182	0.833	0.322	0.089	0.198	2.912	2.922
1977	1.154	1.057	1.111	1.143	0.308	0.097	0.187	0.871	0.355	0.103	0.208	2.828	2.802
1978	1.193	1.073	1.185	1.168	0.331	0.112	0.193	0.923	0.395	0.120	0.229	2.786	2.728
1979	1.257	1.102	1.280	1.215	0.353	0.121	0.200	0.985	0.444	0.133	0.255	2.790	2.697
1980	1.323	1.152	1.429	1.296	0.374	0.124	0.208	1.051	0.495	0.143	0.297	2.809	2.752
1981	1.365	1.178	1.446	1.359	0.386	0.120	0.216	1.117	0.526	0.141	0.313	2.896	2.884
1982	1.409	1.208	1.479	1.428	0.412	0.129	0.226	1.175	0.580	0.155	0.334	2.854	2.892
1983	1.454	1.245	1.521	1.509	0.450	0.145	0.232	1.239	0.654	0.181	0.353	2.754	2.859
1984	1.524	1.304	1.741	1.616	0.519	0.191	0.246	1.313	0.792	0.249	0.428	2.528	2.679
1985	1.673	1.395	2.010	1.753	0.562	0.232	0.260	1.418	0.941	0.323	0.523	2.522	2.642
1986	1.772	1.501	2.284	1.919	0.604	0.240	0.272	1.546	1.071	0.360	0.621	2.558	2.770
1987	1.886	1.578	2.485	2.078	0.653	0.248	0.283	1.670	1.231	0.392	0.704	2.558	2.818
1988	2.051	1.771	2.912	2.341	0.746	0.303	0.295	1.794	1.529	0.537	0.858	2.406	2.746
1989	2.260	1.899	3.179	2.573	0.741	0.273	0.300	1.947	1.674	0.519	0.955	2.629	2.993
1990	2.481	2.045	3.464	2.805	0.749	0.251	0.307	2.067	1.858	0.514	1.064	2.761	3.121
1991	2.689	2.205	3.781	3.111	0.834	0.315	0.315	2.165	2.241	0.695	1.193	2.597	3.005
1992	2.915	2.494	4.283	3.577	0.918	0.373	0.327	2.294	2.676	0.931	1.399	2.499	3.066
1993	3.408	3.118	5.207	4.470	1.020	0.450	0.341	2.463	3.476	1.403	1.776	2.415	3.167
1994	3.924	3.431	6.920	5.008	1.165	0.524	0.347	2.668	4.570	1.799	2.402	2.291	2.924
1995	4.537	3.624	8.154	5.524	1.282	0.607	0.357	2.901	5.818	2.200	2.907	2.262	2.754
1996	4.947	3.758	9.048	5.933	1.392	0.666	0.370	3.169	6.885	2.503	3.350	2.276	2.730
1997	5.076	3.808	9.677	6.209	1.508	0.688	0.380	3.443	7.654	2.621	3.673	2.284	2.793
1998	5.074	3.779	9.995	6.336	1.642	0.768	0.384	3.721	8.331	2.904	3.837	2.266	2.830
1999	5.048	3.744	10.419	6.426	1.768	0.822	0.395	4.005	8.926	3.077	4.112	2.265	2.884
2000	5.159	3.743	10.752	6.588	1.940	0.920	0.412	4.312	10.006	3.443	4.432	2.223	2.839
2001	5.289	3.772	11.369	6.823	2.062	1.035	0.426	4.653	10.907	3.905	4.843	2.256	2.911
2002	5.243	3.787	11.959	7.062	2.263	1.195	0.435	5.023	11.867	4.525	5.198	2.219	2.989
2003	5.345	3.860	13.325	7.408	2.483	1.459	0.450	5.442	13.270	5.630	5.995	2.192	3.038
2004	5.667	4.067	15.076	8.003	2.689	1.671	0.464	5.947	15.241	6.795	6.989	2.212	3.123
2005	5.939	4.212	16.587	8.606	2.967	1.845	0.494	6.515	17.624	7.771	8.198	2.195	3.181
2006	6.327	4.342	19.297	9.198	3.313	2.107	0.495	7.102	20.957	9.148	9.545	2.144	3.117
2007	6.702	4.512	23.473	9.935	3.780	2.498	0.485	7.748	25.330	11.269	11.388	2.050	3.039
2008	7.079	4.766	27.709	10.912	4.275	3.035	0.481	8.499	30.263	14.463	13.333	1.988	3.064
2009	7.092	4.682	30.771	11.177	4.722	3.678	0.489	9.377	33.484	17.220	15.044	1.986	3.130
2010	7.419	4.858	32.584	11.826	5.245	4.176	0.536	10.472	38.912	20.284	17.476	1.997	3.183
2011	8.005	5.158	37.848	12.812	5.638	4.524	0.554	11.665	45.132	23.333	20.964	2.069	3.311
2012	8.221	5.194	43.034	13.278	6.041	4.863	0.564	12.901	49.667	25.261	24.262	2.136	3.449
2013	8.387	5.192	47.859	13.585	6.549	5.430	0.576	14.154	54.928	28.191	27.542	2.161	3.500
2014	8.545	5.197	52.664	13.975	6.887	5.646	0.571	15.497	58.844	29.341	30.069	2.250	3.680
2015	8.761	5.091	58.596	14.186	7.317	5.995	0.556	16.793	64.101	30.519	32.566	2.295	3.716

2016	8.965	5.076	61.386	14.540	7.763	6.410	0.557	18.089	69.589	32.537	34.159	2.330	3.780
2017	9.379	5.336	66.109	15.521	8.615	7.452	0.548	19.419	80.793	39.768	36.244	2.254	3.730
2018	9.789	5.595	71.559	16.514	9.047	7.818	0.544	21.021	88.559	43.743	38.958	2.324	3.920
2019	10.176	5.703	78.310	17.072	9.146	7.535	0.533	22.652	93.065	42.972	41.717	2.477	4.156
2020	10.470	5.687	83.210	17.301	9.275	7.750	0.532	24.074	97.109	44.079	44.287	2.596	4.289

The GDP deflator P_Y^t grew 10.5 fold over the sample period. The investment price index P_I^t and the labour price index P_L^t grew 5.7 fold and 83.2 fold respectively over the 5 decades. Thus, real wages increased enormously over the sample period.

The nominal and real capital output ratios started out at the fairly low level of 2.5. The real capital output ratio barely increased over the sample period to end up at 2.6 while the nominal capital output ratio ended up at 4.3. Thus, it took on average a stock of 4.3 yuan in 2020 to produce 1 yuan of output. The lower is the nominal capital output ratio, the more internationally competitive the economy is. For many advanced countries, the nominal capital output ratio [*17] in 2020 is likely to be in the 6 to 8 range so the Chinese economy in 2020 is very competitive.

We are now in a position where we can calculate an approximation to the aggregate cost of capital in year t, r^t. Once we have an estimate for r^t, the Jorgensonian user costs U_n^t defined by (4) can be calculated using the Chinese data on the beginning of the year capital stocks P_{Kn}^t, on depreciation rates δ_n^t, on ex post asset inflation rates i_n^t and on specific property taxes on assets τ_n^t for $n = 1, \ldots, 16$. Consider the following equation for the year t data which sets the value of gross output V_Y^t equal to the sum of labour earnings V_L^t plus the sum of User costs U_n^t times the corresponding beginning of the year capital stocks Q_{Kn}^t:

$$V_Y^t = V_L^t + \textstyle\sum_{n=1}^{16} [r^{t^*} + \tau_n^t - i_n^t + \delta_n^t(1 + i_n^t)] P_{Kn}^t Q_{Kn}^t; \qquad t = 1970, \ldots, 2020. \tag{10}$$

All of the variables in equation (10) for year t are known except for the national average cost of capital, r^{t^*}. Since the equation is linear in r^{t^*}, it can be solved for r^{t^*} for each year t. Once r^{t^*} is known, the user costs defined by (4), U_n^t for $n = 1, \ldots, 16$, can be calculated for each year t.

The resulting ex post rates of return on Chinese assets, r^{t^*} for $t = 1970, \ldots, 2020$ are listed in Table 3 below. The sample average of these rates of return was 17.25% per year. This is a gigantic average rate of return on assets! However, these rates of return are quite volatile and as a result, the user costs defined by (4) turn out to be very volatile as well and, in particular, these fluctuations in r^{t^*} led to many negative user costs for assets 12-16. There was one negative user cost for inventory services, one for agricultural land services, 15 for industrial land services, 15 for commercial land services and 9 for residential land services. This is not very satisfactory.[*18] We would like user costs to approximate the corresponding rental prices

[*17] Note that our capital aggregate includes the value of land. From Table A4 in the Appendix, the price of the 5 types of aggregate capital in 2020 showed that the price increases over the sample period were 2.1 fold for M&E, 10.5 fold for structures, 3.9 fold for Other types of capital (Cultivated assets, Research and development, Computer software and Other intangible assets), 5.2 fold for Inventories and 308.7 fold for Land assets. Thus, including Land in the capital aggregate will tend to *increase* the nominal capital output ratio for a country. Since quality-adjusted land tends to grow more slowly than output and produced assets over time, the inclusion of land in the aggregate capital stock will tend to *decrease* the real capital output ratio relative to the nominal capital output ratio over time.

[*18] The aggregate user cost of capital turned out to be positive for each year. Thus the negative user cost problem tends to show up only when working with more disaggregated data. This "fact" may explain why the negative user cost of capital problem is rarely discussed in the aggregate productivity literature.

for the various assets (but of course, these rental prices are not available to us) and rental prices are rarely negative.

The volatility in the ex post rates of return is largely caused by the volatility in ex post asset inflation rates i_n^t defined by equations (2) above. Equation (10) is the "right" equation to determine year to year ex post aggregate rates of return on assets but it is not the "right" equation to determine longer run rental prices for assets. In what follows, we will smooth the ex post rates of return in an attempt to find ex ante rates of return which are more suitable to insert into a user cost formula that is supposed to approximate a market rent for the use of asset. Owners of assets that rent the services of these assets to firms use the logic of user costs to form estimates for appropriate rental rates. However, the owners cannot forecast exactly what the ex post inflation rate on the asset will be. Thus, their forecasts for asset inflation rates will probably be extrapolations of past asset inflation rates. We will simply smooth actual ex post asset inflation rates to approximate these forecasts. We use the nonparametric Lowess smoothing method in Shazam (with smoothing parameter Smooth set equal to 0.4) for all 16 assets. The resulting smoothed annual asset inflation rates i_n^t are listed in Table A7 in the Appendix.

Now use the smoothed inflation rates i_n^t in equations (10) in order to determine the smoothed rates for return r^t as solutions to equations (10). The resulting smoothed balancing rates of return r^t are listed in Table 3 below. The average rate of return using the smoothed r^t turned out to be 17.22% per year which is slightly below than the average ex post rate of return which was 17.25%. We used the smoothed r^t and the smoothed i_n^t in equations (4) to define new smoothed user costs, U_n^t for $n = 1, \ldots, 16$. These smoothed user costs are listed in Table A8 in the Appendix. The use of smoothed asset inflation rates and smoothed rates of return did not eliminate negative user costs: there were 11 negative user costs for industrial land and 9 negative user costs for commercial land. A negative user cost is unlikely to approximate a real world rental price for the use of a land asset. However, our method for forming expected asset inflation rates is subject to a considerable amount of error and our highly aggregated estimated cost of capital may not be close to the actual cost of financial capital in particular industries. Moreover, markets for land assets are often not very liquid and hence, the actual user cost of a land asset may well be negative. For very liquid assets, a negative user cost should induce investors to quickly bid up the price of the asset to eliminate the negative user cost. However, the transactions costs of purchasing land can often be large and the lack of sellers of land can cause negative user costs. Thus, we left the negative user costs in our data base.

We use the data on the smoothed user costs, $U_1^t, \ldots, U_{16}^t$, along with the data on the beginning of the year asset stocks, $Q_{K1}^t, \ldots, Q_{K16}^t$, to form *five capital services aggregates* for our five types of aggregate capital. Denote the prices and quantities for these aggregate capital services by $P_{UM}^t, P_{US}^t, P_{UO}^t, P_{UI}^t, P_{UL}^t$ and $Q_{UM}^t, Q_{US}^t, Q_{UO}^t, Q_{UI}^t, Q_{UL}^t$. These aggregate user costs are listed in Table 3 below (with prices normalized to equal 1 in 1970) and the corresponding capital services aggregates are listed in Table 4 below.*19 The year t price and quantity of

In the industry level measurement, this problem has been considered more explicitly. For example, Jorgenson and Nomura (2005)[45] eliminated the occurrence of negative user costs during the Japanese bubble economy with considerable land price appreciation by accounting for differences in risk premiums across assets in the user cost of capital formula.

*19 These capital services input subaggregates were formed using Törnqvist direct aggregation of input quantities; i.e., bilateral chained quantity indexes were formed first (quantities were always positive) and then the corresponding aggregate price indexes were calculated by deflating total value by the quantity index.

aggregate capital services, P_U^t and Q_U^t, were formed by aggregating $P_{UM}^t, P_{US}^t, P_{UO}^t, P_{UI}^t, P_{UL}^t$ and $Q_{UM}^t, Q_{US}^t, Q_{UO}^t, Q_{UI}^t, Q_{UL}^t$.[*20] Finally, the year t price and quantity of *aggregate input*, P_Z^t and Q_Z^t, were calculated by aggregating the five capital services subaggregates with aggregate labour, P_L^t and Q_L^t. These aggregate input prices are listed in Table 3 and the corresponding aggregate input quantities are listed in Table 4.[*21]

Table 3: Ex Post and Smoothed Rates of Return and Aggregate Output and Input Price Indexes

Year	r^t	r^{t^*}	P_Y^t	P_Z^t	P_L^t	P_U^t	P_{UM}^t	P_{US}^t	P_{UO}^t	P_{UI}^t	P_{UL}^t
1970	0.1244	0.1412	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1971	0.1230	0.1256	1.0235	0.9990	1.0102	0.9808	0.9768	0.9854	0.9845	0.9694	0.9813
1972	0.1212	0.1380	1.0408	1.0175	1.0622	0.9472	0.9381	0.9585	0.9877	0.9380	0.9359
1973	0.1222	0.1181	1.0713	1.0257	1.0689	0.9578	0.9516	0.9818	1.0554	0.9219	0.9160
1974	0.1210	0.1102	1.0917	1.0170	1.0721	0.9320	0.9542	0.9491	1.0258	0.8886	0.8606
1975	0.1303	0.1157	1.1131	1.0417	1.0839	0.9744	0.9620	0.9968	1.1615	0.9381	0.9300
1976	0.1143	0.0941	1.1250	1.0082	1.0916	0.8863	0.9241	0.9452	1.1785	0.7846	0.6511
1977	0.1411	0.1266	1.1535	1.0704	1.1112	1.0023	0.9697	1.0445	1.3448	0.9750	0.9261
1978	0.1512	0.1506	1.1927	1.1375	1.1848	1.0600	1.0157	1.1035	1.4243	1.0261	1.0067
1979	0.1590	0.1809	1.2566	1.2137	1.2804	1.1117	1.0427	1.1577	1.5251	1.0818	1.0973
1980	0.1548	0.1527	1.3234	1.2844	1.4287	1.0908	1.0102	1.1616	1.4800	1.0783	1.0151
1981	0.1574	0.1503	1.3645	1.2992	1.4461	1.1020	1.0075	1.1795	1.4896	1.0893	1.0380
1982	0.1736	0.1658	1.4087	1.3677	1.4794	1.2080	1.0532	1.2794	1.5911	1.2150	1.3263
1983	0.1968	0.1943	1.4536	1.4794	1.5211	1.3931	1.0998	1.4874	1.6307	1.3924	1.8388
1984	0.2156	0.2187	1.5242	1.6847	1.7414	1.5765	1.1748	1.6740	1.7450	1.5519	2.3616
1985	0.2184	0.2230	1.6730	1.8607	2.0099	1.6507	1.2195	1.7549	1.8710	1.5955	2.4938
1986	0.2070	0.1943	1.7716	1.9720	2.2837	1.5962	1.2056	1.7239	1.8838	1.5449	2.1281
1987	0.2156	0.2361	1.8860	2.1243	2.4851	1.6961	1.2240	1.8322	1.9223	1.6979	2.4474
1988	0.2251	0.2152	2.0510	2.4765	2.9118	1.9643	1.3708	2.1502	2.1668	1.8423	3.0035
1989	0.2108	0.1896	2.2601	2.5641	3.1789	1.8980	1.3711	2.0843	2.2586	1.8258	2.4530
1990	0.2052	0.2022	2.4813	2.7288	3.4638	1.9574	1.4595	2.1560	2.4508	1.7847	2.2816
1991	0.2203	0.2579	2.6885	3.1671	3.7810	2.4504	1.6867	2.7489	2.6692	2.1405	3.6638
1992	0.2191	0.3560	2.9153	3.5974	4.2833	2.7915	1.8747	3.1876	2.8865	2.2542	4.3835
1993	0.2075	0.2291	3.4081	4.3782	5.2065	3.4020	2.2158	4.1309	3.3035	2.2612	4.4843
1994	0.2064	0.2193	3.9235	5.4203	6.9204	3.9018	2.4189	4.7566	3.6025	2.6442	5.9401
1995	0.2217	0.2122	4.5368	6.4580	8.1537	4.7036	2.6705	5.5693	4.0483	3.8361	10.1554
1996	0.2189	0.1892	4.9465	7.1058	9.0476	5.1330	2.7434	6.1266	4.2361	4.4212	11.8519
1997	0.2152	0.1660	5.0762	7.4107	9.6767	5.2286	2.6973	6.2338	4.1545	4.6410	13.1669
1998	0.2085	0.1592	5.0736	7.6191	9.9946	5.3538	2.7098	6.4975	3.8990	4.5540	13.5019
1999	0.2041	0.1701	5.0482	7.6669	10.4190	5.2273	2.5862	6.3653	3.7616	4.3608	14.1380
2000	0.2107	0.1905	5.1585	8.0085	10.7517	5.5151	2.5970	6.7112	3.8767	4.5685	17.7392
2001	0.2020	0.1838	5.2887	8.1481	11.3688	5.4416	2.5370	6.6303	3.9559	4.5513	17.4219
2002	0.1982	0.1933	5.2431	8.3077	11.9592	5.4131	2.4620	6.6380	3.7562	4.5526	18.1664
2003	0.1892	0.2133	5.3451	8.6210	13.3252	5.3059	2.3585	6.6231	3.7774	4.3315	16.6823
2004	0.1831	0.2023	5.6673	9.1489	15.0759	5.3376	2.2913	6.8047	3.8799	4.2710	15.7171
2005	0.1779	0.1893	5.9393	9.6169	16.5872	5.3951	2.2520	6.9649	3.9268	4.4366	15.2419
2006	0.1847	0.2065	6.3268	10.7226	19.2973	5.8013	2.3026	7.5170	4.0829	4.7716	21.9823
2007	0.1904	0.2305	6.7019	12.2684	23.4732	6.3101	2.3325	8.3020	4.1182	5.1207	31.6168
2008	0.1869	0.1570	7.0790	13.7571	27.7086	6.7902	2.3522	9.1692	4.1180	5.3860	38.6258
2009	0.1833	0.1844	7.0918	14.1206	30.7707	6.5434	2.2577	8.5524	3.9784	5.7642	45.7868
2010	0.1755	0.2032	7.4191	14.5616	32.5842	6.6034	2.2221	8.7583	4.0386	5.3298	49.4213
2011	0.1593	0.1466	8.0047	15.4175	37.8483	6.4673	2.1209	8.8098	3.9922	5.2629	42.9908
2012	0.1422	0.1190	8.2214	15.7239	43.0344	5.9743	1.9984	8.0614	3.7698	5.0142	36.2282

[*20] The year t capital services aggregate price and quantity, P_U^t and Q_U^t, were calculated using Törnqvist direct aggregation of input quantities as were the overall input aggregates, P_Z^t and Q_Z^t.

[*21] We are using two stage aggregation to form our input aggregates. We also used single stage aggregation of the original 16 capital services. The differences between the single stage and two stage aggregates were insignificant.

2013	0.1325	0.1174	8.3871	16.1533	47.8587	5.6783	1.9046	7.5871	3.6320	4.7100	37.6386
2014	0.1211	0.0955	8.5445	16.3952	52.6639	5.3052	1.8039	6.9900	3.4680	4.3354	36.4576
2015	0.1201	0.1044	8.7607	17.2081	58.5960	5.2407	1.7676	6.7133	3.3918	4.3414	51.8734
2016	0.1215	0.1468	8.9645	17.8474	61.3858	5.3812	1.7726	6.7408	3.4489	4.2976	75.7916
2017	0.1339	0.1573	9.3787	19.9407	66.1091	6.2112	1.8675	7.9000	3.5666	4.8219	128.8187
2018	0.1288	0.1246	9.7890	20.8999	71.5585	6.3444	1.8518	8.1007	3.5618	4.9602	143.1607
2019	0.1180	0.0955	10.1757	21.1790	78.3096	6.0462	1.7776	7.5974	3.4429	4.7795	142.4376
2020	0.1113	0.1342	10.4697	21.2395	83.2100	5.7807	1.7143	7.0473	3.3457	4.6434	150.9980
Mean	0.1722	0.1725	4.4282	7.5193	17.9580	3.6875	1.7466	4.5577	2.8209	3.0883	24.4660

As was noted earlier, the average of the ex post rates of return on assets (the average of the r^{t^*}) was 17.25% and the average of the smoothed rates of return (the average of the r^t) was 17.22%. There is a downward trend in the smoothed rates of return from 22.17% in 1995 to 11.13% in 2020. The GDP deflator, P_Y^t, increased 10.47 fold over the sample period while the aggregate input price index, P_Z^t, increased 21.24 fold and the quality-adjusted price index for labour, P_L^t, increased 83.21 fold. The aggregate price index for capital services P_U^t increased only 5.78 fold over the sample period. The price increases for our 5 main components of capital services increased 1.71 fold (M&E), 7.05 fold (Structures), 3.35 fold (Other capital services), 4.64 fold (Inventory services) and 151.00 fold (Land services).

Note that the aggregate land user cost is always positive; i.e., when we aggregate over the 4 types of land services, the negative user costs are outweighed by positive user costs so that aggregate land services are always positive for China. The quantity or volume indexes that match up with the above price indexes are listed below in the following section in Table 4.

The rate of return on all assets used in production is an important statistic that measures the efficiency of an economy. Another important indicator of efficiency is the level of TFP for the economy. In the following section, we use the data developed in this section to measure the Gross Output TFP for the Chinese economy.

3 TFP Estimates for China using Gross Output

Following Jorgenson and Griliches (1967)[43], year t *Gross Output TFP* for the Chinese economy, TFP^t, is defined as the output quantity index Q_Y^t divided by the input quantity index Q_Z^t:

$$TFP^t \equiv Q_Y^t / Q_Z^t; \qquad t = 1970, \ldots, 2020. \tag{11}$$

Year t *TFP Growth* (relative to year $t-1$), TFP_G^t, is defined as follows:

$$TFP_G^t \equiv TFP^t / TFP^{t-1}; \qquad t = 1971, \ldots, 2020. \tag{12}$$

Gross output TFP and the TFP growth for China are listed in Tables 4 and 5 below respectively.

Table 4: Gross Output TFP Levels and GDP Quantity Indexes for China

Year t	TFP^t	Q_Y^t	Q_Z^t	Q_L^t	Q_U^t	Q_{UM}^t	Q_{US}^t	Q_{UO}^t	Q_{UI}^t	Q_{UL}^t
1970	1.0000	0.2360	0.2360	0.1474	0.0886	0.0246	0.0328	0.0034	0.0062	0.0215
1971	0.9761	0.2456	0.2516	0.1548	0.0969	0.0286	0.0356	0.0038	0.0073	0.0216
1972	0.9776	0.2571	0.2630	0.1583	0.1050	0.0321	0.0391	0.0042	0.0079	0.0216
1973	0.9574	0.2646	0.2763	0.1640	0.1129	0.0351	0.0429	0.0046	0.0086	0.0217
1974	0.9316	0.2697	0.2895	0.1696	0.1209	0.0385	0.0465	0.0049	0.0091	0.0217
1975	0.9359	0.2845	0.3040	0.1760	0.1292	0.0416	0.0510	0.0053	0.0092	0.0218

1975	0.9359	0.2845	0.3040	0.1760	0.1292	0.0416	0.0510	0.0053	0.0092	0.0218
1976	0.8962	0.2862	0.3193	0.1816	0.1396	0.0461	0.0564	0.0057	0.0088	0.0219
1977	0.9280	0.3079	0.3318	0.1867	0.1474	0.0488	0.0611	0.0059	0.0086	0.0220
1978	0.9536	0.3312	0.3473	0.1929	0.1571	0.0511	0.0670	0.0061	0.0095	0.0221
1979	0.9659	0.3530	0.3655	0.1995	0.1693	0.0549	0.0734	0.0064	0.0109	0.0221
1980	0.9705	0.3741	0.3855	0.2080	0.1814	0.0565	0.0813	0.0068	0.0127	0.0222
1981	0.9521	0.3857	0.4051	0.2164	0.1936	0.0573	0.0904	0.0072	0.0139	0.0223
1982	0.9709	0.4117	0.4241	0.2257	0.2037	0.0560	0.1001	0.0075	0.0144	0.0223
1983	1.0178	0.4498	0.4419	0.2319	0.2161	0.0569	0.1102	0.0079	0.0145	0.0224
1984	1.1053	0.5194	0.4699	0.2456	0.2308	0.0593	0.1207	0.0086	0.0154	0.0225
1985	1.1122	0.5622	0.5055	0.2604	0.2528	0.0655	0.1328	0.0097	0.0187	0.0227
1986	1.1131	0.6044	0.5430	0.2719	0.2819	0.0773	0.1466	0.0109	0.0227	0.0228
1987	1.1264	0.6526	0.5794	0.2831	0.3108	0.0899	0.1604	0.0123	0.0258	0.0229
1988	1.2075	0.7456	0.6175	0.2947	0.3417	0.1067	0.1750	0.0138	0.0271	0.0229
1989	1.1345	0.7405	0.6527	0.3003	0.3787	0.1248	0.1915	0.0154	0.0315	0.0230
1990	1.0998	0.7486	0.6807	0.3070	0.4056	0.1323	0.2055	0.0163	0.0366	0.0231
1991	1.1780	0.8335	0.7075	0.3154	0.4278	0.1378	0.2179	0.0173	0.0401	0.0232
1992	1.2340	0.9180	0.7439	0.3267	0.4574	0.1468	0.2316	0.0187	0.0476	0.0233
1993	1.2846	1.0198	0.7938	0.3411	0.4996	0.1665	0.2513	0.0204	0.0533	0.0234
1994	1.3815	1.1646	0.8430	0.3471	0.5556	0.2013	0.2754	0.0226	0.0569	0.0235
1995	1.4235	1.2823	0.9008	0.3565	0.6189	0.2412	0.3031	0.0255	0.0615	0.0236
1996	1.4365	1.3920	0.9690	0.3703	0.6887	0.2769	0.3377	0.0286	0.0690	0.0237
1997	1.4599	1.5079	1.0329	0.3796	0.7614	0.3144	0.3740	0.0319	0.0768	0.0238
1998	1.5017	1.6421	1.0935	0.3839	0.8395	0.3626	0.4118	0.0365	0.0817	0.0238
1999	1.5187	1.7681	1.1642	0.3947	0.9209	0.4161	0.4518	0.0407	0.0850	0.0239
2000	1.5525	1.9396	1.2494	0.4122	1.0106	0.4757	0.4955	0.0461	0.0896	0.0239
2001	1.5407	2.0623	1.3386	0.4260	1.1144	0.5500	0.5438	0.0527	0.0958	0.0240
2002	1.5845	2.2633	1.4284	0.4346	1.2320	0.6403	0.5968	0.0604	0.1027	0.0240
2003	1.6129	2.4826	1.5393	0.4499	1.3711	0.7597	0.6548	0.0717	0.1085	0.0243
2004	1.6143	2.6892	1.6658	0.4636	1.5459	0.9263	0.7222	0.0835	0.1181	0.0245
2005	1.6192	2.9674	1.8326	0.4942	1.7472	1.1253	0.7995	0.0973	0.1271	0.0248
2006	1.6948	3.3125	1.9545	0.4946	1.9673	1.3762	0.8765	0.1139	0.1338	0.0251
2007	1.8306	3.7796	2.0647	0.4851	2.2096	1.6617	0.9584	0.1336	0.1479	0.0254
2008	1.9434	4.2751	2.1998	0.4812	2.4934	2.0059	1.0514	0.1593	0.1717	0.0257
2009	1.9911	4.7215	2.3713	0.4889	2.8181	2.4150	1.1503	0.2017	0.1931	0.0270
2010	1.9627	5.2448	2.6722	0.5363	3.2462	2.9441	1.2880	0.2639	0.2149	0.0284
2011	1.9261	5.6382	2.9273	0.5539	3.7369	3.5791	1.4375	0.3377	0.2460	0.0295
2012	1.9126	6.0412	3.1587	0.5638	4.2524	4.1329	1.6204	0.4237	0.2761	0.0304
2013	1.9260	6.5491	3.4004	0.5755	4.8229	4.8081	1.8055	0.5345	0.3033	0.0308
2014	1.9188	6.8867	3.5891	0.5710	5.4240	5.4100	2.0227	0.6614	0.3333	0.0312
2015	1.9642	7.3169	3.7250	0.5558	6.0173	5.9133	2.2624	0.7968	0.3599	0.0314
2016	1.9909	7.7628	3.8991	0.5565	6.5841	6.2926	2.5203	0.9395	0.3813	0.0318
2017	2.1262	8.6146	4.0517	0.5482	7.1724	6.7766	2.7827	1.0730	0.4046	0.0321
2018	2.1350	9.0468	4.2373	0.5444	7.8181	7.3538	3.0516	1.2083	0.4279	0.0338
2019	2.0813	9.1458	4.3942	0.5327	8.4926	7.9637	3.3382	1.3611	0.4441	0.0353
2020	2.0287	9.2753	4.5721	0.5322	9.1376	8.5011	3.6390	1.5361	0.4605	0.0353

From the above Table, it can be seen that gross output TFP growth in China was largely negative for the 1970s. The initial level of TFP in 1970 was not attained until 1983. From the 1983 level of productivity equal to 1.0178, the TFP level grew to 2.1350 in 2018 before falling to 2.0287 in 2020 partly due to the adverse effects of Covid.

In Table 5 below, we list the annual GDP productivity growth rates defined by (12) above. We also list the aggregate value of GDP, V_Y^t (which is equal to the aggregate value of input V_Z^t by construction) and the other macroeconomic input aggregates for labour and the 5 types of capital services, $V_L^t, V_{UM}^t, V_{US}^t, V_{UO}^t, V_{UI}^t$ and V_{UL}^t.

Define the input shares in year t GDP for labour and the 5 types of capital services for

$t = 1970, \ldots, 2020$ as follows:

$$s_L^t \equiv V_L^t / V_Y^t;$$
$$s_{UM}^t \equiv V_{UM}^t / V_Y^t; s_{US}^t \equiv V_{US}^t / V_Y^t; s_{UO}^t \equiv V_{UO}^t / V_Y^t; s_{UI}^t \equiv V_{UI}^t / V_Y^t; s_{UL}^t \equiv V_{UL}^t / V_Y^t. \quad (13)$$

These input shares of GDP are also listed in Table 5.

Table 5: TFP Growth, Output and Input Aggregates and Input Shares of Gross Output

Year t	TFP_G^t	V_Y^t	V_L^t	V_U^t	s_L^t	s_{UM}^t	s_{US}^t	s_{UO}^t	s_{UI}^t	s_{UL}^t
1970		0.2360	0.1474	0.0886	0.6247	0.1043	0.1390	0.0146	0.0264	0.0911
1971	0.9761	0.2513	0.1563	0.0950	0.6220	0.1110	0.1396	0.0149	0.0282	0.0841
1972	1.0016	0.2676	0.1682	0.0994	0.6284	0.1125	0.1401	0.0156	0.0279	0.0756
1973	0.9793	0.2834	0.1753	0.1081	0.6186	0.1180	0.1485	0.0171	0.0278	0.0700
1974	0.9730	0.2945	0.1818	0.1126	0.6175	0.1246	0.1498	0.0170	0.0275	0.0636
1975	1.0046	0.3167	0.1908	0.1259	0.6024	0.1263	0.1606	0.0193	0.0272	0.0641
1976	0.9576	0.3219	0.1982	0.1237	0.6156	0.1323	0.1654	0.0208	0.0216	0.0443
1977	1.0355	0.3552	0.2075	0.1477	0.5841	0.1331	0.1796	0.0223	0.0236	0.0573
1978	1.0276	0.3951	0.2285	0.1665	0.5785	0.1314	0.1872	0.0219	0.0248	0.0562
1979	1.0128	0.4436	0.2554	0.1882	0.5757	0.1290	0.1917	0.0221	0.0267	0.0547
1980	1.0048	0.4951	0.2972	0.1979	0.6003	0.1154	0.1907	0.0204	0.0277	0.0455
1981	0.9810	0.5263	0.3129	0.2134	0.5946	0.1096	0.2026	0.0205	0.0288	0.0439
1982	1.0197	0.5800	0.3339	0.2461	0.5757	0.1017	0.2207	0.0206	0.0302	0.0510
1983	1.0483	0.6538	0.3528	0.3010	0.5396	0.0958	0.2508	0.0198	0.0309	0.0631
1984	1.0860	0.7916	0.4277	0.3639	0.5403	0.0880	0.2552	0.0190	0.0302	0.0673
1985	1.0062	0.9406	0.5233	0.4172	0.5564	0.0849	0.2477	0.0192	0.0317	0.0601
1986	1.0009	1.0707	0.6208	0.4499	0.5798	0.0870	0.2360	0.0192	0.0328	0.0453
1987	1.0119	1.2308	0.7036	0.5272	0.5717	0.0894	0.2388	0.0192	0.0355	0.0455
1988	1.0720	1.5292	0.8580	0.6711	0.5611	0.0957	0.2460	0.0196	0.0326	0.0450
1989	0.9396	1.6735	0.9547	0.7189	0.5705	0.1022	0.2385	0.0207	0.0344	0.0337
1990	0.9694	1.8575	1.0635	0.7940	0.5725	0.1040	0.2385	0.0215	0.0351	0.0284
1991	1.0711	2.2408	1.1925	1.0483	0.5322	0.1037	0.2674	0.0206	0.0383	0.0379
1992	1.0475	2.6761	1.3993	1.2768	0.5229	0.1029	0.2758	0.0202	0.0401	0.0381
1993	1.0410	3.4755	1.7759	1.6996	0.5110	0.1061	0.2987	0.0194	0.0347	0.0301
1994	1.0754	4.5695	2.4018	2.1677	0.5256	0.1065	0.2866	0.0178	0.0329	0.0305
1995	1.0304	5.8175	2.9065	2.9110	0.4996	0.1107	0.2902	0.0177	0.0405	0.0412
1996	1.0092	6.8852	3.3500	3.5352	0.4866	0.1103	0.3005	0.0176	0.0443	0.0408
1997	1.0163	7.6542	3.6732	3.9810	0.4799	0.1108	0.3046	0.0173	0.0466	0.0409
1998	1.0286	8.3313	3.8371	4.4943	0.4606	0.1179	0.3211	0.0171	0.0447	0.0386
1999	1.0113	8.9259	4.1119	4.8140	0.4607	0.1206	0.3222	0.0171	0.0415	0.0379
2000	1.0222	10.0055	4.4322	5.5733	0.4430	0.1235	0.3323	0.0178	0.0409	0.0425
2001	0.9924	10.9071	4.8432	6.0639	0.4440	0.1279	0.3306	0.0191	0.0400	0.0383
2002	1.0285	11.8665	5.1977	6.6687	0.4380	0.1328	0.3338	0.0191	0.0394	0.0368
2003	1.0179	13.2698	5.9947	7.2752	0.4518	0.1350	0.3268	0.0204	0.0354	0.0305
2004	1.0009	15.2406	6.9892	8.2514	0.4586	0.1393	0.3225	0.0213	0.0331	0.0253
2005	1.0030	17.6243	8.1978	9.4265	0.4651	0.1438	0.3160	0.0217	0.0320	0.0214
2006	1.0467	20.9574	9.5446	11.4128	0.4554	0.1512	0.3144	0.0222	0.0305	0.0263
2007	1.0801	25.3304	11.3878	13.9426	0.4496	0.1530	0.3141	0.0217	0.0299	0.0317
2008	1.0616	30.2631	13.3325	16.9307	0.4406	0.1559	0.3186	0.0217	0.0306	0.0327
2009	1.0246	33.4838	15.0436	18.4402	0.4493	0.1628	0.2938	0.0240	0.0332	0.0369
2010	0.9857	38.9117	17.4760	21.4357	0.4491	0.1681	0.2899	0.0274	0.0294	0.0360
2011	0.9813	45.1316	20.9636	24.1680	0.4645	0.1682	0.2806	0.0299	0.0287	0.0281
2012	0.9930	49.6674	24.2623	25.4051	0.4885	0.1663	0.2630	0.0322	0.0279	0.0222
2013	1.0070	54.9280	27.5422	27.3858	0.5014	0.1667	0.2494	0.0353	0.0260	0.0211
2014	0.9963	58.8441	30.0689	28.7752	0.5110	0.1658	0.2403	0.0390	0.0246	0.0193
2015	1.0237	64.1008	32.5660	31.5348	0.5080	0.1631	0.2369	0.0422	0.0244	0.0254
2016	1.0136	69.5893	34.1585	35.4308	0.4909	0.1603	0.2441	0.0466	0.0236	0.0346
2017	1.0679	80.7931	36.2437	44.5493	0.4486	0.1566	0.2721	0.0474	0.0241	0.0512

2018	1.0042	88.5591	38.9578	49.6013	0.4399	0.1538	0.2791	0.0486	0.0240	0.0546
2019	0.9748	93.0646	41.7167	51.3480	0.4483	0.1521	0.2725	0.0504	0.0228	0.0540
2020	0.9747	97.1092	44.2873	52.8219	0.4561	0.1501	0.2641	0.0529	0.0220	0.0548
Mean	1.0148	19.5050	9.1414	10.3630	0.5198	0.1271	0.2535	0.0241	0.0313	0.0441

The arithmetic average of the TFP growth rates over the years 1970-2020 was 1.48% per year which is very good by international standards. The average shares of labour and the 5 types of capital services in GDP were 0.5198, 0.1271 (M&E), 0.2535 (Structures), 0.0241 (Other Capital Services), 0.0313 (Inventories) and 0.0441 (Land). There are some big changes in these shares over time. In particular, the share of labour in GDP has dropped from 0.6247 in 1970 to 0.4561 in 2020. The relatively low average share of labour neat the end of the sample period is not a surprise, given the tremendous amount of investment and capital accumulation that has taken place in the Chinese economy over the past 5 decades. There are other large shifts in GDP shares over the 5 decades. The average share of land services is only 0.0431 but it has grown from 0.0254 to 0.0548 during the past 5 years.

The average TFP growth rates by decade are as follows: 0.9973 or -0.27% per year during the 1970s; 1.0135 or 1.35% per year during the 1980s; 1.0353 or 3.53% per year during the 1990s; 1.0241 or 2.41% during the 2000s and 1.0037 or 0.37% per year during the 2010s. Thus from 1980-2010, the TFP performance of the Chinese economy has been very good by international standards. However, there has been a pronounced productivity slowdown over the years 2018-2020.

In the following section, we decompose real gross income growth into explanatory factors.

4 Decomposition of Chinese Real Gross Income Growth

In this section, we divide the value of year t gross output V_Y^t by the year t price index for consumption P_C^t in order to obtain a measure of the year t real gross output generated by the Chinese production sector. Since the nominal gross output is equal to nominal gross income V_Z^t, V_Y^t/P_C^t is equal to V_Z^t/P_C^t.

In order to simplify our notation for the various explanatory factors, we introduce some new notations for prices and quantities. Define the vectors of *real output prices* $\boldsymbol{p}^t$ and *real input prices* $\boldsymbol{w}^t$ for year t as follows for $t = 1970, \ldots, 2020$:

$$\begin{aligned} \boldsymbol{p}^t &\equiv [p_1^t, \ldots, p_5^t] \equiv (1/P_C^t)[P_C^t, P_G^t, P_I^t, P_X^t, P_M^t]; \\ \boldsymbol{w}^t &\equiv [w_1^t, \ldots, w_6^t] \equiv (1/P_C^t)[P_L^t, P_{UM}^t, P_{US}^t, P_{UO}^t, P_{UI}^t, P_{UL}^t]. \end{aligned} \tag{14}$$

Thus, the real prices are equal to our existing macroeconomic prices divided by the price of consumption.

Define the vector of year t outputs $\boldsymbol{y}^t$ and the year t vector of inputs $\boldsymbol{z}^t$ as follows for all years t:

$$\begin{aligned} \boldsymbol{y}^t &\equiv [y_1^t, \ldots, y_5^t] \equiv [Q_C^t, Q_G^t, Q_I^t, Q_X^t, -Q_M^t]; \\ \boldsymbol{z}^t &\equiv [z_1^t, \ldots, z_6^t] \equiv [Q_L^t, Q_{UM}^t, Q_{US}^t, Q_{UO}^t, Q_{UI}^t, Q_{UL}^t]. \end{aligned} \tag{15}$$

Using the above definitions, we see that *year t real income* is equal to $RI^t \equiv V_Y^t/P_C^t = \boldsymbol{p}^t \cdot \boldsymbol{y}^t = V_Z^t/P_C^t = \boldsymbol{w}^t \cdot \boldsymbol{z}^t$ for all years t. Define (one plus) *real income growth* going from year $t-1$ to year t, RI_G^t, as follows:

$$RI_G^t \equiv \boldsymbol{p}^t \cdot \boldsymbol{y}^t / \boldsymbol{p}^{t-1} \cdot \boldsymbol{y}^{t-1}; \qquad t = 1971, \ldots, 2020. \tag{16}$$

Table 6 below lists the real gross incomes RI^t (in trillions of 1970 yuan), the real output prices $\boldsymbol{p}^t$ and the real input prices $\boldsymbol{w}^t$.

Table 6: Gross Real Income, Real Output Prices and Real Input Prices

Year t	RI^t	p_2^t	p_3^t	p_4^t	p_5^t	w_1^t	w_2^t	w_3^t	w_4^t	w_5^t	w_6^t
1970	0.23602	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
1971	0.24258	0.96273	0.97077	0.92309	0.92735	0.97499	0.94279	0.95108	0.95020	0.93567	0.94716
1972	0.25168	0.94785	0.94145	0.90271	0.88313	0.99906	0.88226	0.90145	0.92894	0.88219	0.88024
1973	0.25949	0.94337	0.94137	0.90471	0.83103	0.97860	0.87123	0.89892	0.96631	0.84406	0.83862
1974	0.26280	0.91006	0.92509	0.92825	0.81999	0.95683	0.85156	0.84704	0.91554	0.79304	0.76804
1975	0.27516	0.90525	0.90288	0.88181	0.78664	0.94173	0.83576	0.86600	1.00915	0.81501	0.80800
1976	0.27402	0.85888	0.89305	0.84990	0.77081	0.92914	0.78657	0.80452	1.00313	0.66789	0.55423
1977	0.29318	0.86562	0.87277	0.83260	0.76031	0.91713	0.80034	0.86210	1.10999	0.80475	0.76434
1978	0.31561	0.90024	0.85715	0.84982	0.75166	0.94648	0.81142	0.88154	1.13780	0.81973	0.80418
1979	0.33418	0.90528	0.82994	0.83552	0.71138	0.96458	0.78549	0.87216	1.14898	0.81500	0.82663
1980	0.35413	0.92164	0.82365	0.81710	0.69876	1.02190	0.72261	0.83084	1.05859	0.77127	0.72606
1981	0.36168	0.90122	0.80959	0.79789	0.70088	0.99375	0.69235	0.81053	1.02365	0.74854	0.71331
1982	0.38524	0.89803	0.80254	0.79240	0.69038	0.98261	0.69952	0.84977	1.05680	0.80700	0.88089
1983	0.42056	0.91582	0.80101	0.80013	0.72134	0.97845	0.70749	0.95680	1.04899	0.89569	1.18285
1984	0.48880	0.98997	0.80502	0.85239	0.81251	1.07525	0.72536	1.03363	1.07746	0.95824	1.45816
1985	0.52248	1.01787	0.77479	0.91635	0.88083	1.11649	0.67744	0.97482	1.03933	0.88630	1.38533
1986	0.56134	1.03957	0.78668	1.15284	1.09034	1.19723	0.63206	0.90375	0.98761	0.80992	1.11567
1987	0.59687	1.05199	0.76528	1.17950	1.16947	1.20509	0.59353	0.88847	0.93218	0.82335	1.18684
1988	0.64249	1.05540	0.74396	0.97930	1.37983	1.22341	0.57596	0.90343	0.91039	0.77405	1.26193
1989	0.62907	1.01995	0.71392	0.79196	1.12052	1.19492	0.51538	0.78346	0.84900	0.68631	0.92208
1990	0.65673	1.02785	0.72304	1.00759	1.19186	1.22467	0.51601	0.76227	0.86651	0.63100	0.80670
1991	0.74152	1.06840	0.72957	1.04243	1.19306	1.25122	0.55816	0.90967	0.88329	0.70833	1.21245
1992	0.85165	1.17127	0.79372	1.01904	1.15761	1.36313	0.59661	1.01441	0.91861	0.71737	1.39500
1993	0.98285	1.25832	0.88178	0.81688	0.99993	1.47235	0.62662	1.16819	0.93422	0.63944	1.26812
1994	1.10693	1.36684	0.83115	1.07740	1.31908	1.67643	0.58597	1.15226	0.87268	0.64055	1.43896
1995	1.13729	1.30839	0.70850	0.89877	1.09756	1.59402	0.52207	1.08878	0.79141	0.74994	1.98532
1996	1.20570	1.29333	0.65807	0.75068	0.88351	1.58435	0.48040	1.07285	0.74179	0.77422	2.07543
1997	1.28922	1.30963	0.64134	0.67694	0.80758	1.62988	0.45432	1.04998	0.69975	0.78170	2.21774
1998	1.40176	1.33609	0.63590	0.61403	0.72284	1.68161	0.45593	1.09320	0.65602	0.76622	2.27170
1999	1.48948	1.34959	0.62483	0.61279	0.75713	1.73863	0.43156	1.06219	0.62770	0.72769	2.35922
2000	1.61983	1.35269	0.60604	0.64306	0.79245	1.74065	0.42044	1.08651	0.62762	0.73962	2.87188
2001	1.74642	1.39417	0.60390	0.63796	0.75111	1.82035	0.40622	1.06163	0.63340	0.72874	2.78955
2002	1.99529	1.50274	0.63681	0.68655	0.78452	2.01089	0.41398	1.11614	0.63159	0.76549	3.05460
2003	2.25427	1.62300	0.65568	0.76039	0.85777	2.26367	0.40065	1.12513	0.64170	0.73583	2.83397
2004	2.54261	1.75212	0.67852	0.86509	0.94291	2.51513	0.38226	1.13523	0.64729	0.71255	2.62210
2005	2.93765	1.86564	0.70202	0.93372	0.96617	2.76479	0.37537	1.16092	0.65453	0.73949	2.54055
2006	3.29684	1.99353	0.68309	0.90830	0.91674	3.03569	0.36222	1.18251	0.64229	0.75062	3.45807
2007	3.91677	2.31068	0.69766	0.92959	0.92112	3.62961	0.36068	1.28371	0.63679	0.79180	4.88883
2008	4.50209	2.52634	0.70904	0.91771	0.92115	4.12207	0.34992	1.36405	0.61262	0.80125	5.74615
2009	5.04601	2.69873	0.70556	0.83437	0.80002	4.63715	0.34024	1.28885	0.59955	0.86866	6.90007
2010	5.55696	2.69293	0.69373	0.87488	0.84312	4.65333	0.31734	1.25076	0.57675	0.76114	7.05783
2011	5.90675	2.76020	0.67502	0.81907	0.78728	4.95352	0.27758	1.15301	0.52249	0.68880	5.62657
2012	6.34471	2.89080	0.66353	0.78298	0.74065	5.49739	0.25529	1.02979	0.48157	0.64053	4.62794
2013	6.81774	2.97994	0.64444	0.73847	0.69274	5.94029	0.23641	0.94172	0.45081	0.58462	4.67176
2014	7.00095	3.02604	0.61833	0.66770	0.63476	6.26566	0.21462	0.83163	0.41261	0.51581	4.33752
2015	7.42623	3.13965	0.58976	0.62164	0.54966	6.78849	0.20478	0.77775	0.39295	0.50296	6.00966
2016	7.66376	3.10734	0.55901	0.57724	0.50712	6.76032	0.19522	0.74236	0.37982	0.47329	8.34681
2017	8.50199	3.19108	0.56154	0.57479	0.52313	6.95677	0.19652	0.83133	0.37532	0.50742	13.55581
2018	9.01631	3.30406	0.56966	0.57136	0.52832	7.28546	0.18853	0.82474	0.36263	0.50500	14.57537
2019	8.90558	3.32806	0.54572	0.55401	0.52213	7.49363	0.17010	0.72701	0.32946	0.45737	13.63020
2020	8.86905	3.27673	0.51943	0.53160	0.48017	7.59962	0.15657	0.64363	0.30557	0.42409	13.79075

Real gross income in China grew 37.58 fold over the 51 years in our sample. This is a spectacular achievement. Real consumption growth over the sample period was lower; from Table A6 in the Appendix, it can be verified that real consumption grew 20.8 fold over the sample period. Real wages grew much slower; a 7.60 fold increase over the sample period. The real user cost growth factors were 0.157 for M&E, 0.643 for Structures, 0.306 for Other Capital Services, 0.424 for Inventory and 13.8 for Land Services. Real consumption prices, p_1^t, are not listed in Table 6 because they are always equal to 1. Real Government Output prices grew 3.28 fold over the sample period which is much lower than real wage growth.[*22] The real price levels for gross investment, exports and imports in 2020 (relative to the corresponding 1970 levels) were $0.519, 0.531$ and 0.480 respectively.

We use the new notation to define the logarithm of the *Törnqvist output price index* for year t, $P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{y}^{t-1}, \boldsymbol{y}^t)$, and the logarithm of the *Törnqvist input quantity index* for year t, $Q_T(\boldsymbol{w}^{t-1}, \boldsymbol{w}^t, \boldsymbol{z}^{t-1}, \boldsymbol{z}^t)$ as follows:

$$\ln P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{y}^{t-1}, \boldsymbol{y}^t) \equiv \textstyle\sum_{n=1}^{5}(1/2)[(p_n^t y_n^t/\boldsymbol{p}^t \cdot \boldsymbol{y}^t) + (p_n^{t-1} y_n^{t-1}/\boldsymbol{p}^{t-1} \cdot \boldsymbol{y}^{t-1})] \ln(p_n^t/p_n^{t-1});\ t = 1971, \ldots, 2020; \tag{17}$$

$$\ln Q_T(\boldsymbol{w}^{t-1}, \boldsymbol{w}^t, \boldsymbol{z}^{t-1}, \boldsymbol{z}^t) \equiv \textstyle\sum_{n=1}^{6}(1/2)[(w_n^t z_n^t/\boldsymbol{w}^t \cdot \boldsymbol{z}^t) + (w_n^{t-1} z_n^{t-1}/\boldsymbol{w}^{t-1} \cdot \boldsymbol{z}^{t-1})] \ln(z_n^t/z_n^{t-1});\ t = 1971, \ldots, 2020. \tag{18}$$

Define the year t *real output price change* n *contribution factor*, α_n^t, as follows:

$$\ln \alpha_n^t \equiv (1/2)[(p_n^t y_n^t/\boldsymbol{p}^t \cdot \boldsymbol{y}^t) + (p_n^{t-1} y_n^{t-1}/\boldsymbol{p}^{t-1} \cdot \boldsymbol{y}^{t-1})] \ln(p_n^t/p_n^{t-1}); \quad n = 1, \ldots, 5; t = 1971, \ldots, 2020. \tag{19}$$

Comparing (17) and (19), it can be seen that the product over n of the year t output price contribution factors α_n^t is equal to the year t Törnqvist output price index; i.e.:

$$P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{y}^{t-1}, \boldsymbol{y}^t) = \textstyle\prod_{n=1}^{5} \alpha_n^t; \qquad t = 1971, \ldots, 2020. \tag{20}$$

Define the year t *input* n *contribution factor*, β_n^t, as follows:

$$\ln \beta_n^t \equiv (1/2)[(w_n^t z_n^t/\boldsymbol{w}^t \cdot \boldsymbol{z}^t) + (w_n^{t-1} z_n^{t-1}/\boldsymbol{w}^{t-1} \cdot \boldsymbol{z}^{t-1})] \ln(z_n^t/z_n^{t-1}); \quad n = 1, \ldots, 6; t = 1971, \ldots, 2020. \tag{21}$$

Comparing (18) and (21), it can be seen that the product over n of the year t input contribution factors β_n^t is equal to the year t Törnqvist input quantity index; i.e.:

$$Q_T(\boldsymbol{w}^{t-1}, \boldsymbol{w}^t, \boldsymbol{z}^{t-1}, \boldsymbol{z}^t) = \textstyle\prod_{n=1}^{6} \beta_n^t; \qquad t = 1971, \ldots, 2020. \tag{22}$$

[*22] In the international SNA, the government output price index is typically set equal to a government input price index which consists of a price index for intermediate input purchases, government labour input and depreciation on government produced assets. There is no imputation for the opportunity cost of government capital in the present SNA. However, we calculated Jorgensonian user costs for all government assets, including government land which led to an overall government input price index that grew more slowly than government wages. As was seen in section 2, Jorgensonian user costs include an imputation for the cost of capital.

Define year t *productivity growth* TFP_G^t *using real prices as weights* as the implicit Törnqvist output quantity index, $[\boldsymbol{p}^t \cdot \boldsymbol{y}^t/\boldsymbol{p}^{t-1} \cdot \boldsymbol{y}^{t-1}]/P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{y}^{t-1}, \boldsymbol{y}^t) = \boldsymbol{p}^t \cdot \boldsymbol{y}^t/[\boldsymbol{p}^{t-1} \cdot \boldsymbol{y}^{t-1} P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{y}^{t-1}, \boldsymbol{y}^t)]$, divided by the direct Törnqvist input quantity index $Q_T(\boldsymbol{w}^{t-1}, \boldsymbol{w}^t, \boldsymbol{z}^{t-1}, \boldsymbol{z}^t)$; i.e., we have the following definitions:

$$TFP_G^t \equiv \boldsymbol{p}^t \cdot \boldsymbol{y}^t/[\boldsymbol{p}^{t-1} \cdot \boldsymbol{y}^{t-1} P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{y}^{t-1}, \boldsymbol{y}^t) Q_T(\boldsymbol{w}^{t-1}, \boldsymbol{w}^t, \boldsymbol{z}^{t-1}, \boldsymbol{z}^t)]; \quad t = 1971, \ldots, 2020. \tag{23}$$

Using the fact that $P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{y}^{t-1}, \boldsymbol{y}^t)$ is homogeneous of degree 1 in the components of $\boldsymbol{p}^t$ and homogeneous of degree -1 in $\boldsymbol{p}^{t-1}$ as well as the fact that $Q_T(\boldsymbol{w}^{t-1}, \boldsymbol{w}^t, \boldsymbol{z}^{t-1}, \boldsymbol{z}^t)$ is homogeneous of degree 0 in the components of $\boldsymbol{w}^t$ and homogeneous of degree 0 in the components of $\boldsymbol{w}^{t-1}$, it can be shown that τ^t is equal to the measure of productivity growth TFP_G^t defined in the previous section for all t.*23

Rearrange equations (23) to give us the following expression for year t *real income growth* over the prior year, $RI_G^t = \boldsymbol{p}^t \cdot \boldsymbol{y}^t/\boldsymbol{p}^{t-1} \cdot \boldsymbol{y}^{t-1}$:

$$\begin{aligned} RI_G^t &\equiv \tau^t P_T(\boldsymbol{p}^{t-1}, \boldsymbol{p}^t, \boldsymbol{y}^{t-1}, \boldsymbol{y}^t) Q_T(\boldsymbol{w}^{t-1}, \boldsymbol{w}^t, \boldsymbol{z}^{t-1}, \boldsymbol{z}^t); \qquad t = 1971, \ldots, 2020 \\ &= TFP_G^t (\textstyle\prod_{n=1}^5 \alpha_n^t)(\prod_{n=1}^6 \beta_n^t) \qquad \text{using (20) and (22).} \end{aligned} \tag{24}$$

The above expression gives us a nice decomposition of year t real income growth into the following explanatory variables: TFP growth TFP_G^t, year t real output price contribution factors, α_2^t-α_5^t, and year t input contribution factors, β_1^t-β_6^t. Table 7 below lists the real income growth factors, RI_G^t, and the 11 contribution factors.

Table 7: Gross Real Income Growth, Real Output Price and Input Growth Contribution Factors

Year t	RI_G^t	TFP_G^t	α_2^t	α_3^t	α_4^t	α_5^t	β_1^t	β_2^t	β_3^t	β_4^t	β_5^t	β_6^t
1971	1.0278	0.9761	0.9957	0.9919	0.9978	1.0024	1.0307	1.0161	1.0115	1.0015	1.0045	1.0002
1972	1.0375	1.0016	0.9982	0.9919	0.9993	1.0016	1.0142	1.0131	1.0132	1.0016	1.0023	1.0002
1973	1.0310	0.9793	0.9995	1.0000	1.0001	1.0025	1.0224	1.0105	1.0133	1.0013	1.0021	1.0002
1974	1.0128	0.9730	0.9959	0.9954	1.0013	1.0008	1.0208	1.0110	1.0122	1.0011	1.0018	1.0002
1975	1.0470	1.0046	0.9994	0.9933	0.9973	1.0026	1.0230	1.0099	1.0146	1.0014	1.0002	1.0003
1976	0.9959	0.9576	0.9939	0.9969	0.9982	1.0011	1.0190	1.0134	1.0163	1.0015	0.9991	1.0002
1977	1.0699	1.0355	1.0009	0.9935	0.9991	1.0007	1.0170	1.0075	1.0139	1.0008	0.9994	1.0002
1978	1.0765	1.0276	1.0046	0.9946	1.0010	1.0006	1.0191	1.0063	1.0172	1.0007	1.0025	1.0002
1979	1.0589	1.0128	1.0007	0.9903	0.9991	1.0035	1.0195	1.0093	1.0175	1.0013	1.0035	1.0002
1980	1.0597	1.0048	1.0023	0.9978	0.9987	1.0013	1.0250	1.0036	1.0196	1.0013	1.0041	1.0001
1981	1.0213	0.9810	0.9972	0.9952	0.9983	0.9998	1.0239	1.0014	1.0212	1.0012	1.0025	1.0001
1982	1.0652	1.0197	0.9996	0.9977	0.9994	1.0012	1.0250	0.9976	1.0217	1.0008	1.0011	1.0001
1983	1.0917	1.0483	1.0025	0.9995	1.0008	0.9966	1.0153	1.0017	1.0231	1.0011	1.0002	1.0003
1984	1.1622	1.0860	1.0105	1.0015	1.0052	0.9894	1.0314	1.0037	1.0232	1.0016	1.0018	1.0003
1985	1.0689	1.0062	1.0038	0.9875	1.0069	0.9894	1.0325	1.0086	1.0242	1.0022	1.0060	1.0003
1986	1.0744	1.0009	1.0029	1.0052	1.0263	0.9659	1.0248	1.0143	1.0242	1.0023	1.0063	1.0003
1987	1.0633	1.0119	1.0016	0.9910	1.0030	0.9891	1.0237	1.0134	1.0216	1.0023	1.0043	1.0002
1988	1.0764	1.0720	1.0004	0.9906	0.9749	0.9752	1.0229	1.0160	1.0213	1.0023	1.0017	1.0001
1989	0.9791	0.9396	0.9956	0.9865	0.9725	1.0322	1.0108	1.0156	1.0222	1.0022	1.0051	1.0001
1990	1.0440	0.9694	1.0011	1.0037	1.0376	0.9905	1.0127	1.0061	1.0169	1.0012	1.0052	1.0001
1991	1.1291	1.0711	1.0054	1.0026	1.0062	0.9998	1.0150	1.0042	1.0150	1.0013	1.0034	1.0001
1992	1.1485	1.0475	1.0132	1.0281	0.9956	1.0055	1.0188	1.0066	1.0166	1.0017	1.0067	1.0002

*23 Diewert and Morrison (1986)[18] and Kohli (1990)[47] provide economic interpretations for TFP_G^t and the counterparts to α_n^t and β_n^t that used un-normalized prices. Diewert and Lawrence (2006)[17] extended the analysis to the case where normalized prices were used to measure the real gross income generated by the Australian production sector.

1993	1.1541	1.0410	1.0106	1.0403	0.9601	1.0292	1.0225	1.0132	1.0238	1.0017	1.0043	1.0001
1994	1.1262	1.0754	1.0124	0.9767	1.0621	0.9390	1.0090	1.0204	1.0271	1.0019	1.0022	1.0001
1995	1.0274	1.0304	0.9937	0.9402	0.9552	1.0457	1.0138	1.0199	1.0281	1.0022	1.0029	1.0002
1996	1.0601	1.0092	0.9984	0.9730	0.9595	1.0478	1.0189	1.0154	1.0324	1.0020	1.0049	1.0002
1997	1.0693	1.0163	1.0018	0.9910	0.9771	1.0176	1.0121	1.0141	1.0314	1.0019	1.0048	1.0001
1998	1.0873	1.0286	1.0030	0.9971	0.9787	1.0201	1.0053	1.0164	1.0306	1.0023	1.0028	1.0001
1999	1.0626	1.0113	1.0016	0.9939	0.9996	0.9917	1.0128	1.0166	1.0303	1.0019	1.0017	1.0001
2000	1.0875	1.0222	1.0004	0.9895	1.0109	0.9906	1.0199	1.0165	1.0306	1.0022	1.0022	1.0001
2001	1.0782	0.9924	1.0051	0.9988	0.9981	1.0120	1.0147	1.0184	1.0314	1.0025	1.0027	1.0001
2002	1.1425	1.0285	1.0125	1.0198	1.0185	0.9899	1.0089	1.0200	1.0313	1.0026	1.0027	1.0001
2003	1.1298	1.0179	1.0125	1.0118	1.0300	0.9760	1.0155	1.0232	1.0311	1.0034	1.0021	1.0004
2004	1.1279	1.0009	1.0121	1.0150	1.0453	0.9697	1.0138	1.0276	1.0323	1.0032	1.0029	1.0003
2005	1.1554	1.0030	1.0099	1.0152	1.0301	0.9915	1.0300	1.0279	1.0330	1.0033	1.0024	1.0002
2006	1.1223	1.0467	1.0104	0.9881	0.9887	1.0185	1.0004	1.0301	1.0294	1.0035	1.0016	1.0003
2007	1.1880	1.0801	1.0232	1.0093	1.0098	0.9984	0.9913	1.0291	1.0285	1.0035	1.0030	1.0003
2008	1.1494	1.0616	1.0139	1.0075	0.9949	1.0000	0.9963	1.0295	1.0297	1.0038	1.0045	1.0003
2009	1.1208	1.0246	1.0102	0.9976	0.9690	1.0393	1.0071	1.0300	1.0279	1.0054	1.0038	1.0017
2010	1.1013	0.9857	0.9997	0.9913	1.0143	0.9863	1.0425	1.0333	1.0336	1.0069	1.0034	1.0018
2011	1.0629	0.9813	1.0039	0.9859	0.9795	1.0199	1.0148	1.0334	1.0318	1.0071	1.0039	1.0013
2012	1.0741	0.9930	1.0078	0.9912	0.9864	1.0174	1.0085	1.0244	1.0331	1.0071	1.0033	1.0007
2013	1.0746	1.0070	1.0052	0.9852	0.9832	1.0180	1.0102	1.0255	1.0281	1.0079	1.0025	1.0003
2014	1.0269	0.9963	1.0026	0.9793	0.9723	1.0229	0.9960	1.0198	1.0282	1.0079	1.0024	1.0003
2015	1.0607	1.0237	1.0064	0.9772	0.9818	1.0339	0.9864	1.0147	1.0271	1.0076	1.0019	1.0001
2016	1.0320	1.0136	0.9982	0.9750	0.9832	1.0165	1.0006	1.0101	1.0263	1.0073	1.0014	1.0003
2017	1.1094	1.0679	1.0046	1.0022	0.9991	0.9939	0.9930	1.0118	1.0259	1.0063	1.0014	1.0004
2018	1.0605	1.0042	1.0059	1.0071	0.9987	0.9980	0.9969	1.0128	1.0258	1.0057	1.0013	1.0027
2019	0.9877	0.9748	1.0013	0.9797	0.9937	1.0023	0.9904	1.0123	1.0251	1.0059	1.0009	1.0023
2020	0.9959	0.9747	0.9972	0.9776	0.9917	1.0157	0.9996	1.0099	1.0234	1.0063	1.0008	1.0000
Mean	1.0763	1.0148	1.0038	0.9950	0.9978	1.0031	1.0140	1.0153	1.0244	1.0031	1.0028	1.0004

On average, real gross income growth generated by the Chinese economy was 7.63% per year. This is an extraordinarily high rate of growth. The sample averages of the factors that contributed to this growth are as follows in annual percentages: 1.48% (TFP change); 0.38% (government real price change); −0.50% (real investment price change); −0.22% (export price change); 0.31% (import price change); 1.40% (quality-adjusted labour growth); 1.53% (M&E capital services growth); 2.44% (structures services growth); 0.31% (other capital services growth); 0.28% (inventory growth services) and 0.04% (land services growth). Real export prices fell and real import prices fell even more over the sample period which when taken together as a terms of trade effect slightly increased overall real gross income growth. Note that since population growth is turning into population decline for China, it is unlikely that quality-adjusted labour growth will be very high in the future. This will lead to a significant slowdown in future growth for China.

Rather than look at year to year increases in real income growth, it is useful to convert the above annual rates of increase into levels. Thus, we express the *level of real income* in year t in terms of an *index of the level of TFP* in year t, TFP^t, of the *level of real output price n* in period t, A_n^t, and of the *level of primary input quantity n* in period t, B_n^t.[*24] We use the

[*24] This type of levels presentation of the data is quite instructive when presented in graphical form. It was suggested by Kohli (1990)[47] and used extensively by him; see Kohli (1991)[48], (2003)[49] (2004a)[50] (2004b)[51] and Fox and Kohli (1998)[30].

growth factors TFP_G^t, α_n^t and β_n^t to define the corresponding levels TFP^t, A_n^t and B_n^t:

$$TFP^{1970} \equiv 1; TFP^t \equiv TFP^{t-1}TFP_G^t; \qquad t = 1971, \ldots, 2020; \tag{25}$$

$$A_n^{1970} \equiv 1; A_n^t \equiv A_n^{t-1}\alpha_n^t; \qquad n = 2, \ldots, 5; t = 1971, \ldots, 2020; \tag{26}$$

$$B_n^{1970} \equiv 1; B_n^t \equiv B_n^{t-1}\beta_n^t; \qquad n = 1, \ldots, 6; t = 1971, \ldots, 2020. \tag{27}$$

Using the above definitions, we can establish the following relationships for the level of *real gross income* in year t relative to 1970, RI^t/RI^{1970} and the year t levels for technology, real output prices and input quantities:

$$RI^t/RI^{1970} = TFP^t A_2^t A_3^t A_4^t A_5^t B_1^t B_2^t B_3^t B_4^t B_5^t B_6^t; \qquad t = 1970, \ldots, 2020. \tag{28}$$

The levels decomposition for relative real gross income for China is shown in Table 8 below.

Table 8: The Levels Decomposition for Real Gross Income Growth in China

Year t	RI^t/RI^{1970}	TFP^t	A_2^t	A_3^t	A_4^t	A_5^t	B_1^t	B_2^t	B_3^t	B_4^t	B_5^t	B_6^t
1970	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1971	1.028	0.976	0.996	0.992	0.998	1.002	1.031	1.016	1.012	1.002	1.004	1.000
1972	1.066	0.978	0.994	0.984	0.997	1.004	1.045	1.029	1.025	1.003	1.007	1.000
1973	1.099	0.957	0.993	0.984	0.997	1.006	1.069	1.040	1.039	1.004	1.009	1.001
1974	1.113	0.932	0.989	0.979	0.998	1.007	1.091	1.052	1.051	1.005	1.011	1.001
1975	1.166	0.936	0.989	0.973	0.996	1.010	1.116	1.062	1.067	1.007	1.011	1.001
1976	1.161	0.896	0.983	0.970	0.994	1.011	1.137	1.076	1.084	1.008	1.010	1.001
1977	1.242	0.928	0.984	0.964	0.993	1.012	1.157	1.084	1.099	1.009	1.009	1.001
1978	1.337	0.954	0.988	0.958	0.994	1.012	1.179	1.091	1.118	1.010	1.012	1.002
1979	1.416	0.966	0.989	0.949	0.993	1.016	1.202	1.101	1.137	1.011	1.015	1.002
1980	1.500	0.971	0.991	0.947	0.992	1.017	1.232	1.105	1.160	1.012	1.020	1.002
1981	1.532	0.952	0.988	0.942	0.990	1.017	1.261	1.107	1.184	1.014	1.022	1.002
1982	1.632	0.971	0.988	0.940	0.989	1.018	1.293	1.104	1.210	1.014	1.023	1.002
1983	1.782	1.018	0.990	0.940	0.990	1.015	1.312	1.106	1.238	1.016	1.023	1.003
1984	2.071	1.105	1.001	0.941	0.995	1.004	1.354	1.110	1.267	1.017	1.025	1.003
1985	2.214	1.112	1.005	0.929	1.002	0.993	1.398	1.120	1.297	1.019	1.031	1.003
1986	2.378	1.113	1.007	0.934	1.029	0.959	1.432	1.136	1.329	1.022	1.038	1.003
1987	2.529	1.126	1.009	0.926	1.032	0.949	1.466	1.151	1.358	1.024	1.042	1.004
1988	2.722	1.207	1.009	0.917	1.006	0.925	1.500	1.170	1.386	1.026	1.044	1.004
1989	2.665	1.135	1.005	0.905	0.978	0.955	1.516	1.188	1.417	1.029	1.049	1.004
1990	2.783	1.100	1.006	0.908	1.015	0.946	1.535	1.195	1.441	1.030	1.055	1.004
1991	3.142	1.178	1.011	0.910	1.021	0.946	1.558	1.200	1.463	1.031	1.058	1.004
1992	3.608	1.234	1.025	0.936	1.017	0.951	1.587	1.208	1.487	1.033	1.066	1.004
1993	4.164	1.285	1.036	0.974	0.976	0.979	1.623	1.224	1.522	1.035	1.070	1.004
1994	4.690	1.382	1.048	0.951	1.037	0.919	1.638	1.249	1.564	1.037	1.072	1.005
1995	4.819	1.423	1.042	0.894	0.990	0.961	1.660	1.274	1.608	1.039	1.076	1.005
1996	5.108	1.437	1.040	0.870	0.950	1.007	1.692	1.293	1.660	1.041	1.081	1.005
1997	5.462	1.460	1.042	0.862	0.929	1.025	1.712	1.311	1.712	1.043	1.086	1.005
1998	5.939	1.502	1.045	0.860	0.909	1.046	1.721	1.333	1.764	1.045	1.089	1.005
1999	6.311	1.519	1.047	0.854	0.908	1.037	1.744	1.355	1.818	1.047	1.091	1.005
2000	6.863	1.552	1.047	0.845	0.918	1.027	1.778	1.377	1.873	1.050	1.093	1.005
2001	7.399	1.541	1.052	0.844	0.917	1.040	1.804	1.403	1.932	1.052	1.096	1.005
2002	8.454	1.584	1.066	0.861	0.934	1.029	1.820	1.431	1.993	1.055	1.099	1.006
2003	9.551	1.613	1.079	0.871	0.962	1.004	1.848	1.464	2.055	1.058	1.102	1.006
2004	10.773	1.614	1.092	0.884	1.005	0.974	1.874	1.504	2.121	1.062	1.105	1.006
2005	12.447	1.619	1.103	0.898	1.035	0.966	1.930	1.546	2.191	1.065	1.108	1.006
2006	13.969	1.695	1.114	0.887	1.024	0.983	1.931	1.593	2.255	1.069	1.109	1.007
2007	16.595	1.831	1.140	0.895	1.034	0.982	1.914	1.639	2.320	1.073	1.113	1.007
2008	19.075	1.943	1.156	0.902	1.028	0.982	1.907	1.688	2.388	1.077	1.118	1.007
2009	21.380	1.991	1.168	0.900	0.997	1.020	1.921	1.738	2.455	1.083	1.122	1.009
2010	23.545	1.963	1.167	0.892	1.011	1.007	2.002	1.796	2.538	1.090	1.126	1.011

2011	25.027	1.926	1.172	0.880	0.990	1.027	2.032	1.856	2.618	1.098	1.130	1.012
2012	26.882	1.913	1.181	0.872	0.977	1.044	2.049	1.901	2.705	1.106	1.134	1.013
2013	28.886	1.926	1.187	0.859	0.960	1.063	2.070	1.950	2.781	1.114	1.137	1.013
2014	29.663	1.919	1.190	0.841	0.934	1.088	2.062	1.989	2.859	1.123	1.139	1.014
2015	31.465	1.964	1.198	0.822	0.917	1.124	2.034	2.018	2.937	1.132	1.142	1.014
2016	32.471	1.991	1.196	0.801	0.901	1.143	2.035	2.038	3.014	1.140	1.143	1.014
2017	36.022	2.126	1.201	0.803	0.900	1.136	2.021	2.062	3.092	1.147	1.145	1.014
2018	38.202	2.135	1.208	0.809	0.899	1.134	2.014	2.089	3.172	1.154	1.146	1.017
2019	37.732	2.081	1.210	0.793	0.894	1.136	1.995	2.114	3.251	1.161	1.147	1.020
2020	37.578	2.029	1.207	0.775	0.886	1.154	1.994	2.135	3.327	1.168	1.148	1.020

As was indicated above, real gross income grew 37.578 fold over the sample period.*25 The growth factors for 2020 that contributed to this overall growth of real income are as follows: 1.029 (TFP growth); 1.207 (Government real price growth); 0.775 (Gross Investment real price growth); 0.886 (Export real price growth)*26; 1.154 (Import real price growth)*27; 1.994 (Quality-adjusted Labour Input growth); 2.135 (M&E services growth); 3.327 (Structures Services growth); 1.168 (Other Capital Services growth); 1.148 (Inventory Services growth); 1.020 (Land Services growth). Multiplication of all of these 2020 growth factors equals real gross income sample period growth of 37.578. Figure 2 below plots the 11 growth factors over the sample period.

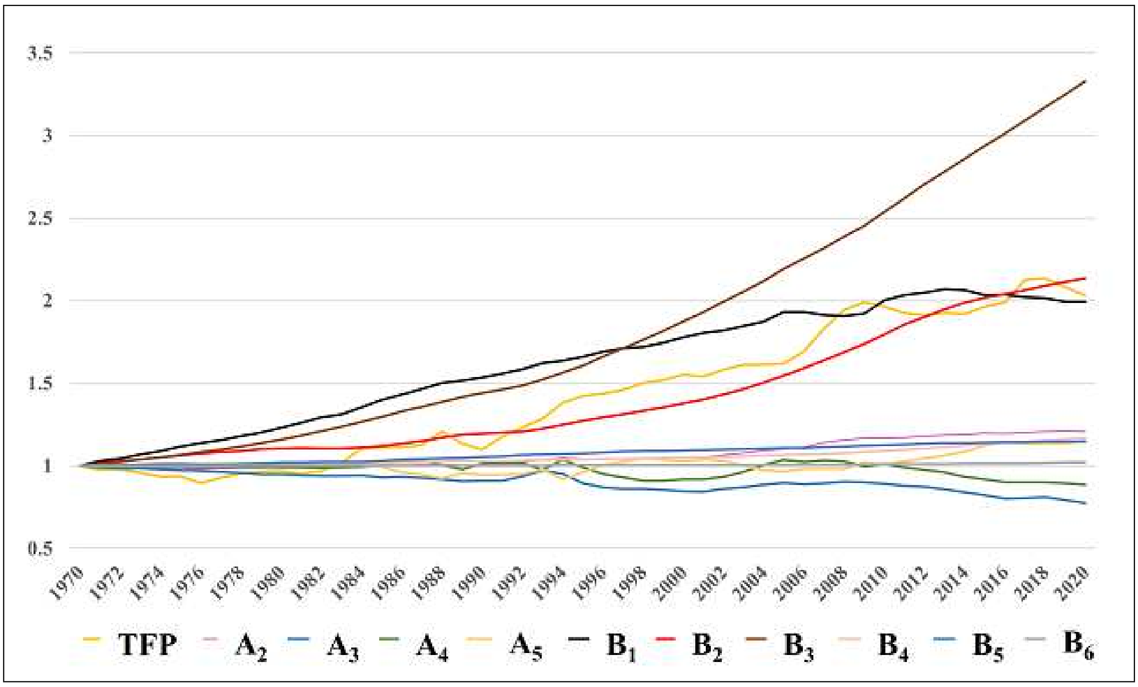

Figure 2 Explanatry Factors For Real Gross Output Growth

*25 Per capita real gross income increased 23.2 fold over the sample period.

*26 This growth factor ended up less than one which indicates that real export prices fell over the sample period.

*27 The fact that this growth factor ended up greater than one indicates that real import prices fell over the sample period. If we combine the export and import growth terms, we find that China's terms of trade improved over the sample period.

The top four explanatory factors for 2020 are B_3 (Structure Services), B_2 (M&E Services), TFP and B_1 (Labour). Note that TFP was near or below one for the first fifteen years of our sample. Note also that the contribution of Labour services is slowly declining over the past decade. It can be seen that the growth in structures services is the largest contributor to real GDP growth over the sample period. Population decline in China is leading to a decline in quality-adjusted labour input and it will likely lead to a slowdown in the demand for structures in the not too distant future. There is also a decline in TFP growth in recent years which may or may not continue. These trends point to a future slow down in the rate of real income growth for the Chinese economy.

It can be seen that our measure of TFP can show declines over time. Thus, it is difficult to interpret TFP as technical progress, which is an outward shift of the production possibilities set due to technical progress. It seems unlikely that technical progress can be regressive in the sense that producers forget methods of production over time which could lead to a contraction of the aggregate production possibilities set. It is likely that the declines in TFP that we see in almost all countries are due to recessions, which lead to decreases in outputs. However, capital cannot be reduced in the short run, so typically, recessions lead to production taking place in the interior of the national production possibilities set and to declines in measured TFP. In the following section, we will look at a nonparametric method for decomposing TFP into technical progress and inefficiency components.

5 A Nonparametric Decomposition of Gross Output Growth for China

The analysis in this section is based on Diewert and Fox (2018)[15]. There are two key concepts that this analysis is based on:

- An approximation to the aggregate production possibilities set for an economy can be formed by using linear multiples of past net output and primary input vectors and
- The *cost constrained value added function* can be used to form measures of efficiency, output price change, input price change, input quantity change and technology change.

We use the notation that was introduced in section 4 for the net output vector in year t, $\boldsymbol{y}^t$, and the corresponding primary input vector $\boldsymbol{x}^t$. As in the previous section, we will work with the year t real price vectors, $\boldsymbol{p}^t$ and $\boldsymbol{w}^t$, that were defined in the previous section along with the observed net output vectors $\boldsymbol{y}^t$ and primary input quantity vectors $\boldsymbol{x}^t$.

The basic assumption that Diewert and Fox make is that the year t national technology set can be approximated by assuming it consists of past observed output and input vectors, $(\boldsymbol{y}^s, \boldsymbol{x}^s)$, and linear multiples of these vectors for past periods and the current period t. Let S^t denote the resulting period t production possibilities set. Thus $S^1 \equiv \{(\boldsymbol{y}, \boldsymbol{x}) : \boldsymbol{y} = \lambda \boldsymbol{y}^1, \boldsymbol{x} = \lambda \boldsymbol{x}^1; \lambda \geq 0\}, S^2 \equiv \{(\boldsymbol{y}, \boldsymbol{x}) : \boldsymbol{y} = \lambda_1 \boldsymbol{y}^1, \boldsymbol{x} = \lambda_1 \boldsymbol{x}^1; \lambda_1 \geq 0, \boldsymbol{y} = \lambda_2 \boldsymbol{y}^2, \boldsymbol{x} = \lambda_2 \boldsymbol{x}^2; \lambda_2 \geq 0\}, \ldots, S^t \equiv \{(\boldsymbol{y}, \boldsymbol{x}) : \boldsymbol{y} = \lambda_s \boldsymbol{y}^s, \boldsymbol{x} = \lambda_s \boldsymbol{x}^s; \lambda_s \geq 0, s = 1, 2, \ldots, t\}$. These definitions for the S^t mean that we are assuming that S^t is a constant returns to scale technology set for each period.*28

The year t *cost constrained value added function* for the Chinese economy, $R^t(\boldsymbol{p}, \boldsymbol{w}, \boldsymbol{x})$, is defined as follows for the positive real price vectors $\boldsymbol{p}$ and $\boldsymbol{w}$, positive primary input vector $\boldsymbol{x}$

*28 This is a weakness of the Diewert and Fox methodology. But it is very difficult to model nonconstant returns to scale using only macroeconomic data.

and period t production possibilities set S^t :[*29]

$$\begin{aligned} R^t(\boldsymbol{p},\boldsymbol{w},\boldsymbol{x}) &\equiv \max_{y,z}\{\boldsymbol{p}\cdot\boldsymbol{y} : \{(\boldsymbol{y},\boldsymbol{z}) \in S^t; \boldsymbol{w}\cdot\boldsymbol{z} \le \boldsymbol{w}\cdot\boldsymbol{x}\}; \qquad t = 1970,\ldots,2020 \\ &= \max_s\{\boldsymbol{p}\cdot\boldsymbol{y}^s\ \boldsymbol{w}\cdot\boldsymbol{x}/\boldsymbol{w}\cdot\boldsymbol{x}^s : s = 1,2,\ldots,t\} \\ &= \boldsymbol{w}\cdot\boldsymbol{x}\ \max_s\{\boldsymbol{p}\cdot\boldsymbol{y}^s/\boldsymbol{w}\cdot\boldsymbol{x}^s : s = 1,2,\ldots,t\}. \end{aligned} \tag{29}$$

Given the period t technology set S^t, nominal output prices $\boldsymbol{P}$, nominal input prices $\boldsymbol{W}$ and the constraint that primary input costs should not exceed cost $\boldsymbol{W}\cdot\boldsymbol{x}$, we assume that producers choose the output vector $\boldsymbol{y}$ and input vector $\boldsymbol{z}$ to maximize national value added, $\boldsymbol{P}\cdot\boldsymbol{y}$, subject to total primary input cost $\boldsymbol{W}\cdot\boldsymbol{z}$ to be equal to or less than the given input cost $\boldsymbol{W}\cdot\boldsymbol{x}$. The price vectors $\boldsymbol{p}$ and $\boldsymbol{w}$ in definition (29) could be nominal price vectors $(\boldsymbol{P},\boldsymbol{W})$ or the real price vectors $(\boldsymbol{p},\boldsymbol{w})$: if producers solve constrained maximization problem defined by (29) using nominal prices, the $(\boldsymbol{y}^*,\boldsymbol{z}^*)$ solution to this problem will also solve the same problem where nominal prices for outputs and inputs are replaced by the corresponding real prices $\boldsymbol{p}\equiv\boldsymbol{P}/p_1$ and $\boldsymbol{w}\equiv\boldsymbol{W}/p_1$. Thus we assume that the $\boldsymbol{p}^t$ and $\boldsymbol{w}^t$ which appear in the cost constrained value added functions defined below are the real price vectors defined in the previous section.

Due to our assumptions on the year t national production possibilities set S^t, the year t cost constrained value added function $R^t(\boldsymbol{p},\boldsymbol{w},\boldsymbol{x})$ can be calculated for any hypothetical $\boldsymbol{p},\boldsymbol{w}$ and $\boldsymbol{x}$ by solving the very simple maximization problem, $\max_s\{\boldsymbol{p}\cdot\boldsymbol{y}^s/\boldsymbol{w}\cdot\boldsymbol{x}^s : s = 1,2,\ldots,t\}$, which involves taking the maximum of t numbers.

The cost constrained value added function defined by (29) can be used to decompose real GDP growth from year $t-1$ to year t, $\boldsymbol{p}^t\cdot\boldsymbol{y}^t/\boldsymbol{p}^{t-1}\cdot\boldsymbol{y}^{t-1}$, into various explanatory growth factors. The explanatory factors are as follows:

- efficiency changes;
- changes in real output prices;
- changes in primary inputs;
- changes in real input prices and
- technical progress.

We now define the above explanatory factors using the observed data and the function $R^t(\boldsymbol{p},\boldsymbol{w},\boldsymbol{x})$ defined by (29). Following the example of Balk (1998; 143)[1], we define the *value added efficiency* of the sector for year t, e^t, as follows:

$$e^t \equiv \boldsymbol{p}^t\cdot\boldsymbol{y}^t/R^t(\boldsymbol{p}^t,\boldsymbol{w}^t,\boldsymbol{x}^t) \le 1; \qquad t = 1970,\ldots,2020. \tag{30}$$

where the inequality in (30) follows using definition (29).[*30] Thus if $e^t = 1$, then production is allocatively efficient in year t and if $e^t < 1$, then production for the sector during period t is allocatively inefficient. Note that the above definition of value added efficiency is a net revenue counterpart to Farrell's (1957; 255)[29] cost based measure of *overall efficiency.*

Define an index of the *change in real value added efficiency* ε^t for the production sector over the years $t-1$ and t as follows:

$$\varepsilon^t \equiv e^t/e^{t-1} = [\boldsymbol{p}^t\cdot\boldsymbol{y}^t/R^t(\boldsymbol{p}^t,\boldsymbol{w}^t,\boldsymbol{x}^t)]/[\boldsymbol{p}^{t-1}\cdot\boldsymbol{y}^{t-1}/R^{t-1}(\boldsymbol{p}^{t-1},\boldsymbol{w}^{t-1},\boldsymbol{x}^{t-1})]; \qquad t = 1971,\ldots,2020. \tag{31}$$

[*29] The cost constrained value added function and its properties are discussed in Diewert and Fox (2018)[15] with references to the literature. It is a relabeling of Diewert's (1983; 1086)[11] *balance of trade restricted value added function.*

[*30] Use the fact that $(\boldsymbol{y}^t,\boldsymbol{x}^t)$ is a feasible solution for the maximization problems in equations (29).

Thus if $\varepsilon^t > 1$, then real value added efficiency has *improved* going from year $t-1$ to t whereas it has *fallen* if $\varepsilon^t < 1$.

We turn our attention to defining nonparametric measures of *real output price change* going from year $t-1$ to t. Following the example of Konüs (1939)[53] in his analysis of the true cost of living index, it is natural to single out two special cases of a family of real output price indexes: one choice is α_L^t where we use the year $t-1$ technology and set the reference input prices and quantities equal to the year $t-1$ real input prices $\boldsymbol{w}^{t-1}$ and primary input quantities $\boldsymbol{x}^{t-1}$ (which gives rise to a *Laspeyres type real output price index*) and another choice is α_P^t where we use the year t technology and set the reference input prices and quantities equal to the year t real input prices and quantities $\boldsymbol{w}^t$ and $\boldsymbol{x}^t$ (which gives rise to a *Paasche type real output price index*). We then define an overall measure of real output price change α^t by taking the geometric mean of these two indexes. These indexes are defined as follows:

$$\alpha_L^t \equiv R^{t-1}(\boldsymbol{p}^t, \boldsymbol{w}^{t-1}, \boldsymbol{x}^{t-1})/R^{t-1}(\boldsymbol{p}^{t-1}, \boldsymbol{w}^{t-1}, \boldsymbol{x}^{t-1}); \qquad t = 1971, \ldots, 2020; \tag{32}$$

$$\alpha_P^t \equiv R^t(\boldsymbol{p}^t, \boldsymbol{w}^t, \boldsymbol{x}^t)/R^t(\boldsymbol{p}^{t-1}, \boldsymbol{w}^t, \boldsymbol{x}^t); \qquad t = 1971, \ldots, 2020; \tag{33}$$

$$\alpha^t \equiv [\alpha_L^t \alpha_P^t]^{1/2}; \qquad t = 1971, \ldots, 2020. \tag{34}$$

Two natural measures of *input quantity change* are the Laspeyres and Paasche input quantity indexes. Denote these year t indexes as β_L^t and β_P^t. Again it is natural to take the geometric average of these two indexes which gives rise to the Fisher ideal input quantity index, β^t. These indexes are defined as follows:

$$\beta_L^t \equiv \boldsymbol{w}^{t-1} \cdot \boldsymbol{x}^t / \boldsymbol{w}^{t-1} \cdot \boldsymbol{x}^{t-1}; \qquad t = 1971, \ldots, 2020; \tag{35}$$

$$\beta_P^t \equiv \boldsymbol{w}^t \cdot \boldsymbol{x}^t / \boldsymbol{w}^t \cdot \boldsymbol{x}^{t-1}; \qquad t = 1971, \ldots, 2020; \tag{36}$$

$$\beta^t \equiv [\beta_L^t \beta_P^t]^{1/2}; \qquad t = 1971, \ldots, 2020. \tag{37}$$

We now consider indexes which measures the effects on cost constrained value added of a change in real input prices going from period $t-1$ to t. Thus we consider measures of the change in cost constrained value added of the form $R^s(\boldsymbol{p}, \boldsymbol{w}^t, \boldsymbol{x})/R^s(\boldsymbol{p}, \boldsymbol{w}^{t-1}, \boldsymbol{x})$. Since $R^s(\boldsymbol{p}, \boldsymbol{w}, \boldsymbol{x})$ is homogeneous of degree 0 in the components of $\boldsymbol{w}$, it can be seen that we cannot interpret $R^s(\boldsymbol{p}, \boldsymbol{w}^t, \boldsymbol{x})/R^s(\boldsymbol{p}, \boldsymbol{w}^{t-1}, \boldsymbol{x})$ as an input price index. If there is only one primary input, $R^s(\boldsymbol{p}, \boldsymbol{w}^t, \boldsymbol{x})/R^s(\boldsymbol{p}, \boldsymbol{w}^{t-1}, \boldsymbol{x})$ is equal to $R^s(\boldsymbol{p}, 1, \boldsymbol{x})/R^s(\boldsymbol{p}, 1, \boldsymbol{x}) = 1$ and this measure of input price change will be independent of changes in the price of the single input. In the case where the number of primary inputs is greater than 1, it is best to interpret $R^s(\boldsymbol{p}, \boldsymbol{w}^t, \boldsymbol{x})/R^s(\boldsymbol{p}, \boldsymbol{w}^{t-1}, \boldsymbol{x})$ as measuring the effects on cost constrained value added of a change in the relative proportions of primary inputs used in production or in the *mix* of inputs used in production that is induced by a change in relative input prices when there is more than one primary input. As usual, we will consider two special cases of this family of input mix indexes, Case 1 and Case 2. The first case index, γ_1^t, will use the period t cost constrained value added function and the period $t-1$ reference vectors $\boldsymbol{p}^{t-1}$ and $\boldsymbol{x}^{t-1}$ while the second case index, γ_2^t, will use the use the period $t-1$ cost constrained value added function and the period t reference vectors $\boldsymbol{p}^t$ and $\boldsymbol{x}^t$. As usual, we take the geometric mean of these two indexes γ^t to provide a measure of the overall effects of a change in input prices.*31

$$\gamma_1^t \equiv R^t(\boldsymbol{p}^{t-1}, \boldsymbol{w}^t, \boldsymbol{x}^t)/R^t(\boldsymbol{p}^{t-1}, \boldsymbol{w}^{t-1}, \boldsymbol{x}^t); \qquad t = 1971, \ldots, 2020; \tag{38}$$

$$\gamma_2^t \equiv R^{t-1}(\boldsymbol{p}^t, \boldsymbol{w}^t, \boldsymbol{x}^{t-1})/R^{t-1}(\boldsymbol{p}^t, \boldsymbol{w}^{t-1}, \boldsymbol{x}^{t-1}); \qquad t = 1971, \ldots, 2020; \tag{39}$$

$$\gamma^t \equiv [\gamma_1^t \gamma_2^t]^{1/2}; \qquad t = 1971, \ldots, 2020. \tag{40}$$

Finally, we use the cost constrained value added function in order to define measures of *technical progress* going from period $t-1$ to t. These measures hold $\boldsymbol{p}, \boldsymbol{w}$ and $\boldsymbol{x}$ constant and only change the technology from the period $t-1$ technology to the period t technology.*32 Thus, these measures are of the form $R^t(\boldsymbol{p}, \boldsymbol{w}, \boldsymbol{x})/R^{t-1}(\boldsymbol{p}, \boldsymbol{w}, \boldsymbol{x})$. If there is positive technical progress going from period $t-1$ to t, then the production possibilities set S^t will be larger than the period $t-1$ set, S^{t-1}, and thus $R^t(\boldsymbol{p}, \boldsymbol{w}, \boldsymbol{x})$ will be equal to or greater than $R^{t-1}(\boldsymbol{p}, \boldsymbol{w}, \boldsymbol{x})$ and our measures of technical progress will be equal to or greater than 1. Our measures of technical progress cannot fall below 1.

We consider two measures of technical progress, a Laspeyres measure τ_L^t and a Paasche measure τ_P^t. However, the Laspeyres case τ_L^t will use the period t input vector $\boldsymbol{x}^t$ as the reference input vector and the period $t-1$ reference real output price and real input price vectors $\boldsymbol{p}^{t-1}$ and $\boldsymbol{w}^{t-1}$ while the Paasche case τ_P^t will use the use the period $t-1$ input vector $\boldsymbol{x}^{t-1}$ as the reference input and the period t reference real output and input price vectors $\boldsymbol{p}^t$ and $\boldsymbol{w}^t$.*33 As usual, we take our overall year t measure of technical change τ^t to be the geometric mean of the Laspeyres and Paasche measures of technical change.

$$\tau_L^t \equiv R^t(\boldsymbol{p}^{t-1}, \boldsymbol{w}^{t-1}, \boldsymbol{x}^t)/R^{t-1}(\boldsymbol{p}^{t-1}, \boldsymbol{w}^{t-1}, \boldsymbol{x}^t); \qquad t = 1971, \ldots, 2020; \tag{41}$$

$$\tau_P^t \equiv R^t(\boldsymbol{p}^t, \boldsymbol{w}^t, \boldsymbol{x}^{t-1})/R^{t-1}(\boldsymbol{p}^t, \boldsymbol{w}^t, \boldsymbol{x}^{t-1}); \qquad t = 1971, \ldots, 2020; \tag{42}$$

$$\tau^t \equiv [\tau_L^t \tau_P^t]^{1/2}; \qquad t = 1971, \ldots, 2020. \tag{43}$$

Finally, as in the previous section, we define RI_G^t to be year t *real gross income growth*. Thus define RI_G^t as follows:

$$RI_G^t \equiv \boldsymbol{p}^t \cdot \boldsymbol{y}^t / \boldsymbol{p}^{t-1} \cdot \boldsymbol{y}^{t-1}; \qquad t = 1971, \ldots, 2020. \tag{44}$$

Diewert and Fox (2018)[15] show that the following *exact decomposition of nominal income growth into explanatory growth factors* holds:

$$RI_G^t = \varepsilon^t \alpha^t \beta^t \gamma^t \tau^t; \qquad t = 1971, \ldots, 2020. \tag{45}$$

Table 9 below lists RI_G^t and the growth components on the right hand side of (45).

A new measure of *TFP growth* for the economy going from period $t-1$ to t can be defined (following Jorgenson and Griliches (1967)[43]) as an index of output growth divided by an index of input growth. An appropriate index of output growth is the net revenue ratio divided

*31 These choices of the reference vectors will make our decomposition of value added growth an exact one. Usually, these input mix growth factors are close to one for all periods.

*32 These measures of technical progress measures were defined by Diewert and Morrison (1986; 662)[18] using the country's GDP function. A special case of the family was defined earlier by Diewert (1983; 1063)[11]. Balk (1998; 99)[1] also used this definition and Balk (1998; 58)[1], following the example of Salter (1960)[60], used the joint cost function to define a similar family of technical progress indexes.

*33 In our case where the reference technology is subject to constant returns to scale, τ_L^t turns out to be independent of $\boldsymbol{x}^t$ and τ_P^t turns out to be independent of $\boldsymbol{x}^{t-1}$. These "mixed" indexes of technical progress are then true Laspeyres and Paasche type indexes.

by the net revenue price index α^t. An appropriate index of input growth is β^t. Thus define the *nonparametric year t TFP growth rate*, $NTFP_G^t$, for the Chinese economy as follows:

$$NTFP_G^t \equiv \{[\boldsymbol{p}^t \cdot \boldsymbol{y}^t/\boldsymbol{p}^{t-1} \cdot \boldsymbol{y}^{t-1}]/\alpha^t\}/\beta^t = \varepsilon^t\gamma^t\tau^t; \qquad t = 1971, \ldots, 2020. \qquad (46)$$

where the last equality in (46) follows from (45). Thus in general, the nonparametric period t TFP growth, $NTFP_G^t$, is equal to the product of period t efficiency change ε^t, a period t input mix index γ^t (which typically will be small in magnitude) and a period t measure of technical progress τ^t. The nonparametric measure of TFP growth, $NTFP_G^t$, and our old index number measure of TFP growth, TFP_G^t, are listed in Table 9 below.

Table 9: A Nonparametric Decomposition of Real GDP Growth for China

Year t	RI_G^t	ε^t	α^t	β^t	γ^t	τ^t	e^t	$NTFP_G^t$	TFP_G^t
1971	1.0278	0.9758	0.9883	1.0659	0.9998	1.0000	0.9758	0.9757	0.9761
1972	1.0375	1.0027	0.9911	1.0454	0.9987	1.0000	0.9785	1.0014	1.0016
1973	1.0310	0.9794	1.0013	1.0506	1.0007	1.0000	0.9583	0.9800	0.9794
1974	1.0128	0.9736	0.9928	1.0479	0.9999	1.0000	0.9331	0.9735	0.9730
1975	1.0470	1.0039	0.9930	1.0500	1.0003	1.0000	0.9367	1.0042	1.0046
1976	0.9959	0.9542	0.9917	1.0503	1.0020	1.0000	0.8938	0.9561	0.9576
1977	1.0699	1.0360	0.9948	1.0392	0.9989	1.0000	0.9260	1.0349	1.0355
1978	1.0765	1.0300	1.0001	1.0467	0.9984	1.0000	0.9538	1.0284	1.0276
1979	1.0589	1.0168	0.9937	1.0522	0.9960	1.0000	0.9698	1.0127	1.0128
1980	1.0597	1.0130	0.9999	1.0547	0.9919	1.0000	0.9824	1.0048	1.0048
1981	1.0213	0.9792	0.9929	1.0510	0.9994	1.0000	0.9619	0.9786	0.9810
1982	1.0652	1.0205	0.9978	1.0468	0.9993	1.0000	0.9817	1.0198	1.0197
1983	1.0917	1.0187	1.0000	1.0421	1.0003	1.0281	1.0000	1.0476	1.0483
1984	1.1622	1.0000	1.0065	1.0633	1.0000	1.0860	1.0000	1.0860	1.0860
1985	1.0689	1.0000	0.9876	1.0758	1.0000	1.0061	1.0000	1.0061	1.0062
1986	1.0744	0.9996	1.0019	1.0742	0.9987	1.0000	0.9996	0.9983	1.0009
1987	1.0633	1.0004	0.9861	1.0671	0.9993	1.0108	1.0000	1.0105	1.0119
1988	1.0764	1.0000	0.9420	1.0657	1.0000	1.0723	1.0000	1.0723	1.0720
1989	0.9791	0.9412	0.9850	1.0570	0.9992	1.0000	0.9412	0.9404	0.9396
1990	1.0440	0.9757	1.0271	1.0429	0.9990	1.0000	0.9183	0.9746	0.9694
1991	1.1291	1.0702	1.0123	1.0394	1.0027	1.0000	0.9827	1.0731	1.0712
1992	1.1485	1.0176	1.0432	1.0515	0.9997	1.0293	1.0000	1.0471	1.0475
1993	1.1541	1.0000	1.0389	1.0671	1.0000	1.0410	1.0000	1.0410	1.0410
1994	1.1262	1.0000	0.9854	1.0620	1.0000	1.0762	1.0000	1.0762	1.0754
1995	1.0274	1.0000	0.9331	1.0686	1.0000	1.0304	1.0000	1.0304	1.0304
1996	1.0601	1.0000	0.9766	1.0757	1.0000	1.0092	1.0000	1.0092	1.0092
1997	1.0693	1.0000	0.9870	1.0659	1.0000	1.0163	1.0000	1.0163	1.0163
1998	1.0873	1.0000	0.9984	1.0587	1.0000	1.0286	1.0000	1.0286	1.0287
1999	1.0626	1.0000	0.9869	1.0647	1.0000	1.0113	1.0000	1.0113	1.0113
2000	1.0875	1.0000	0.9914	1.0731	1.0000	1.0222	1.0000	1.0222	1.0222
2001	1.0782	0.9932	1.0137	1.0714	0.9994	1.0000	0.9932	0.9926	0.9924
2002	1.1425	1.0068	1.0410	1.0671	0.9994	1.0222	1.0000	1.0285	1.0285
2003	1.1298	1.0000	1.0300	1.0776	1.0000	1.0179	1.0000	1.0179	1.0179
2004	1.1279	1.0000	1.0412	1.0823	0.9996	1.0013	1.0000	1.0009	1.0009
2005	1.1554	1.0000	1.0471	1.1001	1.0000	1.0030	1.0000	1.0030	1.0030
2006	1.1223	1.0000	1.0054	1.0665	1.0000	1.0467	1.0000	1.0467	1.0467
2007	1.1880	1.0000	1.0412	1.0564	1.0000	1.0800	1.0000	1.0800	1.0801
2008	1.1494	1.0000	1.0162	1.0655	1.0000	1.0616	1.0000	1.0616	1.0616
2009	1.1208	1.0000	1.0148	1.0779	1.0000	1.0246	1.0000	1.0246	1.0246
2010	1.1013	0.9859	0.9917	1.1269	0.9995	1.0000	0.9859	0.9854	0.9857
2011	1.0629	0.9864	0.9881	1.0955	0.9956	1.0000	0.9725	0.9820	0.9813
2012	1.0741	1.0044	1.0010	1.0790	0.9901	1.0000	0.9767	0.9945	0.9930
2013	1.0746	1.0209	0.9904	1.0765	0.9872	1.0000	0.9972	1.0079	1.0070

2014	1.0269	1.0016	0.9765	1.0555	0.9947	1.0000	0.9988	0.9963	0.9963
2015	1.0607	1.0012	0.9981	1.0379	0.9996	1.0231	1.0000	1.0240	1.0237
2016	1.0320	1.0000	0.9727	1.0467	1.0000	1.0136	1.0000	1.0136	1.0136
2017	1.1094	1.0000	0.9997	1.0391	1.0000	1.0679	1.0000	1.0679	1.0679
2018	1.0605	1.0000	1.0098	1.0458	1.0000	1.0042	1.0000	1.0042	1.0042
2019	0.9877	0.9771	0.9766	1.0370	0.9982	1.0000	0.9771	0.9753	0.9748
2020	0.9959	0.9788	0.9820	1.0405	0.9958	1.0000	0.9564	0.9747	0.9747
Mean	1.0763	0.9993	0.9993	1.0612	0.9989	1.0167	0.9830	1.0149	1.0148

Our nonparametric estimate of average TFP growth rates is 1.49% per year whereas our index number estimate of average TFP growth rates was 1.48%. Table 9 shows that there is very little difference between the two sets of estimates, which helps to establish the credibility of both sets of estimates.

On average, real GDP grew at 7.63% per year. Real output price inflation averaged −0.07% per year which is negligible. There was a great deal of inefficiency in the early years of our sample. Our measure of efficiency, e^t, was below 1 for the years 1971-1982, 1986, 1989-1991, 2001 and 2010-2014 and 2019-2020. The inefficiency in the early years of our sample reflect the problems that China faced in going from a command economy to a more decentralized market economy in the late 1970s and early 1980s.

Aggregate input growth averaged 6.12% per year which is remarkable.[*34] The input mix growth factor, γ^t, was on average equal to 0.9989 which indicates a very small negative contribution to GDP growth over the sample period. The average rate of technical progress τ^t was 1.67% per year which is quite good. Note that when efficiency e^t is below 1, τ^t is equal to 1, which indicates no technical progress. Conversely, when technical progress is greater than 1, then efficiency e^t is equal to 1.

We again follow the example of Kohli (1990)[47] in order to obtain a levels decomposition for the observed level of real GDP in year t, $\boldsymbol{p}^t \cdot \boldsymbol{y}^t$, relative to its observed value in year 1 of our sample, $\boldsymbol{p}^1 \cdot \boldsymbol{y}^1$. Define the cumulated explanatory variables as follows:

$$E^{1970} \equiv 1; A^{1970} \equiv 1; B^{1970} \equiv 1; C^{1970} \equiv 1; T^{1970} \equiv 1. \tag{47}$$

For $t = 1971, \ldots, 2020$, define the above variables recursively as follows:

$$E^t \equiv \varepsilon^t E^{t-1}; A^t \equiv \alpha^t A^{t-1}; B^t \equiv \beta^t B^{t-1}; C^t \equiv \gamma^t C^{t-1}; T^t \equiv \tau^t T^{t-1}; \quad t = 1971, \ldots, 2020. \tag{48}$$

Using the above definitions, it can be seen that we have the following *levels decomposition* for the level of period t observed real GDP or real gross income RI^t to its level in 1970:

$$RI^t/RI^{1970} \equiv \boldsymbol{p}^t \cdot \boldsymbol{y}^t/\boldsymbol{p}^{1970} \cdot \boldsymbol{y}^{1970} = A^t B^t C^t E^t T^t; \qquad t = 1971, \ldots, 2020. \tag{49}$$

Define the period t level of (gross output) Nonparametric TFP, $NTFP^t$, as follows:

$$NTFP^{1970} \equiv 1;\ NTFP^t \equiv (NTFP_G^t)(NTFP^{t-1}); \qquad t = 1971, \ldots, 2020. \tag{50}$$

where $NTFP_G^t$ is defined by (46). Using (47)-(50), it can be seen that we have the following *levels decomposition for Nonparametric TFP* using the cumulated explanatory factors defined by (47) and (48):

$$NTFP^t = [\boldsymbol{p}^t \cdot \boldsymbol{y}^t/\boldsymbol{p}^1 \cdot \boldsymbol{y}^1]/[A^t B^t] = C^t E^t T^t; \qquad t = 1970, \ldots, 2020. \tag{51}$$

[*34] As the population of China starts to decline more noticeably, we can expect input growth to slow down in the future.

The components of the decomposition of real GDP relative to its 1970 level into explanatory factors which is given by (49) are listed in Table 10 below along with our nonparametric estimates of TFP levels relative to 1970, $NTFP^t$.

Table 10: Decomposition of Real GDP Growth Relative to the 1970 Level

Year t	RI^t/RI^{1970}	A^t	B^t	C^t	E^t	T^t	$NTFP^t$
1970	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1971	1.0278	0.9883	1.0659	0.9998	0.9758	1.0000	0.9757
1972	1.0664	0.9794	1.1143	0.9986	0.9785	1.0000	0.9771
1973	1.0994	0.9807	1.1707	0.9992	0.9583	1.0000	0.9576
1974	1.1135	0.9737	1.2268	0.9991	0.9331	1.0000	0.9322
1975	1.1658	0.9668	1.2881	0.9994	0.9367	1.0000	0.9361
1976	1.1610	0.9588	1.3529	1.0014	0.8938	1.0000	0.8950
1977	1.2422	0.9538	1.4060	1.0003	0.9260	1.0000	0.9263
1978	1.3372	0.9539	1.4717	0.9987	0.9538	1.0000	0.9526
1979	1.4159	0.9479	1.5485	0.9947	0.9698	1.0000	0.9647
1980	1.5005	0.9478	1.6332	0.9867	0.9824	1.0000	0.9693
1981	1.5324	0.9411	1.7165	0.9861	0.9619	1.0000	0.9486
1982	1.6323	0.9390	1.7969	0.9854	0.9817	1.0000	0.9674
1983	1.7819	0.9390	1.8724	0.9858	1.0000	1.0281	1.0134
1984	2.0710	0.9452	1.9909	0.9858	1.0000	1.1165	1.1006
1985	2.2137	0.9335	2.1417	0.9858	1.0000	1.1233	1.1073
1986	2.3784	0.9352	2.3006	0.9845	0.9996	1.1233	1.1054
1987	2.5289	0.9222	2.4549	0.9839	1.0000	1.1353	1.1170
1988	2.7222	0.8687	2.6162	0.9839	1.0000	1.2174	1.1977
1989	2.6654	0.8556	2.7654	0.9831	0.9412	1.2174	1.1264
1990	2.7825	0.8788	2.8841	0.9820	0.9183	1.2174	1.0978
1991	3.1418	0.8896	2.9978	0.9847	0.9827	1.2174	1.1781
1992	3.6084	0.9281	3.1520	0.9844	1.0000	1.2531	1.2335
1993	4.1643	0.9642	3.3636	0.9844	1.0000	1.3044	1.2840
1994	4.6900	0.9501	3.5721	0.9844	1.0000	1.4038	1.3819
1995	4.8187	0.8866	3.8170	0.9844	1.0000	1.4465	1.4239
1996	5.1085	0.8659	4.1058	0.9844	1.0000	1.4598	1.4370
1997	5.4624	0.8546	4.3765	0.9844	1.0000	1.4836	1.4604
1998	5.9392	0.8532	4.6334	0.9844	1.0000	1.5261	1.5023
1999	6.3109	0.8420	4.9331	0.9844	1.0000	1.5434	1.5193
2000	6.8631	0.8348	5.2939	0.9844	1.0000	1.5777	1.5530
2001	7.3995	0.8462	5.6721	0.9838	0.9932	1.5777	1.5416
2002	8.4539	0.8809	6.0525	0.9832	1.0000	1.6127	1.5856
2003	9.5512	0.9073	6.5223	0.9832	1.0000	1.6415	1.6140
2004	10.7729	0.9447	7.0589	0.9828	1.0000	1.6436	1.6154
2005	12.4467	0.9892	7.7657	0.9828	1.0000	1.6486	1.6203
2006	13.9686	0.9945	8.2823	0.9828	1.0000	1.7255	1.6959
2007	16.5952	1.0355	8.7495	0.9828	1.0000	1.8636	1.8317
2008	19.0751	1.0523	9.3225	0.9828	1.0000	1.9784	1.9444
2009	21.3797	1.0679	10.0490	0.9828	1.0000	2.0270	1.9922
2010	23.5445	1.0591	11.3243	0.9823	0.9859	2.0270	1.9631
2011	25.0266	1.0465	12.4054	0.9780	0.9725	2.0270	1.9278
2012	26.8822	1.0475	13.3860	0.9683	0.9767	2.0270	1.9172
2013	28.8864	1.0374	14.4103	0.9559	0.9972	2.0270	1.9322
2014	29.6626	1.0131	15.2099	0.9509	0.9988	2.0270	1.9250
2015	31.4645	1.0111	15.7861	0.9505	1.0000	2.0739	1.9713
2016	32.4709	0.9835	16.5239	0.9505	1.0000	2.1020	1.9980
2017	36.0225	0.9832	17.1705	0.9505	1.0000	2.2448	2.1337
2018	38.2017	0.9929	17.9572	0.9505	1.0000	2.2542	2.1426
2019	37.7324	0.9696	18.6219	0.9488	0.9771	2.2542	2.0897
2020	37.5777	0.9522	19.3759	0.9448	0.9564	2.2542	2.0368

Recall that RI^t/RI^{1970} is real GDP in year t relative to 1970 real GDP. From the above Table, it can be seen that Chinese real GDP grew an amazing 37.6 fold over the 51 year sample period. Real output prices grew 0.952 fold over the sample period, an aggregate of labour and capital services grew 19.4 fold, the input mix overall growth factor was 0.945 which means the input mix factor subtracted from GDP growth, the overall efficiency growth factor was 0.956 and finally, the technical progress growth factor in 2020 was 2.25 which was a substantial positive contribution to nominal GDP growth. The explanatory variables that appear on the right hand side of equations (49) are plotted on Figure 3 below.

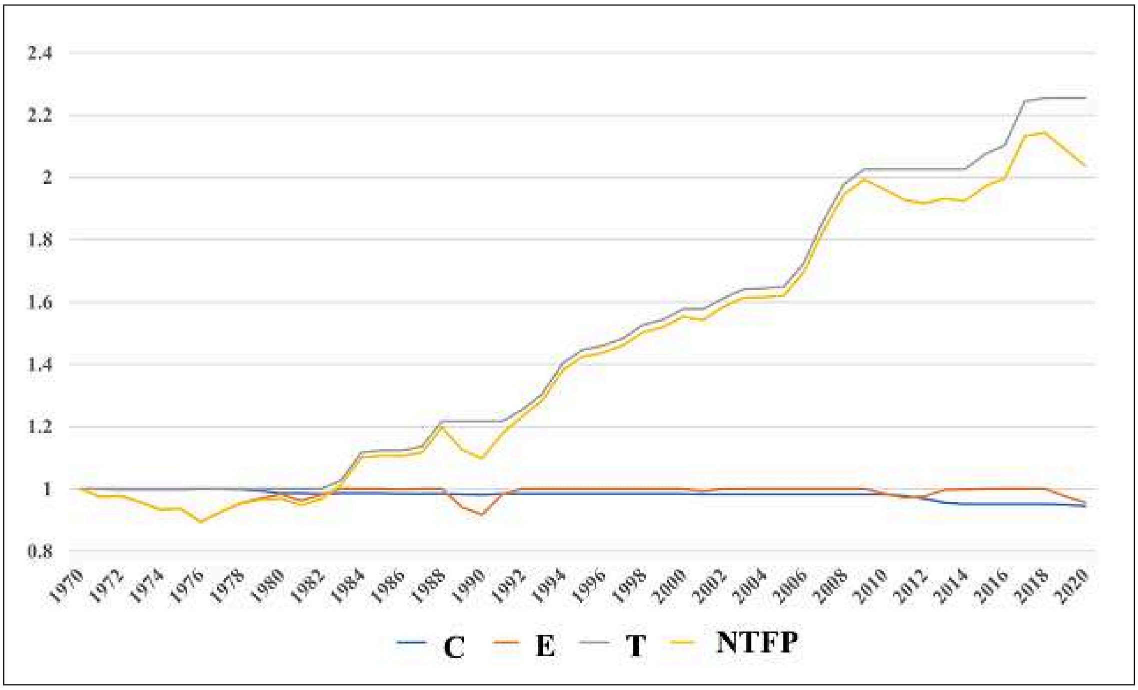

Figure 3 A Decomposition of Chinese Gross Output Nonparametric TFP into Explanatory Factors

The top line in Figure 3 plots the level of technology T^t while the line just below it plots the level of (Nonparametric) TFP, $NTFP^t$. The efficiency level line E^t almost coincides with the $NTFP^t$ line for the years 1970-1982 but then is close to the level 1 for most of the rest of the sample period with noticeable dips for the years 1989-1991 and 2019-2020. When E^t dips below 1, it drags $NTFP^t$ below T^t. The input mix line C^t stays very close to the level 1 throughout the sample period but does steadily decline over the sample period.

It can be seen that the decompositions presented in this section and the previous section have their advantages and disadvantages. The index number decomposition can measure the contributions of individual output prices and input quantities but cannot measure inefficiency. The nonparametric decomposition can measure inefficiency but can only provide the aggregate contributions of output price change and input quantity change.[*35] Both decompositions give the same measures of TFP growth to a high degree of approximation.

[*35] The nonparametric approach to the measurement of TFP could be generalized to include individual price and quantity effects but the resulting decomposition is not as straightforward as the one given by the index number methodology.

The above decompositions of real and nominal GDP are fine for many purposes but they do not accurately reflect the growth of real and nominal *income* for the Chinese economy. The gross income measure includes depreciation (which is not income) and excludes possible long-term real capital gains on assets (which are part of income). Thus, in the following section, we will look at an alternative income concept which adjusts gross income into a more realistic measure of actual income.

6 Decomposing Net Income Growth

In this section, we attempt to define a more realistic income concept that does not count depreciation as income and, in addition, allows longer term capital gains on assets to become a component of income generated by the production sector. The model we use is a generalization of the Austrian model of production that dates back to Böhm-Bawerk (1891)[4].[*36] This Neo-Austrian model of production is based on a well established model of production that is used both by economists and thoughtful accountants as the following two quotations will show:

> "We must look at the production process during a period of time, with a beginning and an end. It starts, at the commencement of the Period, with an Initial Capital Stock; to this there is applied a Flow Input of labour, and from it there emerges a Flow Output called Consumption; then there is a Closing Stock of Capital left over at the end. If Inputs are the things that are put in, the Outputs are the things that are got out, and the production of the Period is considered in isolation, then the Initial Capital Stock is an Input. A Stock Input to the Flow Input of labour; and further (what is less well recognized in the tradition, but is equally clear when we are strict with translation), the Closing Capital Stock is an Output, a Stock Output to match the Flow Output of Consumption Goods. Both input and output have stock and flow components; capital appears both as input and as output." John R. Hicks (1961; 23)[38].

> "The business firm can be viewed as a receptacle into which factors of production, or inputs, flow and out of which outputs flow...The total of the inputs with which the firm can work within the time period specified includes those inherited from the previous period and those acquired during the current period. The total of the outputs of the business firm in the same period includes the amounts of outputs currently sold and the amounts of inputs which are bequeathed to the firm in its succeeding period of activity." Edgar O. Edwards and Philip W. Bell (1961; 71-72)[24].

Hicks, Edwards and Bell obviously had the same model of production in mind: in each accounting period, the business unit combines the capital stocks and goods in process that it has inherited from the previous period with "flow" inputs purchased in the current period (such as labour, materials, services and additional durable inputs) to produce current period "flow" outputs as well as end of the period depreciated capital stock components which are regarded as outputs from the perspective of the current period (but will be regarded as inputs from the perspective of the next period).

In what follows, we use the notation that was used in section 2 above. In the new measurement framework, gross investment disappears from the list of outputs produced by the production

[*36] Further contributions to this model were made by Hicks (1946; 230)[37] (1973; 27-35)[39] and Diewert (1977; 108-111)[9] (1980; 472-474)[10].

sector.[*37] It is replaced by the end of the period value of the capital stock less the beginning of the period value of the capital stock. This difference corresponds to the nominal value of net investment. On the income side of the accounts, the value of capital services using user costs is replaced by the value of *waiting services* which is essentially the value of direct and implicit interest payments for the use of capital plus specific property taxes (if applicable). The counterpart to equations (10) in section 2 is now the following equations, which determine a new balancing rate of return on assets for each year t, $r^{t^{**}}$:[*38]

$$\begin{aligned} &P_C^t Q_C^t + P_G^t Q_G^t + P_X^t Q_X^t - P_M^t Q_M^t + \textstyle\sum_{n=1}^{16} P_{Kn}^{t+1} Q_{Kn}^{t+1} - \sum_{n=1}^{16} P_{Kn}^t Q_{Kn}^t \\ &\quad = P_L^t Q_L^t + \textstyle\sum_{n=1}^{16} P_{Kn}^t (r^{t^{**}} + \tau_n^t) Q_{Kn}^t; \qquad t = 1970, \ldots, 2020. \end{aligned} \tag{52}$$

We use ex ante or *expected prices* to value the end of the year capital stocks. Recall that i_n^t is the year t smoothed asset n inflation rate for $n = 1, \ldots, 16$. We assume that the expected year-end price for asset n in year t is $(1 + i_n^t)$ times the beginning of year t price of asset n:

$$P_{Kn}^{t+1} \equiv (1 + i_n^t) P_{Kn}^t; \qquad n = 1, \ldots, 16; t = 1970, \ldots, 2020. \tag{53}$$

Substitute definitions (53) into equations (52) and solve the resulting equations for the *new balancing rates of return on assets* for year t, $r^{t^{**}}$, for $t = 1970, \ldots, 2020$. These new rates of return are listed in Table 11 below. These new rates of return on assets will differ somewhat from our smoothed balancing rates of return r^t (also listed in Table 11) because we are valuing the gross investment at end of the year prices instead of beginning of the year prices for assets 1-11.

In this new model of production, year t user costs U_n^t are replaced by year t *waiting costs*,[*39] P_{Wn}^t, defined as follows:

$$P_{Wn}^t \equiv (r^{t^{**}} + \tau_n^t) P_{Kn}^t; \qquad n = 1, \ldots, 16; t = 1970, \ldots, 2020. \tag{54}$$

Since the year t rates of return $r^{t^{**}}$ are positive for China, the waiting costs, P_W^t, are also positive. Thus, for the Chinese data, we do not encounter the negative user cost problem that we encountered earlier.

We use the data on the waiting costs, $P_{W1}^t, \ldots, P_{W16}^t$, along with the data on the beginning of the year asset stocks, $Q_{K1}^t, \ldots, Q_{K16}^t$, to form *five waiting services aggregates* for our five types of aggregate capital. Denote the prices and quantities for these aggregate waiting services by $P_{WM}^t, P_{WS}^t, P_{WO}^t, P_{WI}^t, P_{WL}^t$ and $Q_{WM}^t, Q_{WS}^t, Q_{WO}^t, Q_{WI}^t, Q_{WL}^t$. These aggregate waiting costs are listed in Table 11 below (with prices normalized to equal 1 in 1970) and the corresponding waiting services aggregates are listed in Table 12 below along with the corresponding values.[*40] Finally, the year t price and quantity of *aggregate input*, $P_Z^{t^*}$ and $Q_Z^{t^*}$,

[*37] See Diewert and Fox (2022)[16] for a more detailed explanation and justification for the use of equations (52).

[*38] Note that Q_{Kn}^t appears on both sides of equation (52). Thus we have decomposed the consolidated cost of purchasing a unit of capital stock n at the beginning of period t, $(1 + r^{t^{**}} + \tau_n^t) P_{Kn}^t$, into two terms in order to provide a measure of period t income that is defined by the right hand side of (52). This measure of income can be distributed to the labour and capital primary inputs.

[*39] Rymes (1968)[58] (1983)[59] appears to have introduced this terminology. He was a strong advocate for replacing user costs by waiting costs.

[*40] These capital services input subaggregates were formed using Törnqvist direct aggregation of input quantities; i.e., bilateral chained quantity indexes were formed first (quantities were always positive) and then the corresponding aggregate price indexes were calculated by deflating total value by the quantity index.

were calculated by aggregating the five waiting services subaggregates with aggregate labour, P_L^t and Q_L^t.[*41] These aggregate input prices and quantities are listed below in Table 14.

Table 11: Balancing Rates of Return and Price Indexes for Labour and Waiting Services

Year t	$r^{t^{**}}$	r^t	P_L^t	P_{WM}^t	P_{WS}^t	P_{WO}^t	P_{WI}^t	P_{WL}^t
1970	0.12432	0.12441	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
1971	0.12324	0.12300	1.01017	0.98667	1.00662	0.98530	0.99595	1.05032
1972	0.12175	0.12117	1.06223	0.95357	1.00057	0.99356	0.99174	1.08452
1973	0.12299	0.12219	1.06885	0.97917	1.05174	1.07206	1.00303	1.14541
1974	0.12215	0.12102	1.07210	0.98980	1.04497	1.03678	0.99777	1.18655
1975	0.13172	0.13027	1.08392	1.03583	1.13847	1.21863	1.07842	1.32951
1976	0.11598	0.11428	1.09156	0.90952	1.01476	1.14789	0.94705	1.20149
1977	0.14330	0.14108	1.11117	1.11913	1.26830	1.49511	1.17579	1.51555
1978	0.15356	0.15120	1.18479	1.21125	1.37815	1.62984	1.25548	1.70220
1979	0.16117	0.15895	1.28036	1.29038	1.48059	1.78127	1.34450	1.94113
1980	0.15819	0.15483	1.42868	1.26741	1.55333	1.72604	1.41525	2.11631
1981	0.16130	0.15743	1.44613	1.29863	1.62116	1.77694	1.50098	2.42004
1982	0.17802	0.17363	1.47941	1.44084	1.84302	2.00348	1.70754	2.98252
1983	0.20192	0.19682	1.52109	1.60167	2.19596	2.17622	1.95556	3.79854
1984	0.22203	0.21558	1.74143	1.78699	2.55902	2.44275	2.18484	4.72048
1985	0.22569	0.21836	2.00989	1.88042	2.81243	2.67552	2.29782	5.39588
1986	0.21506	0.20695	2.28369	1.87122	2.92633	2.69315	2.35391	5.80475
1987	0.22458	0.21564	2.48508	1.98243	3.28404	2.86107	2.65717	6.91727
1988	0.23412	0.22506	2.91181	2.27836	3.86746	3.32291	2.95787	8.36285
1989	0.21941	0.21081	3.17887	2.30921	3.88246	3.44945	3.17691	9.07581
1990	0.21249	0.20520	3.46380	2.44465	4.02024	3.69119	3.23343	10.10835
1991	0.22852	0.22032	3.78100	2.80710	4.74235	4.08052	3.70650	12.81426
1992	0.22770	0.21915	4.28333	3.08872	5.52487	4.39503	3.82217	15.09742
1993	0.21612	0.20746	5.20646	3.44755	6.90158	4.84144	3.79431	17.43785
1994	0.21359	0.20636	6.92044	3.65712	7.53449	5.11736	4.20082	20.66918
1995	0.22848	0.22172	8.15375	4.11283	8.44461	5.87037	5.63374	27.13299
1996	0.22549	0.21886	9.04757	4.07947	8.75612	6.02291	6.30698	30.83771
1997	0.22076	0.21521	9.67671	3.95016	8.83003	5.79684	6.44845	34.09368
1998	0.21332	0.20851	9.99464	3.76774	8.54912	5.28894	6.20823	36.48272
1999	0.20788	0.20413	10.41900	3.57058	8.34885	5.00240	5.78405	39.13542
2000	0.21353	0.21068	10.75174	3.59205	8.66298	5.18243	5.81109	44.64475
2001	0.20457	0.20204	11.36884	3.42210	8.42779	5.16621	5.66283	47.86938
2002	0.20078	0.19816	11.95922	3.30285	8.46013	4.79016	5.56723	52.62542
2003	0.19185	0.18923	13.32518	3.09273	8.44409	4.76659	5.31362	56.47958
2004	0.18571	0.18314	15.07586	3.00576	8.86496	4.87519	5.33176	62.05183
2005	0.18073	0.17791	16.58724	2.94286	9.11616	4.90870	5.68459	70.77599
2006	0.18761	0.18472	19.29728	3.09988	9.85501	5.25977	6.14315	87.55691
2007	0.19308	0.19041	23.47325	3.19907	10.80051	5.38530	6.54135	107.98685
2008	0.19001	0.18688	27.70863	3.18503	11.56050	5.21760	6.84094	129.33378
2009	0.18807	0.18328	30.77075	3.10822	11.04857	5.00881	7.26864	151.83078
2010	0.17889	0.17550	32.58420	2.98186	11.05824	5.01058	6.56766	165.51051
2011	0.16236	0.15932	37.84829	2.76090	10.99510	4.74376	6.41408	168.89664
2012	0.14512	0.14218	43.03437	2.46120	10.04165	4.18498	6.10498	169.46795
2013	0.13558	0.13254	47.85866	2.28415	9.44053	3.93799	5.67318	175.06528
2014	0.12387	0.12108	52.66391	2.07791	8.70755	3.61274	5.14487	180.32902
2015	0.12291	0.12010	58.59600	2.04104	8.39833	3.58625	5.01511	201.95573
2016	0.12401	0.12148	61.38581	2.04542	8.41189	3.76530	4.81480	228.31355
2017	0.13713	0.13392	66.10905	2.27469	10.00917	4.22124	5.26844	276.03030
2018	0.13210	0.12880	71.55850	2.21550	10.34370	4.13493	5.31749	287.65761
2019	0.12045	0.11804	78.30957	2.02712	9.72047	3.75481	4.99356	280.40940

[*41] The year t aggregate price and quantity, $P_Z^{t^*}$ and $Q_Z^{t^*}$, were calculated using Törnqvist direct aggregation of input quantities. The year t total value of net income is $V_Z^{t^*} \equiv P_Z^{t^*} Q_Z^{t^*}$.

2020	0.11371	0.11127	83.20997	1.90654	9.14698	3.50861	4.75749	280.38985
Mean	0.17621	0.17216	17.95800	2.35580	6.09990	3.58070	3.96810	69.28900

The average of the new balancing rates of return $r^{t^{**}}$ is 17.62%, which is somewhat higher than our previous average (smoothed) rate of return for the gross output model which was 17.22%. There is an 83.2 fold increase in quality-adjusted wage rates over the sample period and a 280.4 fold increase in the price of waiting services for land. For Table 12 below, the units of measurement for the quantity indexes are in trillions of 1970 yuan and in trillions of current yuan for the value estimates.

Table 12: Quantity Indexes and Current Yuan Values for Labour and Waiting Services

Year	Q_L^t	Q_{WM}^t	Q_{WS}^t	Q_{WO}^t	Q_{WI}^t	Q_{WL}^t	V_L^t	V_{WM}^t	V_{WS}^t	V_{WO}^t	V_{WI}^t	V_{WL}^t
1970	0.1474	0.0114	0.0259	0.0015	0.0060	0.0275	0.1474	0.0114	0.0259	0.0015	0.0060	0.0275
1971	0.1548	0.0132	0.0281	0.0016	0.0070	0.0275	0.1563	0.0130	0.0283	0.0016	0.0070	0.0289
1972	0.1583	0.0148	0.0309	0.0018	0.0076	0.0276	0.1682	0.0142	0.0309	0.0018	0.0076	0.0299
1973	0.1640	0.0163	0.0339	0.0020	0.0082	0.0277	0.1753	0.0159	0.0356	0.0021	0.0083	0.0317
1974	0.1696	0.0178	0.0368	0.0021	0.0088	0.0278	0.1818	0.0176	0.0384	0.0022	0.0088	0.0330
1975	0.1760	0.0192	0.0404	0.0023	0.0089	0.0279	0.1908	0.0199	0.0460	0.0028	0.0095	0.0371
1976	0.1816	0.0212	0.0446	0.0025	0.0085	0.0280	0.1982	0.0193	0.0453	0.0028	0.0081	0.0336
1977	0.1867	0.0225	0.0484	0.0025	0.0083	0.0281	0.2075	0.0251	0.0614	0.0038	0.0098	0.0426
1978	0.1929	0.0235	0.0531	0.0026	0.0092	0.0282	0.2285	0.0285	0.0732	0.0043	0.0115	0.0480
1979	0.1995	0.0252	0.0582	0.0028	0.0105	0.0283	0.2554	0.0326	0.0862	0.0049	0.0142	0.0549
1980	0.2080	0.0260	0.0645	0.0029	0.0123	0.0284	0.2972	0.0329	0.1001	0.0051	0.0174	0.0601
1981	0.2164	0.0263	0.0717	0.0031	0.0134	0.0285	0.3129	0.0341	0.1162	0.0055	0.0201	0.0689
1982	0.2257	0.0256	0.0793	0.0032	0.0139	0.0286	0.3339	0.0369	0.1462	0.0065	0.0237	0.0853
1983	0.2319	0.0260	0.0874	0.0034	0.0140	0.0287	0.3528	0.0417	0.1919	0.0074	0.0273	0.1091
1984	0.2456	0.0270	0.0957	0.0037	0.0148	0.0289	0.4277	0.0483	0.2448	0.0090	0.0324	0.1363
1985	0.2604	0.0297	0.1052	0.0041	0.0180	0.0290	0.5233	0.0559	0.2959	0.0110	0.0414	0.1567
1986	0.2719	0.0347	0.1161	0.0046	0.0219	0.0292	0.6208	0.0650	0.3398	0.0125	0.0515	0.1695
1987	0.2831	0.0403	0.1270	0.0052	0.0248	0.0293	0.7036	0.0799	0.4172	0.0148	0.0659	0.2029
1988	0.2947	0.0477	0.1386	0.0058	0.0261	0.0294	0.8580	0.1086	0.5359	0.0191	0.0771	0.2462
1989	0.3003	0.0556	0.1517	0.0064	0.0303	0.0296	0.9547	0.1285	0.5889	0.0219	0.0963	0.2683
1990	0.3070	0.0590	0.1628	0.0067	0.0352	0.0297	1.0635	0.1443	0.6544	0.0246	0.1138	0.2999
1991	0.3154	0.0614	0.1727	0.0070	0.0386	0.0298	1.1925	0.1724	0.8190	0.0287	0.1429	0.3818
1992	0.3267	0.0654	0.1835	0.0075	0.0458	0.0299	1.3993	0.2020	1.0140	0.0331	0.1750	0.4517
1993	0.3411	0.0740	0.1991	0.0081	0.0513	0.0300	1.7759	0.2551	1.3743	0.0394	0.1946	0.5238
1994	0.3471	0.0887	0.2181	0.0089	0.0547	0.0302	2.4018	0.3243	1.6434	0.0457	0.2300	0.6237
1995	0.3565	0.1055	0.2400	0.0100	0.0592	0.0303	2.9065	0.4341	2.0271	0.0586	0.3334	0.8225
1996	0.3703	0.1206	0.2673	0.0111	0.0665	0.0304	3.3500	0.4921	2.3405	0.0668	0.4192	0.9381
1997	0.3796	0.1365	0.2959	0.0123	0.0739	0.0305	3.6732	0.5390	2.6130	0.0712	0.4767	1.0404
1998	0.3839	0.1567	0.3258	0.0140	0.0786	0.0306	3.8371	0.5903	2.7849	0.0740	0.4882	1.1164
1999	0.3947	0.1803	0.3574	0.0155	0.0818	0.0307	4.1119	0.6436	2.9835	0.0775	0.4734	1.2006
2000	0.4122	0.2057	0.3918	0.0175	0.0863	0.0307	4.4322	0.7387	3.3946	0.0907	0.5013	1.3720
2001	0.4260	0.2353	0.4300	0.0200	0.0922	0.0308	4.8432	0.8053	3.6242	0.1035	0.5224	1.4736
2002	0.4346	0.2701	0.4717	0.0229	0.0988	0.0308	5.1977	0.8922	3.9910	0.1098	0.5502	1.6231
2003	0.4499	0.3142	0.5174	0.0271	0.1045	0.0312	5.9947	0.9718	4.3694	0.1291	0.5552	1.7632
2004	0.4636	0.3767	0.5703	0.0313	0.1137	0.0316	6.9892	1.1324	5.0554	0.1527	0.6063	1.9593
2005	0.4942	0.4538	0.6308	0.0362	0.1223	0.0319	8.1978	1.3353	5.7501	0.1775	0.6953	2.2601
2006	0.4946	0.5524	0.6910	0.0418	0.1288	0.0323	9.5446	1.7124	6.8102	0.2201	0.7911	2.8320
2007	0.4851	0.6669	0.7553	0.0485	0.1423	0.0327	11.3878	2.1334	8.1580	0.2609	0.9310	3.5338
2008	0.4812	0.8075	0.8285	0.0571	0.1653	0.0331	13.3325	2.5718	9.5775	0.2979	1.1308	4.2769
2009	0.4889	0.9738	0.9060	0.0713	0.1859	0.0347	15.0436	3.0268	10.0097	0.3572	1.3510	5.2743
2010	0.5363	1.1900	1.0138	0.0921	0.2069	0.0362	17.4760	3.5486	11.2104	0.4616	1.3589	5.9941
2011	0.5539	1.4485	1.1309	0.1162	0.2368	0.0373	20.9636	3.9990	12.4342	0.5511	1.5191	6.3072
2012	0.5638	1.6727	1.2744	0.1422	0.2658	0.0381	24.2623	4.1168	12.7969	0.5950	1.6226	6.4531

2013	0.5755	1.9447	1.4197	0.1739	0.2919	0.0384	27.5422	4.4420	13.4024	0.6848	1.6561	6.7221
2014	0.5710	2.1874	1.5902	0.2084	0.3209	0.0389	30.0689	4.5453	13.8468	0.7527	1.6508	7.0128
2015	0.5558	2.3919	1.7783	0.2432	0.3465	0.0390	32.5660	4.8820	14.9349	0.8720	1.7377	7.8671
2016	0.5565	2.5475	1.9808	0.2785	0.3671	0.0394	34.1585	5.2108	16.6626	1.0486	1.7675	8.9990
2017	0.5482	2.7438	2.1872	0.3111	0.3895	0.0398	36.2437	6.2412	21.8921	1.3131	2.0520	10.9843
2018	0.5444	2.9778	2.3990	0.3442	0.4119	0.0419	38.9578	6.5973	24.8145	1.4231	2.1904	12.0552
2019	0.5327	3.2263	2.6248	0.3815	0.4275	0.0437	41.7167	6.5400	25.5145	1.4324	2.1348	12.2625
2020	0.5322	3.4467	2.8620	0.4249	0.4433	0.0438	44.2873	6.5713	26.1790	1.4908	2.1090	12.2703

We need to form a new net investment aggregate. The year t value of this investment aggregate is $V_I^{t^*}$ which is defined as follows:

$$V_I^{t^*} \equiv \textstyle\sum_{n=1}^{16}(1+i_n^t)P_{Kn}^t Q_{Kn}^{t+1} - \sum_{n=1}^{16} P_{Kn}^t Q_{Kn}^t; \qquad t = 1970,\ldots,2020. \qquad (55)$$

The year t price index for this net investment aggregate is $P_I^{t^*}$ which is calculated as the direct Törnqvist price index of the 32 components of this aggregate. The Q_{Kn}^{t+1} enter the index number formula with plus signs and the Q_{Kn}^t enter the index formula with minus signs. The new year t net investment aggregate quantity $Q_I^{t^*}$ is defined as $V_I^{t^*}/P_I^{t^*}$. Once the $P_I^{t^*}$ and $Q_I^{t^*}$ have been defined, a new year t net output aggregate $V_Y^{t^*}$ can be defined as follows:

$$V_Y^{t^*} \equiv P_C^t Q_C^t + P_G^t Q_G^t + P_I^{t^*} Q_I^{t^*} + P_X^t Q_X^t - P_M^t Q_M^t; \qquad t = 1970,\ldots,2020. \qquad (56)$$

The year t price index for this net output aggregate is $P_Y^{t^*}$ which is calculated as the direct Törnqvist price index of the 5 components of this aggregate. The quantities enter the index number formula with plus signs except for imports, Q_M^t, which enters the index formula with a minus sign. The new year t net output aggregate quantity $Q_Y^{t^*}$ is defined as $V_Y^{t^*}/P_Y^{t^*}$. The new net investment aggregates and the new measures of net output (and net income) are compared with our old gross investment and gross output measures in Table 13 below.

Table 13: Net Output, Gross Output and Investment Aggregates for China

Year	$P_Y^{t^*}$	P_Y^t	$Q_Y^{t^*}$	Q_Y^t	$V_Y^{t^*}$	V_Y^t	$P_I^{t^*}$	P_I^t	$Q_I^{t^*}$	Q_I^t	$V_I^{t^*}$	V_I^t
1970	1.0000	1.0000	0.2197	0.2360	0.2197	0.2360	1.0000	1.0000	0.0492	0.0655	0.0492	0.0655
1971	1.0381	1.0235	0.2267	0.2456	0.2353	0.2513	1.0659	1.0058	0.0486	0.0674	0.0518	0.0678
1972	1.0716	1.0408	0.2357	0.2571	0.2526	0.2676	1.1293	1.0010	0.0486	0.0699	0.0549	0.0699
1973	1.1170	1.0713	0.2408	0.2646	0.2690	0.2834	1.2274	1.0282	0.0487	0.0722	0.0598	0.0742
1974	1.1551	1.0917	0.2439	0.2697	0.2818	0.2945	1.3168	1.0365	0.0504	0.0763	0.0664	0.0791
1975	1.1968	1.1131	0.2557	0.2845	0.3061	0.3167	1.4052	1.0392	0.0560	0.0860	0.0787	0.0894
1976	1.2271	1.1250	0.2504	0.2862	0.3073	0.3219	1.5021	1.0492	0.0494	0.0847	0.0743	0.0889
1977	1.2775	1.1535	0.2740	0.3079	0.3501	0.3552	1.6021	1.0574	0.0610	0.0973	0.0978	0.1029
1978	1.3410	1.1927	0.2938	0.3312	0.3940	0.3951	1.7110	1.0730	0.0697	0.1122	0.1193	0.1204
1979	1.4346	1.2566	0.3124	0.3530	0.4482	0.4436	1.8478	1.1017	0.0744	0.1207	0.1375	0.1329
1980	1.5496	1.3234	0.3309	0.3741	0.5127	0.4951	2.0966	1.1515	0.0765	0.1240	0.1604	0.1428
1981	1.6397	1.3645	0.3402	0.3857	0.5578	0.5263	2.3349	1.1781	0.0738	0.1196	0.1724	0.1409
1982	1.7386	1.4087	0.3638	0.4117	0.6325	0.5800	2.6073	1.2083	0.0797	0.1285	0.2077	0.1552
1983	1.8483	1.4536	0.3951	0.4498	0.7303	0.6538	2.9341	1.2452	0.0878	0.1454	0.2575	0.1811
1984	1.9943	1.5242	0.4506	0.5194	0.8986	0.7916	3.3169	1.3038	0.1074	0.1912	0.3563	0.2493
1985	2.2382	1.6730	0.4844	0.5622	1.0842	0.9406	3.7735	1.3948	0.1237	0.2318	0.4669	0.3232
1986	2.4414	1.7716	0.5157	0.6044	1.2590	1.0707	4.3252	1.5006	0.1267	0.2397	0.5479	0.3596
1987	2.6729	1.8860	0.5553	0.6526	1.4843	1.2308	4.8734	1.5781	0.1324	0.2483	0.6452	0.3918
1988	2.9692	2.0510	0.6214	0.7456	1.8451	1.5292	5.6656	1.7707	0.1506	0.3033	0.8530	0.5371
1989	3.3189	2.2601	0.6202	0.7405	2.0585	1.6735	6.3400	1.8992	0.1426	0.2734	0.9042	0.5193
1990	3.6510	2.4813	0.6301	0.7486	2.3006	1.8575	6.9183	2.0450	0.1383	0.2511	0.9566	0.5135
1991	3.9788	2.6885	0.6880	0.8335	2.7372	2.2408	7.5765	2.2046	0.1572	0.3150	1.1910	0.6945
1992	4.3224	2.9153	0.7577	0.9180	3.2752	2.6761	8.4609	2.4941	0.1808	0.3733	1.5300	0.9309

1993	5.0272	3.4081	0.8281	1.0198	4.1631	3.4755	10.2153	3.1181	0.2047	0.4500	2.0907	1.4031
1994	5.6833	3.9235	0.9271	1.1646	5.2688	4.5695	10.9787	3.4311	0.2276	0.5244	2.4984	1.7991
1995	6.4956	4.5368	1.0133	1.2823	6.5822	5.8175	11.5868	3.6241	0.2559	0.6071	2.9647	2.2000
1996	7.0218	4.9465	1.0833	1.3920	7.6066	6.8852	11.9258	3.7579	0.2704	0.6661	3.2245	2.5032
1997	7.1632	5.0762	1.1745	1.5079	8.4135	7.6542	11.9446	3.8077	0.2830	0.6884	3.3806	2.6213
1998	7.1114	5.0736	1.2502	1.6421	8.8908	8.3313	11.6713	3.7794	0.2967	0.7683	3.4634	2.9039
1999	7.0329	5.0482	1.3495	1.7681	9.4906	8.9259	11.3898	3.7444	0.3197	0.8217	3.6414	3.0767
2000	7.1632	5.1585	1.4699	1.9396	10.5295	10.0055	11.3256	3.7434	0.3503	0.9199	3.9675	3.4434
2001	7.3678	5.2887	1.5435	2.0623	11.3722	10.9071	11.5323	3.7716	0.3789	1.0354	4.3700	3.9049
2002	7.3977	5.2431	1.6713	2.2633	12.3640	11.8665	11.9428	3.7872	0.4206	1.1948	5.0227	4.5251
2003	7.6626	5.3451	1.7988	2.4826	13.7833	13.2698	12.6350	3.8597	0.4863	1.4588	6.1439	5.6304
2004	8.2533	5.6673	1.9259	2.6892	15.8954	15.2406	13.7874	4.0671	0.5403	1.6707	7.4496	6.7948
2005	8.8279	5.9393	2.0861	2.9674	18.4161	17.6243	14.9323	4.2117	0.5734	1.8451	8.5629	7.7711
2006	9.5650	6.3268	2.2907	3.3125	21.9103	20.9574	16.0194	4.3423	0.6306	2.1068	10.1011	9.1481
2007	10.2721	6.7019	2.5705	3.7796	26.4049	25.3304	17.1745	4.5119	0.7187	2.4976	12.3435	11.2689
2008	10.9984	7.0790	2.8356	4.2751	31.1874	30.2631	18.6623	4.7662	0.8245	3.0345	15.3871	14.4628
2009	11.2165	7.0918	3.1260	4.7215	35.0627	33.4838	19.0056	4.6819	0.9891	3.6780	18.7991	17.2202
2010	11.7536	7.4191	3.4074	5.2448	40.0495	38.9117	19.7916	4.8577	1.0824	4.1756	21.4216	20.2838
2011	12.6813	8.0047	3.6096	5.6382	45.7744	45.1316	21.0269	5.1576	1.1402	4.5240	23.9758	23.3331
2012	13.1145	8.2214	3.8009	6.0412	49.8467	49.6674	21.4670	5.1942	1.1851	4.8632	25.4402	25.2609
2013	13.4258	8.3871	4.0556	6.5491	54.4497	54.9280	21.6040	5.1920	1.2828	5.4297	27.7130	28.1914
2014	13.7430	8.5445	4.2114	6.8867	57.8773	58.8441	21.8216	5.1971	1.3003	5.6456	28.3744	29.3411
2015	14.1964	8.7607	4.4279	7.3169	62.8597	64.1008	21.6736	5.0906	1.3508	5.9951	29.2777	30.5187
2016	14.5938	8.9645	4.6490	7.7628	67.8470	69.5893	21.8012	5.0760	1.4125	6.4099	30.7942	32.5365
2017	15.3115	9.3787	5.1416	8.6146	78.7263	80.7931	23.0653	5.3362	1.6345	7.4524	37.7009	39.7677
2018	16.0217	9.7890	5.3701	9.0468	86.0382	88.5591	24.3190	5.5953	1.6951	7.8178	41.2223	43.7431
2019	16.6811	10.1757	5.3714	9.1458	89.6009	93.0646	24.8363	5.7029	1.5908	7.5352	39.5086	42.9723
2020	17.1864	10.4697	5.4059	9.2753	92.9078	97.1092	24.7714	5.6874	1.6098	7.7504	39.8778	44.0792
Mean	6.6508	4.4282	1.7196	2.5995	19.5250	19.5050	10.7440	3.0678	0.4938	1.8699	9.1717	9.1517

It can be seen that switching from a gross output measure to a net output measure makes a big difference in the price and quantity (or volume) of net investment relative to gross investment. The price of net investment ended up at 24.77 while the price of gross investment ended up at 5.69. The volume of net investment ended up at 1.61 while the volume of gross investment ended up at 7.75. Net investment value for 2020 was 39.88 trillion yuan in 2020 while gross investment value was 44.08 trillion yuan, a difference of 11.5%. Our net investment aggregate adds (smoothed) capital gains (or losses) on all assets that accrue over the course of each year whereas the gross investment model does not include these gains. However, gross investment does not deduct depreciation whereas net investment does. On average, the effects of increasing asset capital gains and increasing depreciation over the sample period cancel each other out in value terms. However, for some years, the difference between the value of gross and net output is quite high: in 1990, the value of net output was 23.9% higher than the value of gross output, which translates into a 23.9% difference in net income over gross income for that year.[*42]

[*42] The differences in the volumes of net and gross investments and outputs are large: the investment ratios $Q_I^{t^*}/Q_I^t$ for $t = 1970$ and 2020 were 0.751 and 0.207 respectively and the output volume ratios $Q_Y^{t^*}/Q_Y^t$ for $t = 1970$ and 2020 were 0.931 and 0.583 respectively. The gross over net output value ratios $V_Y^{t^*}/V_Y^t$ for $t = 1970$ and 2020 were 0.931 and 0.957 respectively.

The shares of labour and the five types of waiting services in net income in year t are defined as follows:[*43]

$$s_L^{t^*} \equiv V_L^t/V_Z^{t^*}; s_{WM}^t \equiv V_{WM}^t/V_Z^{t^*}; s_{WS}^t \equiv V_{WS}^t/V_Z^{t^*}; s_{WO}^t \equiv V_{WO}^t/V_Z^{t^*}; s_{WI}^t \equiv V_{WI}^t/V_Z^{t^*};$$
$$s_{WL}^t \equiv V_{WL}^t/V_Z^{t^*}; \qquad t = 1970, \ldots, 2020. \tag{57}$$

These income shares of total net income are listed in Table 14 below.

Having defined new measures of year t net output and input, $Q_Y^{t^*}$ and $Q_Z^{t^*}$, a new measure of (Net Output) *TFP* for year t, TFP^{t^*}, can be defined by dividing $Q_Y^{t^*}$ by $Q_Z^{t^*}$:

$$TFP^{t^*} \equiv Q_Y^{t^*}/Q_Z^{t^*}; \qquad t = 1970, \ldots, 2020. \tag{58}$$

A new measure of *Net Output TFP growth* is defined as follows:

$$TFP_G^{t^*} \equiv TFP^{t^*}/TFP^{t-1^*}; \qquad t = 1971, \ldots, 2020. \tag{59}$$

These TFP measures are listed in Table 14 below.

Table 14: Net TFP Levels and Growth, Input Aggregates and Input Shares

Year	TFP^{t^*}	TFP^t	$TFP_G^{t^*}$	$P_Z^{t^*}$	$Q_Z^{t^*}$	$V_Z^{t^*}$	$s_L^{t^*}$	s_{WM}^t	s_{WS}^t	s_{WO}^t	s_{WI}^t	s_{WL}^t
1970	1.0000	1.0000		1.0000	0.2197	0.2197	0.6711	0.0519	0.1179	0.0068	0.0273	0.1250
1971	0.9756	0.9761	0.9756	1.0128	0.2323	0.2353	0.6645	0.0554	0.1204	0.0069	0.0298	0.1229
1972	0.9783	0.9776	1.0027	1.0484	0.2409	0.2526	0.6657	0.0561	0.1225	0.0072	0.0300	0.1185
1973	0.9570	0.9574	0.9782	1.0689	0.2517	0.2690	0.6518	0.0592	0.1325	0.0079	0.0307	0.1179
1974	0.9304	0.9316	0.9723	1.0748	0.2622	0.2818	0.6453	0.0624	0.1364	0.0078	0.0311	0.1170
1975	0.9341	0.9359	1.0040	1.1180	0.2738	0.3061	0.6234	0.0650	0.1503	0.0091	0.0312	0.1211
1976	0.8781	0.8962	0.9400	1.0775	0.2852	0.3073	0.6449	0.0629	0.1473	0.0092	0.0262	0.1094
1977	0.9286	0.9280	1.0575	1.1863	0.2951	0.3501	0.5927	0.0718	0.1752	0.0109	0.0279	0.1216
1978	0.9538	0.9536	1.0271	1.2790	0.3081	0.3940	0.5800	0.0723	0.1858	0.0109	0.0293	0.1218
1979	0.9676	0.9659	1.0145	1.3881	0.3229	0.4482	0.5698	0.0726	0.1923	0.0110	0.0316	0.1225
1980	0.9731	0.9705	1.0057	1.5079	0.3400	0.5127	0.5796	0.0642	0.1953	0.0099	0.0338	0.1172
1981	0.9529	0.9521	0.9792	1.5625	0.3570	0.5578	0.5610	0.0611	0.2084	0.0099	0.0360	0.1236
1982	0.9732	0.9709	1.0214	1.6921	0.3738	0.6325	0.5279	0.0584	0.2312	0.0102	0.0375	0.1348
1983	1.0155	1.0178	1.0434	1.8770	0.3891	0.7303	0.4831	0.0571	0.2628	0.0101	0.0374	0.1494
1984	1.0934	1.1053	1.0767	2.1804	0.4121	0.8986	0.4760	0.0538	0.2724	0.0100	0.0361	0.1517
1985	1.0981	1.1122	1.0044	2.4578	0.4411	1.0842	0.4827	0.0515	0.2729	0.0102	0.0382	0.1445
1986	1.0950	1.1131	0.9972	2.6733	0.4710	1.2590	0.4931	0.0516	0.2699	0.0099	0.0409	0.1347
1987	1.1111	1.1264	1.0147	2.9700	0.4998	1.4843	0.4740	0.0538	0.2811	0.0100	0.0444	0.1367
1988	1.1747	1.2075	1.0572	3.4880	0.5290	1.8451	0.4650	0.0589	0.2905	0.0104	0.0418	0.1335
1989	1.1126	1.1345	0.9471	3.6926	0.5575	2.0585	0.4638	0.0624	0.2861	0.0106	0.0468	0.1303
1990	1.0835	1.0998	0.9738	3.9559	0.5816	2.3006	0.4623	0.0627	0.2845	0.0107	0.0495	0.1304
1991	1.1394	1.1780	1.0516	4.5334	0.6038	2.7372	0.4357	0.0630	0.2992	0.0105	0.0522	0.1395
1992	1.1961	1.2340	1.0497	5.1699	0.6335	3.2752	0.4273	0.0617	0.3096	0.0101	0.0534	0.1379
1993	1.2323	1.2846	1.0303	6.1947	0.6720	4.1631	0.4266	0.0613	0.3301	0.0095	0.0467	0.1258
1994	1.3092	1.3815	1.0624	7.4403	0.7082	5.2688	0.4559	0.0616	0.3119	0.0087	0.0436	0.1184
1995	1.3503	1.4235	1.0314	8.7711	0.7504	6.5822	0.4416	0.0659	0.3080	0.0089	0.0507	0.1250
1996	1.3512	1.4365	1.0007	9.4881	0.8017	7.6066	0.4404	0.0647	0.3077	0.0088	0.0551	0.1233
1997	1.3832	1.4599	1.0237	9.9080	0.8492	8.4135	0.4366	0.0641	0.3106	0.0085	0.0567	0.1237
1998	1.4022	1.5017	1.0138	9.9718	0.8916	8.8908	0.4316	0.0664	0.3132	0.0083	0.0549	0.1256
1999	1.4345	1.5187	1.0230	10.0883	0.9407	9.4906	0.4333	0.0678	0.3144	0.0082	0.0499	0.1265
2000	1.4703	1.5525	1.0250	10.5320	0.9998	10.5295	0.4209	0.0702	0.3224	0.0086	0.0476	0.1303
2001	1.4572	1.5407	0.9911	10.7363	1.0592	11.3722	0.4259	0.0708	0.3187	0.0091	0.0459	0.1296
2002	1.4970	1.5845	1.0273	11.0746	1.1164	12.3640	0.4204	0.0722	0.3228	0.0089	0.0445	0.1313
2003	1.5165	1.6129	1.0130	11.6202	1.1861	13.7833	0.4349	0.0705	0.3170	0.0094	0.0403	0.1279
2004	1.5246	1.6143	1.0053	12.5826	1.2633	15.8954	0.4397	0.0712	0.3180	0.0096	0.0381	0.1233

[*43] Note that $V_Y^{t^*} = V_Z^{t^*}$ for all t.

2005	1.5260	1.6192	1.0009	13.4711	1.3671	18.4161	0.4451	0.0725	0.3122	0.0096	0.0378	0.1227
2006	1.5962	1.6948	1.0460	15.2676	1.4351	21.9103	0.4356	0.0782	0.3108	0.0100	0.0361	0.1293
2007	1.7197	1.8306	1.0774	17.6653	1.4947	26.4049	0.4313	0.0808	0.3090	0.0099	0.0353	0.1338
2008	1.8065	1.9434	1.0505	19.8688	1.5697	31.1874	0.4275	0.0825	0.3071	0.0096	0.0363	0.1371
2009	1.8703	1.9911	1.0353	20.9781	1.6714	35.0627	0.4290	0.0863	0.2855	0.0102	0.0385	0.1504
2010	1.8404	1.9627	0.9840	21.6316	1.8514	40.0495	0.4364	0.0886	0.2799	0.0115	0.0339	0.1497
2011	1.8114	1.9261	0.9842	22.9713	1.9927	45.7744	0.4580	0.0874	0.2716	0.0120	0.0332	0.1378
2012	1.7946	1.9126	0.9907	23.5352	2.1180	49.8467	0.4867	0.0826	0.2567	0.0119	0.0326	0.1295
2013	1.8102	1.9260	1.0087	24.3039	2.2404	54.4497	0.5058	0.0816	0.2461	0.0126	0.0304	0.1235
2014	1.8069	1.9188	0.9982	24.8321	2.3307	57.8773	0.5195	0.0785	0.2392	0.0130	0.0285	0.1212
2015	1.8545	1.9642	1.0264	26.3278	2.3876	62.8597	0.5181	0.0777	0.2376	0.0139	0.0276	0.1252
2016	1.8772	1.9909	1.0122	27.3952	2.4766	67.8470	0.5035	0.0768	0.2456	0.0155	0.0261	0.1326
2017	2.0164	2.1262	1.0741	30.8735	2.5500	78.7263	0.4604	0.0793	0.2781	0.0167	0.0261	0.1395
2018	2.0239	2.1350	1.0038	32.4267	2.6533	86.0382	0.4528	0.0767	0.2884	0.0165	0.0255	0.1401
2019	1.9640	2.0813	0.9704	32.7621	2.7349	89.6009	0.4656	0.0730	0.2848	0.0160	0.0238	0.1369
2020	1.9153	2.0287	0.9752	32.9178	2.8224	92.9078	0.4767	0.0707	0.2818	0.0160	0.0227	0.1321
Mean	1.3664	1.4256	1.0136	10.8760	1.0552	19.5250	0.4961	0.0680	0.2583	0.0104	0.0375	0.1297

The level of Net Output TFP^{t^*} finished at 1.9153 which is somewhat lower than the final level for Gross Output TFP^t which was 2.0287. On average, the Net Output TFP growth rate $TFP_G^{t^*}$ was 1.36% per year whereas the average growth rate for Gross Output TFP was 1.48% per year. The labour share of net income, $s_L^{t^*}$, was quite variable. It started at 67.11% in 1970, decreased to 42.04% in 2002, increased to 51.95 in 2014 and then declined to 47.67% in 2020. Thus over the entire sample period, the net income share of capital increased enormously which is perhaps not surprising given the very large rates of gross investment for the Chinese economy. The net income share of M&E varied between 5.1% and 8.9% and the Land share varied between 10.9% and 15.2%. The income share of structures increased from 11.8% in 1970 to 28.2% in 2020, which is a very large increase. The share of inventories started at 2.7%, increased to 5.7% in 1997 and then decreased steadily to end up at 2.3% in 2020. The average share of Other Capital was small at 1.04%.

The average annual rates of Net Output TFP growth over the 5 decades were as follows: −0.22% (1970s), 1.15% (1980s), 3.11% (1990s), 2.31% (2000s), 0.44% (2010s).

The index number decomposition of GDP that was undertaken in section 4 above can be repeated using the new data for the Net Income model that was explained above in this section. Using the new data, the computations are the same as in section 4. The net income counterparts to Tables 6, 7 and 8 in section 4 are Tables 15, 16 and 17 and they are listed below.

Table 15: Net Real Income, Real Net Output Prices and Real Net Input Prices

Year t	RI^{t^*}	$p_2^{t^*}$	$p_3^{t^*}$	$p_4^{t^*}$	$p_5^{t^*}$	$w_1^{t^*}$	$w_2^{t^*}$	$w_3^{t^*}$	$w_4^{t^*}$	$w_5^{t^*}$	$w_6^{t^*}$
1970	0.2197	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1971	0.2271	0.9627	1.0288	0.9231	0.9273	0.9750	0.9523	0.9716	0.9510	0.9613	1.0137
1972	0.2376	0.9479	1.0622	0.9027	0.8831	0.9991	0.8969	0.9411	0.9345	0.9328	1.0200
1973	0.2463	0.9434	1.1238	0.9047	0.8310	0.9786	0.8965	0.9629	0.9815	0.9183	1.0487
1974	0.2515	0.9101	1.1752	0.9282	0.8200	0.9568	0.8834	0.9326	0.9253	0.8905	1.0590
1975	0.2659	0.9053	1.2208	0.8818	0.7866	0.9417	0.8999	0.9891	1.0588	0.9370	1.1551
1976	0.2616	0.8589	1.2786	0.8499	0.7708	0.9291	0.7742	0.8638	0.9771	0.8061	1.0227
1977	0.2889	0.8656	1.3223	0.8326	0.7603	0.9171	0.9237	1.0468	1.2340	0.9705	1.2509
1978	0.3148	0.9002	1.3668	0.8498	0.7517	0.9465	0.9676	1.1009	1.3020	1.0029	1.3598
1979	0.3376	0.9053	1.3921	0.8355	0.7114	0.9646	0.9721	1.1154	1.3419	1.0129	1.4624
1980	0.3667	0.9216	1.4996	0.8171	0.6988	1.0219	0.9066	1.1111	1.2346	1.0123	1.5138
1981	0.3833	0.9012	1.6045	0.7979	0.7009	0.9937	0.8924	1.1140	1.2211	1.0314	1.6630

1982	0.4201	0.8980	1.7318	0.7924	0.6904	0.9826	0.9570	1.2241	1.3307	1.1341	1.9810
1983	0.4697	0.9158	1.8874	0.8001	0.7213	0.9785	1.0303	1.4126	1.3999	1.2579	2.4434
1984	0.5548	0.9900	2.0481	0.8524	0.8125	1.0753	1.1034	1.5801	1.5083	1.3490	2.9147
1985	0.6023	1.0179	2.0961	0.9163	0.8808	1.1165	1.0446	1.5623	1.4862	1.2764	2.9974
1986	0.6601	1.0396	2.2675	1.1528	1.0903	1.1972	0.9810	1.5341	1.4119	1.2340	3.0432
1987	0.7198	1.0520	2.3633	1.1795	1.1695	1.2051	0.9613	1.5925	1.3874	1.2885	3.3544
1988	0.7752	1.0554	2.3804	0.9793	1.3798	1.2234	0.9573	1.6249	1.3961	1.2428	3.5137
1989	0.7738	1.0200	2.3832	0.7920	1.1205	1.1949	0.8680	1.4594	1.2966	1.1942	3.4115
1990	0.8134	1.0279	2.4461	1.0076	1.1919	1.2247	0.8643	1.4214	1.3051	1.1432	3.5739
1991	0.9058	1.0684	2.5072	1.0424	1.1931	1.2512	0.9289	1.5693	1.3503	1.2266	4.2405
1992	1.0423	1.1713	2.6926	1.0190	1.1576	1.3631	0.9830	1.7582	1.3987	1.2164	4.8046
1993	1.1773	1.2583	2.8888	0.8169	0.9999	1.4723	0.9749	1.9517	1.3691	1.0730	4.9313
1994	1.2763	1.3668	2.6595	1.0774	1.3191	1.6764	0.8859	1.8252	1.2396	1.0176	5.0070
1995	1.2868	1.3084	2.2652	0.8988	1.0976	1.5940	0.8040	1.6509	1.1476	1.1014	5.3044
1996	1.3320	1.2933	2.0884	0.7507	0.8835	1.5844	0.7144	1.5333	1.0547	1.1044	5.4001
1997	1.4171	1.3096	2.0119	0.6769	0.8076	1.6299	0.6653	1.4873	0.9764	1.0861	5.7425
1998	1.4959	1.3361	1.9637	0.6140	0.7228	1.6816	0.6339	1.4384	0.8899	1.0445	6.1383
1999	1.5837	1.3496	1.9006	0.6128	0.7571	1.7386	0.5958	1.3932	0.8348	0.9652	6.5306
2000	1.7047	1.3527	1.8336	0.6431	0.7925	1.7406	0.5815	1.4025	0.8390	0.9408	7.2277
2001	1.8209	1.3942	1.8465	0.6380	0.7511	1.8203	0.5479	1.3494	0.8272	0.9067	7.6647
2002	2.0790	1.5027	2.0081	0.6865	0.7845	2.0109	0.5554	1.4225	0.8054	0.9361	8.8487
2003	2.3415	1.6230	2.1464	0.7604	0.8578	2.2637	0.5254	1.4345	0.8097	0.9027	9.5947
2004	2.6518	1.7521	2.3002	0.8651	0.9429	2.5151	0.5015	1.4790	0.8133	0.8895	10.3522
2005	3.0696	1.8656	2.4890	0.9337	0.9662	2.7648	0.4905	1.5195	0.8182	0.9475	11.7971
2006	3.4468	1.9935	2.5200	0.9083	0.9167	3.0357	0.4876	1.5503	0.8274	0.9664	13.7737
2007	4.0829	2.3107	2.6557	0.9296	0.9211	3.6296	0.4947	1.6701	0.8327	1.0115	16.6977
2008	4.6396	2.5263	2.7763	0.9177	0.9211	4.1221	0.4738	1.7198	0.7762	1.0177	19.2403
2009	5.2840	2.6987	2.8641	0.8344	0.8000	4.6372	0.4684	1.6650	0.7548	1.0954	22.8809
2010	5.7195	2.6929	2.8264	0.8749	0.8431	4.6533	0.4258	1.5792	0.7156	0.9379	23.6365
2011	5.9909	2.7602	2.7520	0.8191	0.7873	4.9535	0.3613	1.4390	0.6209	0.8395	22.1049
2012	6.3676	2.8908	2.7423	0.7830	0.7407	5.4974	0.3144	1.2828	0.5346	0.7799	21.6485
2013	6.7584	2.9799	2.6815	0.7385	0.6927	5.9403	0.2835	1.1718	0.4888	0.7042	21.7294
2014	6.8859	3.0260	2.5962	0.6677	0.6348	6.2657	0.2472	1.0360	0.4298	0.6121	21.4546
2015	7.2825	3.1397	2.5109	0.6216	0.5497	6.7885	0.2365	0.9730	0.4155	0.5810	23.3971
2016	7.4719	3.1073	2.4009	0.5772	0.5071	6.7603	0.2253	0.9264	0.4147	0.5302	25.1438
2017	8.2845	3.1911	2.4272	0.5748	0.5231	6.9568	0.2394	1.0533	0.4442	0.5544	29.0471
2018	8.7597	3.3041	2.4760	0.5714	0.5283	7.2855	0.2256	1.0531	0.4210	0.5414	29.2868
2019	8.5741	3.3281	2.3766	0.5540	0.5221	7.4936	0.1940	0.9302	0.3593	0.4778	26.8331
2020	8.4853	3.2767	2.2624	0.5316	0.4802	7.5996	0.1741	0.8354	0.3204	0.4345	25.6082

There are some substantial differences between the Net Output real waiting costs listed in Table 15 compared to their user cost counterparts in Table 6. For example, the land real waiting cost $w_6^{t^*}$ is equal to 25.61 for $t = 2020$ but the corresponding land real user cost w_6^{2020} was only equal to 13.79.

Table 16: Net Real Income Growth and Real Output Price and Input Growth Contribution Factors

Year	$RI_G^{t^*}$	$TFP_G^{t^*}$	$\alpha_2^{t^*}$	$\alpha_3^{t^*}$	$\alpha_4^{t^*}$	$\alpha_5^{t^*}$	$\beta_1^{t^*}$	$\beta_2^{t^*}$	$\beta_3^{t^*}$	$\beta_4^{t^*}$	$\beta_5^{t^*}$	$\beta_6^{t^*}$
1971	1.0337	0.9756	0.9954	1.0063	0.9976	1.0026	1.0329	1.0080	1.0099	1.0007	1.0047	1.0003
1972	1.0462	1.0027	0.9981	1.0070	0.9993	1.0017	1.0151	1.0065	1.0115	1.0007	1.0024	1.0003
1973	1.0367	0.9782	0.9994	1.0125	1.0001	1.0026	1.0237	1.0052	1.0118	1.0006	1.0022	1.0004
1974	1.0211	0.9723	0.9957	1.0103	1.0013	1.0008	1.0218	1.0055	1.0110	1.0005	1.0020	1.0004
1975	1.0574	1.0040	0.9994	1.0094	0.9972	1.0027	1.0239	1.0049	1.0135	1.0006	1.0002	1.0005
1976	0.9836	0.9400	0.9937	1.0116	0.9981	1.0012	1.0198	1.0065	1.0149	1.0007	0.9989	1.0004
1977	1.1047	1.0575	1.0009	1.0088	0.9990	1.0007	1.0175	1.0037	1.0131	1.0004	0.9993	1.0004
1978	1.0894	1.0271	1.0047	1.0097	1.0010	1.0006	1.0192	1.0034	1.0170	1.0004	1.0029	1.0004
1979	1.0726	1.0145	1.0007	1.0056	0.9991	1.0035	1.0195	1.0051	1.0175	1.0006	1.0042	1.0005

1980	1.0862	1.0057	1.0022	1.0233	0.9987	1.0012	1.0244	1.0019	1.0199	1.0006	1.0050	1.0004
1981	1.0452	0.9792	0.9973	1.0212	0.9984	0.9998	1.0228	1.0007	1.0217	1.0006	1.0030	1.0004
1982	1.0960	1.0214	0.9996	1.0246	0.9995	1.0012	1.0232	0.9986	1.0225	1.0004	1.0013	1.0005
1983	1.1181	1.0434	1.0022	1.0297	1.0007	0.9969	1.0138	1.0009	1.0241	1.0005	1.0003	1.0007
1984	1.1812	1.0767	1.0093	1.0311	1.0047	0.9906	1.0278	1.0021	1.0245	1.0008	1.0022	1.0008
1985	1.0854	1.0044	1.0034	1.0096	1.0060	0.9908	1.0284	1.0050	1.0262	1.0011	1.0072	1.0008
1986	1.0960	0.9972	1.0025	1.0346	1.0225	0.9707	1.0213	1.0081	1.0272	1.0012	1.0077	1.0008
1987	1.0905	1.0147	1.0013	1.0182	1.0025	0.9909	1.0199	1.0079	1.0251	1.0011	1.0054	1.0006
1988	1.0770	1.0572	1.0003	1.0033	0.9792	0.9794	1.0189	1.0095	1.0251	1.0011	1.0021	1.0005
1989	0.9981	0.9471	0.9964	1.0005	0.9774	1.0263	1.0089	1.0094	1.0264	1.0010	1.0067	1.0005
1990	1.0512	0.9738	1.0009	1.0112	1.0303	0.9923	1.0103	1.0037	1.0204	1.0005	1.0072	1.0005
1991	1.1136	1.0516	1.0044	1.0106	1.0051	0.9999	1.0121	1.0025	1.0174	1.0005	1.0047	1.0005
1992	1.1507	1.0497	1.0107	1.0327	0.9964	1.0045	1.0153	1.0039	1.0187	1.0007	1.0091	1.0006
1993	1.1295	1.0303	1.0087	1.0347	0.9669	1.0241	1.0186	1.0076	1.0264	1.0007	1.0057	1.0005
1994	1.0841	1.0624	1.0105	0.9604	1.0528	0.9477	1.0077	1.0112	1.0297	1.0008	1.0029	1.0005
1995	1.0082	1.0314	0.9945	0.9285	0.9607	1.0399	1.0121	1.0112	1.0301	1.0010	1.0037	1.0006
1996	1.0352	1.0007	0.9986	0.9651	0.9637	1.0426	1.0169	1.0088	1.0337	1.0009	1.0061	1.0004
1997	1.0639	1.0237	1.0016	0.9847	0.9792	1.0160	1.0110	1.0080	1.0320	1.0009	1.0060	1.0004
1998	1.0556	1.0138	1.0027	0.9905	0.9804	1.0185	1.0049	1.0090	1.0304	1.0011	1.0035	1.0003
1999	1.0587	1.0230	1.0015	0.9875	0.9996	0.9922	1.0120	1.0095	1.0295	1.0008	1.0021	1.0003
2000	1.0764	1.0250	1.0004	0.9864	1.0104	0.9911	1.0188	1.0091	1.0298	1.0010	1.0026	1.0002
2001	1.0682	0.9911	1.0049	1.0027	0.9982	1.0115	1.0140	1.0095	1.0302	1.0012	1.0031	1.0002
2002	1.1417	1.0273	1.0120	1.0337	1.0178	0.9903	1.0085	1.0099	1.0301	1.0012	1.0031	1.0002
2003	1.1263	1.0130	1.0120	1.0288	1.0288	0.9770	1.0149	1.0108	1.0300	1.0015	1.0024	1.0016
2004	1.1325	1.0053	1.0116	1.0321	1.0435	0.9709	1.0132	1.0129	1.0313	1.0014	1.0033	1.0014
2005	1.1575	1.0009	1.0094	1.0375	1.0288	0.9918	1.0287	1.0135	1.0323	1.0014	1.0028	1.0014
2006	1.1229	1.0460	1.0100	1.0058	0.9892	1.0177	1.0003	1.0149	1.0288	1.0014	1.0019	1.0016
2007	1.1846	1.0774	1.0222	1.0246	1.0094	0.9984	0.9917	1.0151	1.0280	1.0015	1.0036	1.0015
2008	1.1363	1.0505	1.0134	1.0216	0.9951	1.0000	0.9965	1.0157	1.0289	1.0016	1.0054	1.0014
2009	1.1389	1.0353	1.0098	1.0162	0.9701	1.0378	1.0068	1.0159	1.0269	1.0022	1.0044	1.0071
2010	1.0824	0.9840	0.9997	0.9929	1.0138	0.9868	1.0409	1.0177	1.0323	1.0028	1.0039	1.0063
2011	1.0475	0.9842	1.0039	0.9860	0.9800	1.0194	1.0145	1.0174	1.0306	1.0027	1.0045	1.0044
2012	1.0629	0.9907	1.0077	0.9982	0.9865	1.0172	1.0084	1.0123	1.0321	1.0024	1.0038	1.0026
2013	1.0614	1.0087	1.0052	0.9886	0.9831	1.0181	1.0102	1.0124	1.0275	1.0025	1.0030	1.0011
2014	1.0189	0.9982	1.0027	0.9840	0.9720	1.0231	0.9960	1.0095	1.0279	1.0023	1.0028	1.0016
2015	1.0576	1.0264	1.0065	0.9842	0.9815	1.0346	0.9861	1.0070	1.0270	1.0021	1.0022	1.0002
2016	1.0260	1.0122	0.9982	0.9796	0.9828	1.0169	1.0006	1.0049	1.0264	1.0020	1.0016	1.0015
2017	1.1088	1.0741	1.0047	1.0051	0.9991	0.9937	0.9929	1.0058	1.0263	1.0018	1.0015	1.0013
2018	1.0574	1.0038	1.0061	1.0096	0.9987	0.9980	0.9968	1.0064	1.0265	1.0017	1.0014	1.0073
2019	0.9788	0.9704	1.0013	0.9813	0.9935	1.0024	0.9901	1.0060	1.0261	1.0017	1.0009	1.0059
2020	0.9896	0.9752	0.9971	0.9788	0.9914	1.0163	0.9996	1.0048	1.0248	1.0017	1.0008	1.0001
Mean	1.0769	1.0136	1.0035	1.0052	0.9978	1.0031	1.0131	1.0080	1.0247	1.0012	1.0034	1.0013

The sample average Net Real Income growth was 7.69% per year which is somewhat greater than the corresponding average Gross Real Income growth which was 7.63% per year. The biggest changes in the contribution factors going from the gross output model to the net output model took place in investment prices (the average contribution factor changed from −0.50% to +0.52% per year) and in M&E input services (the average contribution factor changed from 1.53% to 0.80% per year). The contribution of land services increased from 0.04% to 0.13% per year. Thus moving from the gross output measurement framework to the net output framework did lead to some substantial changes in the explanatory variables for real gross and net income growth.

Table 17 below is the net output counterpart to Table 8 in section 4. It cumulates the contribution factors listed in Table 16 into levels.

Table 17: The Levels Decomposition for Real Net Income Growth in China

Year	RI^{t^*}/RI^{1970^*}	TFP^{t^*}	$A_2^{t^*}$	$A_3^{t^*}$	$A_4^{t^*}$	$A_5^{t^*}$	$B_1^{t^*}$	$B_2^{t^*}$	$B_3^{t^*}$	$B_4^{t^*}$	$B_5^{t^*}$	$B_6^{t^*}$
1970	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1971	1.0337	0.9756	0.9954	1.0063	0.9976	1.0026	1.0329	1.0080	1.0099	1.0007	1.0047	1.0003
1972	1.0814	0.9783	0.9935	1.0134	0.9969	1.0042	1.0486	1.0146	1.0215	1.0015	1.0071	1.0006
1973	1.1211	0.9570	0.9929	1.0260	0.9970	1.0069	1.0734	1.0199	1.0335	1.0021	1.0094	1.0009
1974	1.1447	0.9304	0.9887	1.0366	0.9983	1.0077	1.0969	1.0254	1.0450	1.0026	1.0114	1.0013
1975	1.2105	0.9341	0.9880	1.0464	0.9955	1.0104	1.1231	1.0305	1.0591	1.0032	1.0116	1.0018
1976	1.1906	0.8781	0.9818	1.0585	0.9936	1.0115	1.1454	1.0372	1.0749	1.0039	1.0105	1.0022
1977	1.3153	0.9286	0.9827	1.0678	0.9927	1.0123	1.1654	1.0411	1.0890	1.0042	1.0098	1.0026
1978	1.4329	0.9538	0.9873	1.0781	0.9936	1.0129	1.1878	1.0446	1.1075	1.0046	1.0127	1.0031
1979	1.5369	0.9676	0.9880	1.0842	0.9927	1.0164	1.2109	1.0498	1.1269	1.0052	1.0170	1.0035
1980	1.6694	0.9731	0.9902	1.1095	0.9914	1.0176	1.2405	1.0519	1.1493	1.0058	1.0220	1.0039
1981	1.7449	0.9529	0.9875	1.1330	0.9898	1.0174	1.2688	1.0526	1.1743	1.0064	1.0252	1.0043
1982	1.9124	0.9732	0.9871	1.1609	0.9893	1.0186	1.2983	1.0512	1.2007	1.0068	1.0265	1.0048
1983	2.1383	1.0155	0.9893	1.1955	0.9900	1.0154	1.3162	1.0521	1.2297	1.0073	1.0268	1.0055
1984	2.5257	1.0934	0.9985	1.2326	0.9946	1.0059	1.3529	1.0543	1.2599	1.0081	1.0291	1.0063
1985	2.7415	1.0981	1.0019	1.2445	1.0006	0.9966	1.3913	1.0595	1.2930	1.0092	1.0365	1.0071
1986	3.0046	1.0950	1.0043	1.2876	1.0231	0.9674	1.4208	1.0681	1.3281	1.0104	1.0445	1.0079
1987	3.2765	1.1111	1.0057	1.3109	1.0257	0.9586	1.4490	1.0765	1.3614	1.0115	1.0501	1.0085
1988	3.5288	1.1747	1.0060	1.3152	1.0044	0.9388	1.4765	1.0868	1.3956	1.0126	1.0524	1.0090
1989	3.5223	1.1126	1.0024	1.3159	0.9816	0.9635	1.4896	1.0970	1.4324	1.0137	1.0594	1.0096
1990	3.7026	1.0835	1.0032	1.3306	1.0114	0.9561	1.5049	1.1010	1.4616	1.0142	1.0671	1.0101
1991	4.1232	1.1394	1.0076	1.3447	1.0165	0.9560	1.5231	1.1038	1.4870	1.0148	1.0720	1.0106
1992	4.7445	1.1961	1.0184	1.3886	1.0129	0.9603	1.5464	1.1081	1.5149	1.0155	1.0818	1.0112
1993	5.3591	1.2323	1.0273	1.4368	0.9794	0.9834	1.5752	1.1166	1.5549	1.0163	1.0880	1.0117
1994	5.8099	1.3092	1.0381	1.3799	1.0312	0.9320	1.5873	1.1291	1.6010	1.0171	1.0912	1.0123
1995	5.8574	1.3503	1.0324	1.2813	0.9906	0.9691	1.6064	1.1416	1.6493	1.0181	1.0952	1.0129
1996	6.0633	1.3512	1.0309	1.2365	0.9546	1.0105	1.6336	1.1517	1.7048	1.0190	1.1019	1.0133
1997	6.4507	1.3832	1.0325	1.2176	0.9348	1.0266	1.6515	1.1608	1.7592	1.0200	1.1085	1.0137
1998	6.8093	1.4022	1.0354	1.2060	0.9164	1.0456	1.6596	1.1713	1.8127	1.0211	1.1123	1.0141
1999	7.2090	1.4345	1.0369	1.1909	0.9161	1.0374	1.6796	1.1824	1.8662	1.0219	1.1147	1.0144
2000	7.7597	1.4703	1.0373	1.1747	0.9256	1.0282	1.7111	1.1932	1.9217	1.0230	1.1175	1.0146
2001	8.2887	1.4572	1.0423	1.1779	0.9239	1.0400	1.7351	1.2046	1.9799	1.0242	1.1210	1.0148
2002	9.4634	1.4970	1.0548	1.2176	0.9403	1.0299	1.7498	1.2165	2.0395	1.0254	1.1245	1.0151
2003	10.6585	1.5165	1.0675	1.2526	0.9674	1.0062	1.7758	1.2297	2.1008	1.0270	1.1272	1.0167
2004	12.0713	1.5246	1.0799	1.2929	1.0095	0.9769	1.7993	1.2456	2.1666	1.0284	1.1309	1.0181
2005	13.9730	1.5260	1.0901	1.3414	1.0386	0.9689	1.8510	1.2624	2.2366	1.0298	1.1341	1.0195
2006	15.6897	1.5962	1.1010	1.3491	1.0273	0.9861	1.8516	1.2813	2.3011	1.0313	1.1362	1.0212
2007	18.5855	1.7197	1.1255	1.3823	1.0369	0.9846	1.8362	1.3006	2.3654	1.0328	1.1403	1.0228
2008	21.1194	1.8065	1.1405	1.4122	1.0318	0.9845	1.8297	1.3211	2.4337	1.0345	1.1464	1.0242
2009	24.0526	1.8703	1.1517	1.4350	1.0009	1.0218	1.8422	1.3421	2.4990	1.0368	1.1514	1.0315
2010	26.0350	1.8404	1.1513	1.4248	1.0147	1.0084	1.9175	1.3658	2.5797	1.0396	1.1559	1.0379
2011	27.2705	1.8114	1.1558	1.4049	0.9944	1.0280	1.9454	1.3897	2.6587	1.0425	1.1612	1.0425
2012	28.9855	1.7946	1.1647	1.4023	0.9810	1.0457	1.9617	1.4068	2.7440	1.0450	1.1656	1.0453
2013	30.7642	1.8102	1.1708	1.3864	0.9644	1.0646	1.9818	1.4243	2.8195	1.0476	1.1690	1.0464
2014	31.3448	1.8069	1.1739	1.3642	0.9374	1.0892	1.9738	1.4378	2.8982	1.0500	1.1723	1.0480
2015	33.1498	1.8545	1.1816	1.3426	0.9200	1.1269	1.9464	1.4478	2.9765	1.0522	1.1748	1.0482
2016	34.0122	1.8772	1.1794	1.3152	0.9042	1.1459	1.9476	1.4549	3.0550	1.0543	1.1767	1.0498
2017	37.7112	2.0164	1.1850	1.3219	0.9034	1.1387	1.9337	1.4633	3.1353	1.0562	1.1785	1.0512
2018	39.8741	2.0239	1.1922	1.3345	0.9022	1.1364	1.9275	1.4727	3.2185	1.0579	1.1802	1.0588
2019	39.0296	1.9640	1.1937	1.3096	0.8963	1.1392	1.9084	1.4816	3.3026	1.0597	1.1813	1.0651
2020	38.6254	1.9153	1.1903	1.2819	0.8886	1.1577	1.9076	1.4886	3.3845	1.0615	1.1822	1.0652

Figure 4 below plots the 11 explanatory factors that explain real net income growth for China.

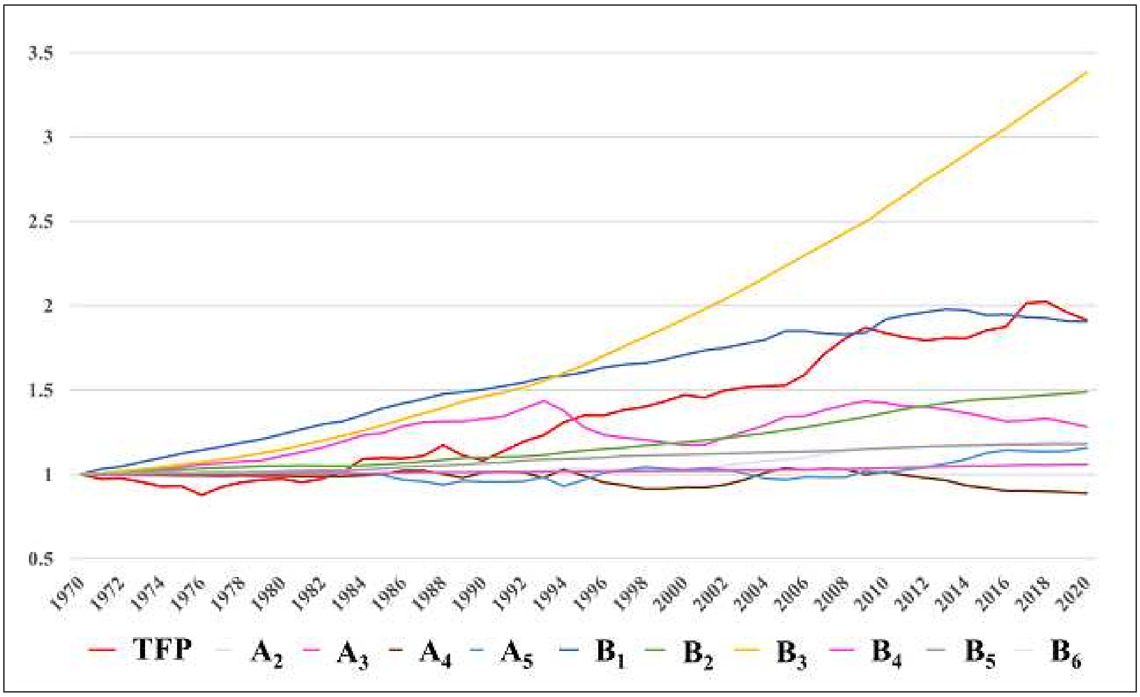

Figure 4 Explanatory Factors for Chinese Real Net Income Growth

It can be seen that the main factors which explain real net income growth are (i) Structure Waiting Services (the gold line), (ii) Labour Services (the blue line), (iii) TFP Growth (the red line), (iv) M&E Waiting Services (the bright green line) and (v) the price of real net investment (the pink line). Inventory Waiting Services (the grey line) was a small but steady contributor to real income growth. Real export prices (the brown line) fell below 1 for most of the last half of the sample period, indicating declining real export prices and a drag on real income growth. However, this negative effect was offset by declining real import prices (the bright blue line), leading to a terms of trade effect which was negligible for the Chinese economy.

As was mentioned earlier, Chinese real gross income grew 37.58 fold over our 51 year sample period. It turns out that real net income grew 38.63 fold over the same period.[*44] The average annual growth rate for real net income was 7.69% which is very close to 7.63%, the average growth rate for real gross income. Several of the explanatory factors explaining net and gross real income growth changed but the overall growth rates turned out to be almost identical.

It is possible to implement the Diewert and Fox nonparametric productivity model using the net output (real) price and quantity data in place of the corresponding gross output price and quantity data. The algebra in the previous section is exactly the same: only the

[*44] In absolute terms, real net income grew from 219.68 billion Yuan in 1970 to 8485.33 billion Yuan in 2020 while real gross income grew from 236.02 billion Yuan in 1970 to 8869.05 billion Yuan in 2020. Per capita real net income grew from 264.70 Yuan in 1970 to 6008.93 Yuan in 2020 (22.7 fold increase) while real gross income grew from 284.39 Yuan in 1970 to 6280.67 Yuan in 2020 (22.1 fold increase). The units are in 1970 Yuan. To convert these estimates into 2020 Yuan, multiply them by 10.94922, the price of consumption in 2020.

data has changed. Denote the resulting Nonparametric TFP level for year t by $NTFP^{t^*}$ and the corresponding year t growth factor by $NTFP_G^{t^*} \equiv NTFP^{t^*}/NTFP^{t-1^*}$ for $t = 1971, \ldots, 2020$. The counterparts to Tables 9 and 10 in the previous section are Tables 18 and 19 listed below. Recall that $TFP_G^{t^*}$ is the year t index number estimate for TFP Growth using the net output accounting framework. This series is also listed in Table 18 so that it can be compared with the nonparametric estimates of real net income defined by $NTFP_G^{t^*}$.

Table 18: A Nonparametric Decomposition of Real Net Output Growth for China

Year t	$RI_G^{t^*}$	ε^{t^*}	α^{t^*}	β^{t^*}	γ^{t^*}	τ^{t^*}	e^{t^*}	$NTFP_G^{t^*}$	$TFP_G^{t^*}$
1971	1.0337	0.9752	1.0025	1.0575	0.9998	1.0000	0.9752	0.9750	0.9756
1972	1.0462	1.0030	1.0067	1.0371	0.9990	1.0000	0.9782	1.0020	1.0028
1973	1.0367	0.9775	1.0151	1.0445	1.0002	1.0000	0.9562	0.9777	0.9782
1974	1.0211	0.9726	1.0086	1.0418	0.9992	1.0000	0.9300	0.9718	0.9723
1975	1.0574	1.0028	1.0092	1.0442	1.0006	1.0000	0.9326	1.0034	1.0040
1976	0.9836	0.9416	1.0069	1.0417	0.9959	1.0000	0.8781	0.9377	0.9400
1977	1.1047	1.0503	1.0100	1.0348	1.0064	1.0000	0.9223	1.0571	1.0575
1978	1.0894	1.0300	1.0139	1.0440	0.9993	1.0000	0.9499	1.0292	1.0271
1979	1.0726	1.0200	1.0068	1.0480	0.9967	1.0000	0.9689	1.0166	1.0145
1980	1.0862	1.0141	1.0239	1.0531	0.9933	1.0000	0.9826	1.0073	1.0057
1981	1.0452	0.9817	1.0185	1.0500	0.9957	1.0000	0.9646	0.9774	0.9792
1982	1.0960	1.0222	1.0251	1.0470	0.9989	1.0000	0.9860	1.0211	1.0214
1983	1.1181	1.0142	1.0305	1.0407	0.9998	1.0282	1.0000	1.0426	1.0434
1984	1.1812	1.0000	1.0357	1.0593	1.0000	1.0766	1.0000	1.0766	1.0767
1985	1.0854	1.0000	1.0098	1.0704	1.0000	1.0043	1.0000	1.0043	1.0044
1986	1.0960	0.9976	1.0301	1.0677	0.9988	1.0000	0.9976	0.9965	0.9972
1987	1.0905	1.0024	1.0133	1.0611	0.9995	1.0123	1.0000	1.0142	1.0147
1988	1.0770	1.0000	0.9623	1.0585	1.0000	1.0574	1.0000	1.0574	1.0572
1989	0.9981	0.9480	0.9998	1.0538	0.9993	1.0000	0.9480	0.9473	0.9471
1990	1.0512	0.9792	1.0307	1.0432	0.9984	1.0000	0.9283	0.9776	0.9738
1991	1.1136	1.0520	1.0191	1.0382	1.0005	1.0000	0.9766	1.0525	1.0516
1992	1.1507	1.0240	1.0451	1.0492	0.9994	1.0254	1.0000	1.0493	1.0497
1993	1.1295	1.0000	1.0336	1.0609	1.0000	1.0302	1.0000	1.0302	1.0303
1994	1.0841	1.0000	0.9677	1.0538	1.0000	1.0632	1.0000	1.0632	1.0624
1995	1.0082	1.0000	0.9224	1.0597	1.0000	1.0315	1.0000	1.0315	1.0314
1996	1.0352	1.0000	0.9683	1.0683	0.9997	1.0010	1.0000	1.0007	1.0007
1997	1.0639	1.0000	0.9812	1.0592	1.0000	1.0237	1.0000	1.0237	1.0236
1998	1.0556	1.0000	0.9917	1.0500	1.0000	1.0138	1.0000	1.0138	1.0138
1999	1.0587	1.0000	0.9809	1.0551	1.0000	1.0230	1.0000	1.0230	1.0230
2000	1.0764	1.0000	0.9882	1.0627	1.0000	1.0250	1.0000	1.0250	1.0250
2001	1.0682	0.9923	1.0169	1.0595	0.9992	1.0000	0.9923	0.9915	0.9911
2002	1.1417	1.0077	1.0542	1.0540	0.9993	1.0204	1.0000	1.0275	1.0273
2003	1.1263	1.0000	1.0465	1.0625	1.0000	1.0130	1.0000	1.0130	1.0130
2004	1.1325	1.0000	1.0577	1.0650	1.0000	1.0053	1.0000	1.0053	1.0053
2005	1.1575	1.0000	1.0687	1.0822	0.9998	1.0012	1.0000	1.0009	1.0009
2006	1.1229	1.0000	1.0226	1.0498	1.0000	1.0460	1.0000	1.0460	1.0460
2007	1.1846	1.0000	1.0556	1.0416	1.0000	1.0773	1.0000	1.0773	1.0774
2008	1.1363	1.0000	1.0301	1.0502	1.0000	1.0504	1.0000	1.0504	1.0505
2009	1.1389	1.0000	1.0331	1.0648	1.0000	1.0353	1.0000	1.0353	1.0353
2010	1.0824	0.9845	0.9933	1.1077	0.9993	1.0000	0.9845	0.9838	0.9840
2011	1.0475	0.9887	0.9877	1.0763	0.9966	1.0000	0.9733	0.9853	0.9842
2012	1.0629	1.0018	1.0072	1.0629	0.9910	1.0000	0.9750	0.9928	0.9907
2013	1.0614	1.0213	0.9928	1.0578	0.9895	1.0000	0.9958	1.0106	1.0087
2014	1.0189	1.0042	0.9806	1.0404	0.9943	1.0003	1.0000	0.9987	0.9982
2015	1.0576	1.0000	1.0058	1.0244	1.0000	1.0264	1.0000	1.0264	1.0264
2016	1.0260	1.0000	0.9772	1.0373	1.0000	1.0122	1.0000	1.0122	1.0122
2017	1.1088	1.0000	1.0025	1.0296	1.0000	1.0742	1.0000	1.0742	1.0741
2018	1.0574	1.0000	1.0124	1.0405	1.0000	1.0038	1.0000	1.0038	1.0038

2019	0.9788	0.9727	0.9780	1.0308	0.9981	1.0000	0.9727	0.9709	0.9704
2020	0.9896	0.9794	0.9829	1.0320	0.9962	1.0000	0.9527	0.9756	0.9752
Mean	1.0769	0.9992	1.0093	1.0525	0.9989	1.0156	0.9824	1.0137	1.0136

Our nonparametric estimate of average net output TFP growth rates is 1.37% per year whereas our index number estimate of average net output TFP growth rates was 1.36%. Table 18 shows that there is very little difference between the two sets of estimates, which again helps to establish the credibility of both sets of estimates.

On average, real net output and income grew at 7.69% per year. Nonparametric real net output price inflation averaged 0.93% per year whereas the real gross output price inflation averaged −0.07% per year. The big difference is due to the replacement of gross investment by net investment (including real capital gains and losses on assets held over the accounting period). Our measure of efficiency, e^t, was below 1 for the years 1971-1981, 1986, 1989-1991, 1998, 2005 and 2010-2012 and 2019-2020.

Aggregate input growth averaged 5.25% per year which is remarkable. The input mix growth factor, γ^t, was on average equal to 0.9989 which indicates a small negative contribution to GDP growth over the sample period. The average rate of net output technical progress τ^t was 1.49% per year which is quite good.

We again follow the example of Kohli (1990)[47] and obtain a levels decomposition for the observed level of real NDP in year t, $\boldsymbol{p}^t \cdot \boldsymbol{y}^t$, relative to its observed value in year 1 of our sample, $\boldsymbol{p}^1 \cdot \boldsymbol{y}^1$. The cumulated explanatory variables are again defined by (47) and (48) and as in the previous section, we obtain the following *levels decomposition* for the level of period t observed real NDP or real net income RI^{t^*} to its level in 1970:

$$RI^{t^*}/RI^{1970^*} \equiv \boldsymbol{p}^t \cdot \boldsymbol{y}^t/\boldsymbol{p}^{1970} \cdot \boldsymbol{y}^{1970} = A^{t^*}B^{t^*}C^{t^*}E^{t^*}T^{t^*}; \qquad t = 1970, \ldots, 2020. \qquad (60)$$

The year t level of Net Output TFP, $NTFP^{t^*}$, is defined as follows:

$$NTFP^{t^*} = [\boldsymbol{p}^t \cdot \boldsymbol{y}^t/\boldsymbol{p}^1 \cdot \boldsymbol{y}^1]/[A^{t^*}B^{t^*}] = C^{t^*}E^{t^*}T^{t^*}; \qquad t = 1970, \ldots, 2020. \qquad (61)$$

The components of the decomposition of real NDP relative to its 1970 level into explanatory factors which is given by (60) are listed in Table 19 below along with our nonparametric estimates of TFP relative to 1970, $NTFP^{t^*}$.

Table 19: A Decomposition of Real NDP Growth Relative to the 1970 Level

Year t	RI^{t^*}/RI^{1970^*}	A^{t^*}	B^{t^*}	C^{t^*}	E^{t^*}	T^{t^*}	$NTFP^{t^*}$
1970	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
1971	1.0337	1.0025	1.0575	0.9998	0.9752	1.0000	0.9750
1972	1.0814	1.0093	1.0967	0.9987	0.9782	1.0000	0.9770
1973	1.1211	1.0245	1.1455	0.9990	0.9562	1.0000	0.9552
1974	1.1447	1.0333	1.1934	0.9982	0.9300	1.0000	0.9283
1975	1.2105	1.0428	1.2461	0.9988	0.9326	1.0000	0.9315
1976	1.1906	1.0500	1.2982	0.9947	0.8781	1.0000	0.8735
1977	1.3153	1.0605	1.3433	1.0011	0.9223	1.0000	0.9233
1978	1.4329	1.0753	1.4023	1.0004	0.9499	1.0000	0.9503
1979	1.5369	1.0825	1.4696	0.9970	0.9689	1.0000	0.9660
1980	1.6694	1.1084	1.5477	0.9903	0.9826	1.0000	0.9731
1981	1.7449	1.1289	1.6250	0.9860	0.9646	1.0000	0.9511
1982	1.9124	1.1573	1.7015	0.9850	0.9860	1.0000	0.9712
1983	2.1383	1.1926	1.7708	0.9848	1.0000	1.0282	1.0125
1984	2.5257	1.2351	1.8758	0.9848	1.0000	1.1070	1.0901
1985	2.7415	1.2472	2.0078	0.9848	1.0000	1.1118	1.0948

1986	3.0046	1.2847	2.1437	0.9836	0.9976	1.1118	1.0909
1987	3.2765	1.3018	2.2748	0.9831	1.0000	1.1254	1.1064
1988	3.5288	1.2527	2.4078	0.9831	1.0000	1.1900	1.1699
1989	3.5222	1.2525	2.5374	0.9824	0.9480	1.1900	1.1083
1990	3.7026	1.2910	2.6470	0.9808	0.9283	1.1900	1.0835
1991	4.1232	1.3156	2.7483	0.9813	0.9766	1.1900	1.1404
1992	4.7445	1.3750	2.8835	0.9807	1.0000	1.2202	1.1966
1993	5.3591	1.4211	3.0590	0.9807	1.0000	1.2571	1.2328
1994	5.8099	1.3752	3.2234	0.9807	1.0000	1.3365	1.3106
1995	5.8574	1.2685	3.4159	0.9807	1.0000	1.3785	1.3518
1996	6.0633	1.2283	3.6493	0.9804	1.0000	1.3798	1.3527
1997	6.4507	1.2051	3.8653	0.9804	1.0000	1.4125	1.3848
1998	6.8093	1.1951	4.0585	0.9804	1.0000	1.4320	1.4039
1999	7.2090	1.1722	4.2822	0.9804	1.0000	1.4649	1.4361
2000	7.7596	1.1584	4.5508	0.9804	1.0000	1.5015	1.4720
2001	8.2887	1.1779	4.8215	0.9795	0.9923	1.5015	1.4595
2002	9.4634	1.2418	5.0819	0.9788	1.0000	1.5320	1.4996
2003	10.6585	1.2995	5.3993	0.9788	1.0000	1.5519	1.5191
2004	12.0712	1.3745	5.7505	0.9788	1.0000	1.5602	1.5272
2005	13.9729	1.4689	6.2230	0.9786	1.0000	1.5620	1.5286
2006	15.6896	1.5021	6.5327	0.9786	1.0000	1.6339	1.5989
2007	18.5854	1.5856	6.8044	0.9786	1.0000	1.7602	1.7226
2008	21.1194	1.6334	7.1458	0.9786	1.0000	1.8490	1.8094
2009	24.0525	1.6875	7.6089	0.9786	1.0000	1.9142	1.8732
2010	26.0349	1.6762	8.4286	0.9779	0.9845	1.9142	1.8428
2011	27.2704	1.6556	9.0719	0.9746	0.9733	1.9142	1.8157
2012	28.9853	1.6675	9.6425	0.9658	0.9750	1.9142	1.8027
2013	30.7641	1.6556	10.2000	0.9557	0.9958	1.9142	1.8218
2014	31.3447	1.6235	10.6117	0.9503	1.0000	1.9147	1.8194
2015	33.1496	1.6329	10.8708	0.9503	1.0000	1.9653	1.8675
2016	34.0120	1.5957	11.2761	0.9503	1.0000	1.9893	1.8903
2017	37.7110	1.5997	11.6100	0.9503	1.0000	2.1368	2.0305
2018	39.8739	1.6195	12.0805	0.9503	1.0000	2.1448	2.0381
2019	39.0294	1.5839	12.4520	0.9485	0.9727	2.1448	1.9789
2020	38.6252	1.5569	12.8506	0.9449	0.9527	2.1448	1.9306

Recall that RI^{t^*}/RI^{1970^*} is real NDP in year t relative to 1970 real NDP. From the above Table, it can be seen that Chinese real NDP grew 38.6 fold over the 50 year sample period. Real output prices grew 1.557 fold over the sample period, an aggregate of labour and capital waiting services grew 12.851 fold, the final input mix overall growth factor was 0.945 which means the input mix factor subtracted from GDP growth, the overall efficiency growth factor was 0.953 and the technical progress growth factor in 2020 was 2.145. Net output TFP ended up at 1.931, which is lower that the corresponding level of technical progress due to the fact that C^{2020^*} and E^{2020^*} were less that one; see equations (61) for $t = 2020$. The explanatory variables that appear on the right hand side of equations (61) are plotted on Figure 5 below.

The top line in Figure 5 plots the level of technology T^{t^*} while the line just below it plots the level of TFP $NTFP^{t^*}$. The efficiency level line E^{t^*} almost coincides with the $NTFP^{t^*}$ line for the years 1970-1982 but then is close to the level 1 for most of the rest of the sample period with noticeable dips for the years 1989-1991 and 2019-2020. When E^{t^*} dips below 1, it drags $NTFP^{t^*}$ below T^{t^*}. The input mix line C^{t^*} stays close to the level 1 throughout the sample period but does steadily decline near the end of the sample period. It can be seen that Figure 5 is very similar to Figure 3: Gross output TFP is close to net output TFP and their decompositions into explanatory factors is much the same.

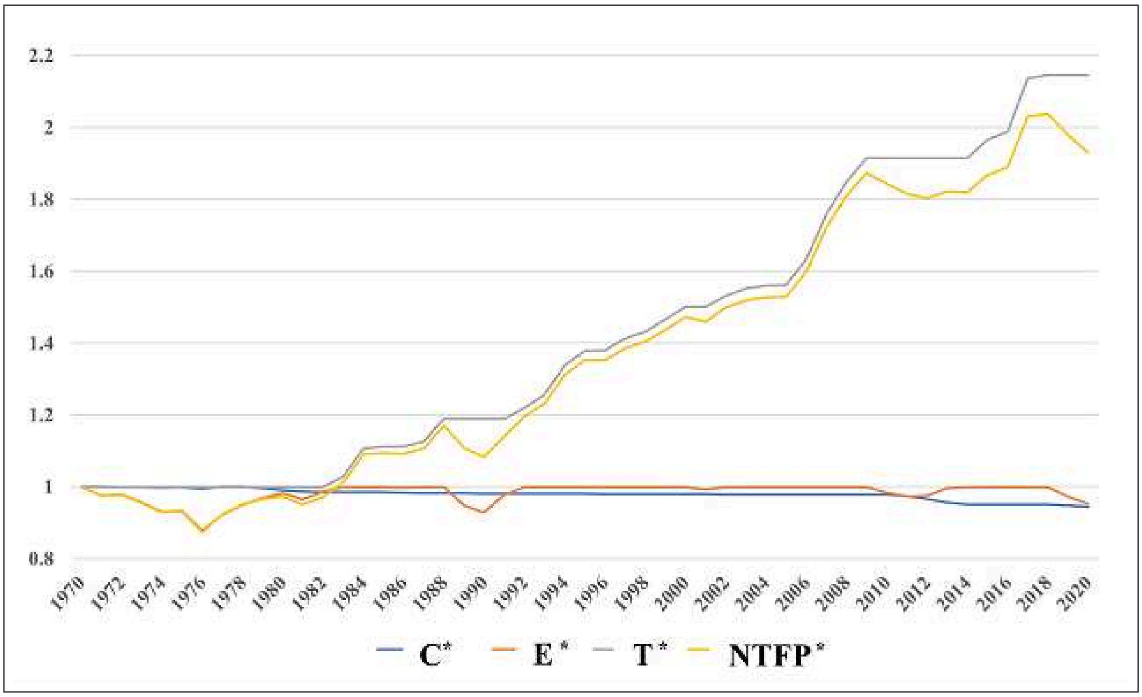

Figure 5 Decomposition of Chinese Net Output Nonparametric TFP into Explanatory Factors

7 Conclusion

The APDB on the price and volume of land used in production indicates that land is an input that is growing in importance.*45 A big problem with existing estimates of TFP and many macroeconomic models is that they ignore land. Some possible reasons for this omission are:

- The current SNA does not assign much of a role to changes in land use in the flow accounts and as a result, most countries do not collect or publish data on the price and quantity of land broken down by different categories of land use.
- It is difficult to decompose market prices for properties into their land and structure components.*46 This hinders the production of land price and quantity indexes.
- Transactions in commercial and industrial land are sparse, making the construction of indexes difficult.
- The aggregate land stock is constant and hence it is thought that land does not play much of a role as a contributor to economic growth. But once land is subdivided into different categories of land use, we see that land usage changes significantly over time. In general, agricultural land is converted into other land uses.

*45 From Table 1 above, we see that the average share of land in the total value of the Chinese capital stock was 23%. But many countries have higher land shares; see APO (2022; 179)[2] for 2020 land shares for 25 Asian countries.

*46 Methods are available to decompose property prices into structure and land components; see Eurostat (2013)[26] (2017)[27], Diewert, de Haan and Hendriks (2015)[13] and Diewert and Shimizu (2015)[20] (2017)[21] (2019)[22] (2022)[23]. However, these decomposition methods involve nonlinear hedonic regressions and hence are difficult to implement at scale.

The work of the APO (led by Koji Nomura and his team at Keio University) has led to the development of a useful data base on national stocks of 4 types of land for 25 Asian countries. We utilized this data base for China to develop alternative measures of TFP Growth. Our work indicates that land is an important factor of production and neglecting land inputs into production can lead to substantial measurement differences. We also argued that changes in land use by type of land should be recorded as part of investment. This would put land stocks on the same footing as inventory stocks. Changes in inventory stocks are routinely regarded as current output. We argue that changes in land stocks should also be recorded as part of current output and we implemented this approach using our data for China.

There is another important reason why National Statistical Offices should supply information on the price and quantity of land by type of land. The growth in the value of land relative to other assets has led taxation experts to take a new look at land taxes.*47 The case for taxing land rents (over other forms of taxation) dates back to Henry George and his single tax theory:

> "Taxes levied upon the value of land cannot check production in the slightest degree, until they exceed rent, or the value of land taken annually, for unlike taxes upon commodities, or exchange, or capital, or any of the tools or processes of production, they do not bear upon production. The value of land does not express the reward of production, as does the value of crops, of cattle, of buildings, or any of the things which are styled personal property and improvements. It expresses the exchange value of monopoly. It is not in any case the creation of the individual who owns the land; it is created by the growth of the community. Hence the community can take it all without in any way lessening the incentive to improvement or in the slightest degree lessening the production of wealth. Taxes may be imposed upon the value of land until all rent is taken by the State, without reducing the wages of labor or the reward of capital one iota; without increasing the price of a single commodity, or making production in any way more difficult.
> ...
> It is sufficiently evident that with regard to production, the tax upon the value of land is the best tax that can be imposed. Tax manufactures, and the effect is to check manufacturing; tax improvements, and the effect is to lessen improvement; tax commerce, and the effect is to prevent exchange; tax capital, and the effect is to drive it away. But the whole value of land may be taken in taxation, and the only effect will be to stimulate industry, to open new opportunities to capital, and to increase the production of wealth." Henry George (1935; 413-414)[32]

Until recent times, land values in most countries were not high enough to yield enough tax revenue to fund a large portion of government expenditures. This is no longer the case for many countries.

The current international SNA focuses on the measurement of GDP and the corresponding measure of Gross National Income. But these gross measures include depreciation which is not "income" and they exclude longer term capital gains (and losses) on assets which households typically regard as "income". Thus, our recommendation is that the next revision of the international SNA should develop income accounts which would supplement the usual gross output accounts.

*47 See the recent (excellent) paper by Kumhof, Tideman, Hudson and Goodhart (2021)[52] who make a strong case for increasing taxes on land.

Here are some important measurement problems which require more research:

- How exactly should expected asset inflation rates be estimated?
- What is the "right" cost of capital to use in user costs and in waiting costs?
- Why does the current SNA not impute a rate of return for the user cost of capital applied to government assets? Only depreciation is regarded as a cost of using a government asset and so there is no opportunity cost assigned to the use of land in the government sector in the SNA.
- How fine should we make the land classification? There is forest land, park land, and land that is tied up in roads. Commercial land includes a wide variety of different uses of land. And of course, land should be disaggregated by geographical location.
- How do we deal with negative user costs?
- What about including other missing assets such as forest land, natural resource stocks,[*48] environmental stocks and business holdings of money?

The above research questions also indicate that our efforts to better measure the income generated by the production sector of a country (and the associated measures of TFP) suffer from some weaknesses. However, many of the above weaknesses also apply to the measures of capital services that are used by all countries that provide TFP measures to the public. Hopefully, in the future, at least some of the above weaknesses will be addressed and the economic measurement of production and income will gradually improve over time.

Appendix: Data on Outputs and Inputs for China

In this paper, we used the APDB for 2022 developed by APO and Keio University dated December 22, 2022.[*49] This database has current yuan and constant yuan estimates for the main economic aggregates for the People's Republic of China as well as detailed investment data for 12 types of capital for the years 1970-2020. The implicit price indexes were formed by dividing the current yuan series by the corresponding constant yuan series. The database has current and constant yuan estimates for the 12 corresponding beginning of the year capital stocks as well as current and constant yuan estimates for 4 types of land. The APDB also has detailed information on hourly wage rates and annual hours worked for many types of labour classified by age, sex, education and type of worker (employee or self-employed). We will not make use of the detailed labour information: we simply used the resulting aggregate quality-adjusted price and quantity of labour for year t, P_L^t and Q_L^t, which are listed in the APDB.

The price indexes for the output aggregates for year t are defined as P_C^t (private consumption), P_G^t (government consumption), P_I^t (gross investment), P_X^t (exports of goods and services), and

[*48] See Brandt, Schreyer and Zipperer (2017)[5] and Freeman, Inklaar and Diewert (2021)[31] on the importance of resources stocks in measuring wealth and productivity. The World Bank (2021)[67] has estimates of natural resource stocks by country that cover the years 1970-2018. However, there are some methodological problems with their estimates so we did not use this data base. Diewert and Fox (2016)[14] outlined how user cost theory could be applied to resource stocks.

[*49] The methodology for constructing the productivity accounts for Asian countries is explained in APO (2022; 165-188)[2]. The APDB includes estimates adjusted for official national accounts. In particular, imputed rents (including land) for free housing and owner-occupied housing, which are not included in Chinese official national accounts, are estimated in the APDB and added to the official estimates of the household consumption and GDP. It was about 15% of the official nominal GDP in the late 1970s and has tended to diminish to about 4% in recent years. These adjustments have the effect of revising the official GDP growth rate downward. The Chinese national accounts and balance sheet data are far from being completely comprehensive and accurate, so our estimates are provisional.

P_M^t (imports of goods and services). The corresponding quantity or volume indexes are defined as $Q_C^t, Q_G^t, Q_I^t, Q_X^t$ and Q_M^t. The 12 components of the investment series are as follows: (1) IT hardware; (2) Communications equipment; (3) Transport equipment; (4) Other machinery and equipment; (5) Dwelling structures; (6) Non-residential buildings; (7) Other structures; (8) Cultivated assets; (9) Research and development; (10) Computer software; (11) Other intangible assets and (12) Net increase in inventory stocks.*50 Denote the year t price index for investment good n by P_{In}^t and the corresponding quantity or volume index by Q_{In}^t for $n = 1, \ldots, 12$ and $t = 1970, \ldots, 2020$.

The corresponding beginning of the year t capital stocks for the above 12 investment assets are also available in the APDB. Denote the asset n and year t stock price index by P_{Kn}^t and the corresponding quantity index by Q_{Kn}^t for $n = 1, \ldots, 12$ and $t = 1970, 1971, \ldots, 2021$. The APDB also has current and constant yuan series for four types of land used by the Chinese production sector: (13) Agricultural land; (14) Industrial Land; (15) Commercial Land and (16) Residential Land. Denote the beginning of the year t price index for these land assets by P_{Kn}^t and the corresponding quantity index by Q_{Kn}^t for $n = 13, \ldots, 16$ and $t = 1970, \ldots, 2021$.*51

Assets 12-16 are non-depreciable assets so we set the period t depreciation rate for these assets, δ_n^t, equal to 0 for $n = 12, \ldots, 16$ and $t = 1970, \ldots, 2020$. Since the APDB uses the geometric model for depreciation for assets 1-11, the depreciation rates should satisfy the following equations:

$$Q_{Kn}^{t+1} = (1 - \delta_n^t) Q_{Kn}^t + Q_{In}^t; \qquad n = 1, \ldots, 11; t = 1970, \ldots, 2020. \tag{A1}$$

Since we can obtain estimates for the Q_{Kn}^t and Q_{In}^t for the years t and assets n listed at the end of equations (A1), we can solve equations (A1) for the depreciation rates δ_n^t for the years 1970-2020 for assets 1-11. The resulting estimates for the depreciation rates were quite reasonable and are fairly smooth except that the depreciation rates for asset 1 showed unusual volatility for 4 observations so we smoothed the rates δ_1^t using the Lowess nonparametric smoothing method in Shazam.*52

Equations (A1) enabled us to determine depreciation rates for assets 1-11 for the years 1970-2020. The depreciation rates for inventory stocks, δ_{12}^t, were assumed to be equal to 0 as indicated earlier. The nonzero depreciation rates are listed below in Table A3.

Land prices turn out to be very volatile. Rather than use short run fluctuations in land prices in order to value the opportunity costs of holding land, we chose to smooth the land prices to capture longer run trends in the value of land assets used in production. Again, we used

*50 The APDB estimates inventory stocks by assuming a time-variant disposal rates to suppress the size of inventory stocks estimated from the net increase in inventory in Chinese official national accounts to a realistic level. We differenced the APDB real inventory stocks to obtain our estimates of inventory change. We set the price of inventory change equal to the end of year price of inventory stock. These conventions allowed us to apply user cost theory to the stock of inventories.

*51 The APDB land price estimates for China are primarily based on the cost of long-term leases for the land uses (e.g.,70 years for residential land, 50 years for industrial land, and 40 years for commercial land). The land prices for agricultural use are approximated by the discounted present value of the capital incomes, which are estimated based on Mixed Income, in the agricultural sector. Intra-regional and inter-regional price differences are significant. Total land values are adjusted based on comparisons with countries with better data quality, such as Japan.

*52 The smoothing parameter was chosen to be 0.15. Equations (A1) for $n = 1$ were used recursively to generate new estimates for the Q_{K1}^t; i.e., we assumed that the APDB beginning of 1970 capital stock Q_{K1}^{1970} was the "correct" estimate along with the investments in asset 1 (the Q_{I1}^t were also assumed to be correct) and the new smoothed depreciation rates δ_1^t were also correct.

the Lowess nonparametric smoothing method to smooth the land prices $P^t_{K13}, P^t_{K14}, P^t_{K15}$ and P^t_{K16} using the Smooth parameter set equal to 0.25.*[53] The smoothed land price indexes are listed in Table A1 below along with the APDB beginning of the year prices for assets 1-12.

Table A1: Beginning of the Year Capital Stocks

Year t	P^t_{K1}	P^t_{K2}	P^t_{K3}	P^t_{K4}	P^t_{K5}	P^t_{K6}	P^t_{K7}	P^t_{K8}
1970	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
1971	0.959575	0.942699	0.993207	0.995763	1.011661	1.009440	1.043196	0.923448
1972	0.872886	0.894536	0.989991	0.972020	1.021736	0.997483	1.042595	0.895127
1973	0.752161	0.819623	0.964846	0.994047	1.073243	1.011204	1.053099	0.953971
1974	0.755800	0.729851	0.891169	1.024038	1.057895	1.033924	1.114301	0.863096
1975	0.698193	0.706550	0.955974	0.981463	1.060059	1.054508	1.158528	0.974140
1976	0.762481	0.688447	0.959737	0.977770	1.075716	1.061582	1.166881	1.026349
1977	0.752603	0.660124	0.933399	0.977244	1.089105	1.069025	1.181379	1.091283
1978	0.661580	0.633761	0.937103	0.988375	1.097700	1.082451	1.223820	1.043241
1979	0.586099	0.632083	0.936320	1.005977	1.130091	1.098988	1.239102	1.086288
1980	0.451621	0.595385	0.890998	1.015081	1.206910	1.168757	1.333445	1.018089
1981	0.381752	0.577681	0.897262	1.020277	1.223533	1.206707	1.390667	0.979012
1982	0.337681	0.562436	0.901742	1.026215	1.260528	1.239340	1.435583	0.999415
1983	0.296187	0.531984	0.869999	1.008713	1.325792	1.299283	1.506423	0.934003
1984	0.276745	0.526682	0.877373	1.024954	1.405023	1.378355	1.595211	0.942626
1985	0.275690	0.532032	0.902220	1.062680	1.523385	1.490425	1.715108	1.049631
1986	0.272105	0.532283	0.942431	1.110861	1.667376	1.618741	1.867164	1.074026
1987	0.251299	0.520100	0.944522	1.131541	1.800579	1.721085	1.989367	1.070671
1988	0.246725	0.548064	1.033818	1.251706	2.037273	1.942867	2.245579	1.177518
1989	0.259316	0.578855	1.092144	1.362034	2.189015	2.077433	2.393969	1.325522
1990	0.274550	0.617836	1.172326	1.496075	2.338780	2.221752	2.560678	1.436610
1991	0.278725	0.637879	1.225687	1.606531	2.565436	2.439219	2.809855	1.351462
1992	0.292728	0.694034	1.358849	1.773754	3.008278	2.846343	3.278489	1.421858
1993	0.306203	0.809827	1.594088	2.089428	4.001307	3.715242	4.282095	1.496312
1994	0.318050	0.860230	1.693884	2.249878	4.439009	4.076880	4.717640	1.588981
1995	0.301500	0.891381	1.778522	2.369633	4.631114	4.288093	4.948459	1.724635
1996	0.266651	0.839385	1.800903	2.384120	4.865847	4.503920	5.193147	1.858433
1997	0.245313	0.782901	1.788111	2.362146	5.025287	4.619377	5.340891	1.802772
1998	0.236193	0.740188	1.766509	2.336061	5.020262	4.605519	5.380686	1.610629
1999	0.224538	0.677320	1.721092	2.277225	5.040343	4.600913	5.384222	1.530931
2000	0.211279	0.634686	1.674019	2.239455	5.110908	4.541101	5.520625	1.575409
2001	0.179814	0.604073	1.678892	2.230819	5.208015	4.595595	5.596647	1.724434
2002	0.161693	0.563502	1.672490	2.197005	5.416336	4.655337	5.644894	1.522635
2003	0.137578	0.522005	1.649801	2.166311	5.725067	4.781031	5.888597	1.686803
2004	0.122285	0.504483	1.671558	2.186295	6.263223	5.120485	6.384145	1.871628
2005	0.109311	0.489473	1.694933	2.213053	6.791943	5.408939	6.531487	1.997477
2006	0.103447	0.474962	1.724935	2.260154	7.227193	5.626198	6.628401	2.086162
2007	0.098970	0.452488	1.739191	2.277061	7.819823	5.952517	6.963099	2.032212
2008	0.089766	0.437789	1.769473	2.318788	8.375030	6.226333	7.947105	1.830137
2009	0.077606	0.412709	1.773079	2.291944	8.085591	5.997398	7.643597	1.837153
2010	0.074030	0.388550	1.810411	2.314460	8.453857	6.293803	8.041611	2.068573
2011	0.071046	0.366994	1.857100	2.369335	9.136616	6.987016	8.756002	2.201303
2012	0.067353	0.340120	1.854894	2.372544	9.243807	7.103370	8.929690	2.144999
2013	0.065576	0.335720	1.866860	2.345451	9.304580	7.122108	8.928161	2.363735
2014	0.066277	0.338277	1.863172	2.330687	9.396534	7.126606	8.984390	2.508305
2015	0.067704	0.340497	1.847490	2.301628	9.145469	6.923964	8.749338	2.773096
2016	0.063843	0.330743	1.830290	2.294299	9.096491	6.884999	8.688695	3.380879
2017	0.064675	0.330171	1.838584	2.308959	9.836509	7.424249	9.384671	3.528379
2018	0.065294	0.322683	1.853940	2.340710	10.542147	7.952212	10.071367	3.630329

*[53] The lower is the Smooth number, the less severe is the smoothing. Thus, we did a fair amount of smoothing of the land prices at this stage of the data construction process.

2019	0.064164	0.320021	1.856800	2.353396	10.798474	8.182066	10.378349	3.604211
2020	0.063201	0.315220	1.856786	2.341960	10.839683	8.126947	10.349777	3.237668
2021	0.063111	0.314906	1.858602	2.372085	11.738936	8.801150	11.208425	3.264013

Year t	P_{K9}^t	P_{K10}^t	P_{K11}^t	P_{K12}^t	P_{K13}^t	P_{K14}^t	P_{K15}^t	P_{K16}^t
1970	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
1971	1.065251	0.949261	1.077944	1.004600	1.051034	1.117073	1.117073	1.051034
1972	1.133825	0.899456	1.152770	1.012600	1.088840	1.234162	1.234162	1.088840
1973	1.215266	0.837882	1.218519	1.013877	1.128134	1.361289	1.361290	1.128134
1974	1.246914	0.682308	1.249319	1.015422	1.165120	1.498713	1.498713	1.165120
1975	1.329486	0.655302	1.354567	1.017780	1.199236	1.635834	1.635835	1.199236
1976	1.437302	0.645592	1.512847	1.015103	1.210626	1.817907	1.817908	1.210626
1977	1.507955	0.625067	1.612688	1.020042	1.205279	2.066794	2.066795	1.205279
1978	1.592842	0.605910	1.709758	1.016370	1.229281	2.399109	2.399110	1.229281
1979	1.659495	0.619428	1.744173	1.037070	1.308393	2.793627	2.793628	1.308393
1980	1.685631	0.592190	1.759652	1.112182	1.435795	3.222865	3.222866	1.435795
1981	1.742476	0.597708	1.861601	1.156806	1.597610	3.700331	3.700332	1.597610
1982	1.780888	0.609517	1.890484	1.192400	1.755420	4.326982	4.326984	1.755421
1983	1.724135	0.588441	1.863775	1.203949	1.920203	5.204788	5.204790	1.920203
1984	1.770026	0.591492	1.908263	1.223297	2.102513	6.342564	6.342567	2.102514
1985	1.880530	0.606585	1.977724	1.265668	2.281605	7.694877	7.694880	2.281606
1986	2.020869	0.626679	2.094917	1.360657	2.476112	9.364810	9.364814	2.476113
1987	2.077564	0.643996	2.163940	1.470836	2.722408	11.366082	11.366087	2.722409
1988	2.333640	0.711873	2.404088	1.570620	3.034662	13.715999	13.716005	3.034663
1989	2.567301	0.739852	2.722080	1.800042	3.421388	16.453649	16.453656	3.421389
1990	2.889151	0.773259	2.966423	1.891672	3.817611	19.390415	19.865643	3.846229
1991	3.144567	0.816036	3.170622	2.016350	4.282868	26.135371	23.907333	4.233943
1992	3.473658	0.848221	3.551318	2.086768	4.774769	33.096260	30.416709	4.664874
1993	4.280162	1.006470	4.302278	2.182509	5.587602	42.551128	41.182785	5.170022
1994	4.596284	1.080281	4.676174	2.445004	6.748801	53.329590	52.239485	5.682245
1995	4.887362	1.153616	4.961746	3.065268	8.182217	63.617829	52.993120	8.182218
1996	4.959844	1.150962	5.021192	3.477156	9.682796	70.661964	56.973550	9.986912
1997	4.963839	1.109219	4.979351	3.631350	11.021025	72.627435	59.569758	12.371006
1998	4.909743	1.081982	4.965314	3.617903	12.019022	71.428152	62.596663	14.891071
1999	4.855507	1.054517	4.913455	3.458903	12.697148	71.313245	68.066331	17.292886
2000	4.849119	1.029378	4.878054	3.383137	13.262029	75.231850	76.866685	19.670410
2001	4.872957	1.013344	4.923506	3.441180	13.920176	85.204190	87.974776	21.941799
2002	4.861522	0.986288	4.934437	3.446933	14.897708	101.877246	99.746351	23.915702
2003	4.897257	0.948335	4.940310	3.443139	16.416811	122.228543	112.496888	25.995077
2004	5.026072	0.945405	5.051443	3.569202	18.354872	143.834558	126.492344	29.051063
2005	5.117686	0.937646	5.123077	3.910147	20.699154	177.167304	144.499893	33.578663
2006	5.275747	0.940925	5.211315	4.070684	23.745482	230.999146	166.580384	38.672377
2007	5.329532	0.931837	5.249080	4.211737	27.389590	292.255478	193.857678	44.974393
2008	5.477237	0.931826	5.316363	4.475830	31.305061	348.396661	233.428236	54.740734
2009	5.224559	0.896812	5.288683	4.804670	35.891907	396.683427	280.616218	66.052410
2010	5.406611	0.892359	5.397057	4.564146	41.451811	427.686055	326.207038	76.908786
2011	5.641059	0.900126	5.629000	4.911134	47.705560	440.302976	370.642731	88.477893
2012	5.633154	0.876303	5.604462	5.229627	54.353286	453.485337	412.897340	100.817764
2013	5.540005	0.842376	5.509684	5.201899	61.155818	475.435530	447.989843	113.789029
2014	5.518866	0.815287	5.477543	5.163335	67.568077	500.437613	487.797080	132.293802
2015	5.398438	0.783365	5.373458	5.072240	73.286553	524.914220	545.551809	157.344492
2016	5.381356	0.778445	5.414976	4.826518	78.617706	543.252468	623.401794	183.025207
2017	5.474391	0.771865	5.462909	4.776075	84.235173	553.992982	718.680690	205.320353
2018	5.624206	0.769465	5.557798	5.004074	90.853363	569.712430	828.066119	222.614795
2019	5.646795	0.758676	5.574464	5.153957	99.057378	603.291950	945.294503	231.669929
2020	5.599200	0.770056	5.613396	5.201421	107.373044	637.171369	1062.650295	239.652704
2021	5.644093	0.776284	5.656905	5.167286	115.898009	673.802773	1179.845845	246.716204

It can be seen that land prices increased very rapidly during the past three decades. The price of commercial land increased 1180 fold over the five decades. At the other extreme, the prices of IT hardware and Communications equipment, assets 1 and 2, fell dramatically over the sample period.

The corresponding constant yuan beginning of the year capital stocks, Q^t_{Kn} are listed in Table A2 below. The units of measurement are in 10 billions of 1970 yuan. Values for these capital stocks (in units of 10 billion current year yuan) can be obtained as $V^t_{Kn} = P^t_{Kn}Q^t_{Kn}$.

Table A2: Beginning of Year Capital Stocks in Constant 10 Billions 1970 Yuan

Year t	Q^t_{K1}	Q^t_{K2}	Q^t_{K3}	Q^t_{K4}	Q^t_{K5}	Q^t_{K6}	Q^t_{K7}	Q^t_{K8}
1970	0.013639	0.033935	1.023039	8.093273	16.057123	2.211398	2.572765	0.606410
1971	0.014810	0.037472	1.188200	9.392588	17.311245	2.461569	2.864712	0.649254
1972	0.016589	0.042269	1.346399	10.539475	18.762139	2.839732	3.264751	0.712497
1973	0.019124	0.047748	1.487062	11.521179	20.154756	3.340438	3.776844	0.766196
1974	0.024628	0.057277	1.668271	12.555167	21.415186	3.859979	4.322490	0.808925
1975	0.030162	0.070662	1.889974	13.467364	22.845280	4.598815	5.046099	0.868013
1976	0.040720	0.090800	2.152502	14.833811	24.579725	5.432661	5.853716	0.925290
1977	0.046228	0.106456	2.328645	15.620208	25.850106	6.306001	6.703144	0.940423
1978	0.051540	0.122578	2.505988	16.289820	27.450428	7.411655	7.776313	0.954351
1979	0.067983	0.151570	2.786311	17.351715	29.544773	8.406796	8.764440	1.013858
1980	0.081022	0.169646	2.951712	17.759648	31.922945	9.725914	10.042405	1.055315
1981	0.102361	0.186980	3.089933	17.855037	34.248904	11.500164	11.699431	1.103761
1982	0.116998	0.194017	3.073655	17.378987	36.362368	13.544524	13.592493	1.130963
1983	0.161458	0.227511	3.206711	17.539766	38.354512	15.800378	15.701239	1.211232
1984	0.212357	0.280207	3.479310	18.056890	40.650685	17.961753	17.794675	1.328677
1985	0.355553	0.406408	4.070844	19.547000	43.027310	20.595983	20.318760	1.520619
1986	0.756112	0.627244	5.583879	21.972830	45.986604	23.479839	23.122660	1.800701
1987	0.932236	0.804326	6.911842	25.077773	48.900986	26.366048	25.986007	2.141298
1988	1.270777	1.117108	8.335388	29.442970	52.207566	29.259323	28.936553	2.549034
1989	1.698142	1.420645	9.857684	34.154581	56.006066	32.547970	32.260331	3.010157
1990	1.785095	1.484838	10.429041	36.264551	59.476606	35.074787	35.077482	3.174763
1991	1.955976	1.530222	10.900363	37.703880	62.300285	37.385431	37.785600	3.396810
1992	2.238385	1.669737	11.778699	39.963944	65.318133	39.999574	40.750400	3.807861
1993	2.505076	2.163110	13.586397	44.919391	68.757858	44.446406	45.258236	4.286616
1994	3.459070	3.184497	19.216501	51.315537	73.028277	49.920062	50.652980	5.120128
1995	4.615528	4.796798	25.263525	58.818316	78.575369	55.938738	56.571030	6.123693
1996	5.577932	7.028212	28.744549	66.722574	85.856952	63.251172	63.699496	7.105196
1997	7.478771	9.248342	32.062824	75.256912	92.978721	71.199084	71.458477	8.035846
1998	9.330019	13.150404	35.917733	86.179143	100.425820	79.346963	79.635326	9.389129
1999	9.341269	14.694201	37.210910	102.541572	108.862109	87.747594	87.983435	10.288753
2000	11.586374	18.511230	39.743897	118.436312	118.847973	96.387436	96.825928	11.599379
2001	17.252997	28.938694	43.366232	134.605403	129.601027	106.381836	106.532021	12.972893
2002	29.179060	44.247335	50.201957	150.537339	141.041435	117.509657	117.280600	14.457406
2003	72.758620	60.081047	60.287340	168.814536	152.933608	130.054351	129.410639	16.716674
2004	145.554987	76.509406	74.598821	196.069554	164.806058	146.055354	144.094152	18.399102
2005	223.836531	92.543400	92.611897	231.405358	178.024480	164.825367	161.029609	19.632889
2006	321.613814	108.331357	116.008402	277.819800	189.337845	184.193650	179.502122	20.621416
2007	405.534265	123.978548	143.966100	333.034989	201.380051	204.485144	199.732373	21.480247
2008	460.421684	140.703034	179.233421	402.565019	215.742546	227.071856	222.426581	22.536812
2009	537.017139	158.530092	223.990685	482.207364	230.820828	252.667126	245.248464	27.442264
2010	598.098286	181.057421	285.098448	584.553592	249.799685	290.256039	277.541129	35.341612
2011	694.452520	206.685916	361.275970	703.554542	270.535613	330.781159	312.676783	43.773416
2012	774.493113	234.419452	431.455762	802.746659	299.905225	377.286053	353.949265	49.225560
2013	893.104610	268.346375	521.385944	918.529920	326.857876	425.753394	397.602765	53.673126
2014	1000.701622	299.139988	598.573012	1023.987131	356.581825	484.179259	449.720446	55.378131
2015	1065.743164	320.967934	662.843548	1114.793538	385.934186	551.064008	509.006601	55.445742
2016	1088.365043	333.830273	711.185049	1185.650205	413.318242	625.671177	575.294403	53.869953

2017	1165.972121	354.427615	771.435896	1273.513906	439.466469	701.900653	644.580241	50.385132
2018	1254.033672	380.162318	842.853353	1378.612528	465.259049	779.994852	716.938976	46.322881
2019	1317.218394	403.970590	919.233580	1491.122634	492.860261	862.810417	794.333791	43.170096
2020	1351.066166	418.198894	987.156557	1592.308082	522.301093	948.961455	875.869516	40.610225
2021	1335.264360	419.172784	1038.576120	1672.831992	552.239154	1036.069198	959.697715	38.786610

Year t	Q^t_{K9}	Q^t_{K10}	Q^t_{K11}	Q^t_{K12}	Q^t_{K13}	Q^t_{K14}	Q^t_{K15}	Q^t_{K16}
1970	0.569645	0.008015	0.010287	4.817399	2.551503	1.473411	1.339184	16.732628
1971	0.655397	0.008772	0.011700	5.670054	2.584688	1.476549	1.340884	16.745833
1972	0.736329	0.010093	0.012801	6.152536	2.618284	1.479813	1.342694	16.760221
1973	0.800794	0.012016	0.012986	6.624688	2.651657	1.485202	1.345873	16.786631
1974	0.856724	0.014485	0.012997	7.068945	2.692194	1.490656	1.349311	16.814730
1975	0.924406	0.018631	0.012715	7.121748	2.740207	1.496591	1.353448	16.844440
1976	1.005607	0.023035	0.012767	6.850491	2.773521	1.502623	1.358069	16.872397
1977	1.055482	0.028264	0.012027	6.670529	2.816150	1.508900	1.363232	16.899132
1978	1.100988	0.034713	0.011247	7.388506	2.858772	1.515771	1.369273	16.925152
1979	1.158504	0.043033	0.011510	8.471736	2.901915	1.522751	1.376097	16.950814
1980	1.238051	0.052927	0.011515	9.864223	2.934915	1.529445	1.383135	16.976287
1981	1.316061	0.068211	0.011297	10.761024	2.967872	1.535997	1.390570	17.001831
1982	1.367433	0.085107	0.010128	11.159500	3.006182	1.542712	1.398737	17.027480
1983	1.421654	0.103912	0.010104	11.242834	3.075588	1.549780	1.407323	17.053162
1984	1.531950	0.129030	0.010566	11.933089	3.150871	1.557555	1.416381	17.079022
1985	1.681444	0.167431	0.011868	14.483773	3.234787	1.566257	1.425910	17.105183
1986	1.823782	0.222449	0.014818	17.584757	3.320141	1.575234	1.435063	17.131600
1987	1.956181	0.303712	0.018414	19.955061	3.364308	1.583805	1.443171	17.158136
1988	2.069772	0.408059	0.022903	20.971323	3.402683	1.592101	1.450442	17.184474
1989	2.151821	0.540814	0.027140	24.381199	3.443300	1.600402	1.456798	17.210292
1990	2.220767	0.697608	0.027898	28.313613	3.487466	1.608881	1.462329	17.235298
1991	2.266123	0.901095	0.027829	31.020497	3.532320	1.618244	1.467784	17.259267
1992	2.327072	1.129884	0.028870	36.829104	3.573378	1.628919	1.473790	17.282212
1993	2.408391	1.368522	0.032080	41.256578	3.594539	1.640477	1.480323	17.304396
1994	2.470595	1.590429	0.038255	44.034952	3.622793	1.652258	1.487484	17.325963
1995	2.567656	2.001929	0.045973	47.610617	3.656100	1.663693	1.495169	17.347030
1996	2.678011	2.477382	0.052945	53.461387	3.656108	1.674344	1.503183	17.367745
1997	2.837280	3.045590	0.060277	59.462909	3.656382	1.683802	1.511363	17.388022
1998	3.104450	3.697990	0.067280	63.252748	3.656326	1.692204	1.519701	17.407677
1999	3.397033	4.430685	0.076274	65.838229	3.656285	1.699671	1.528110	17.426610
2000	3.819670	5.132553	0.084791	69.393743	3.622847	1.706680	1.536609	17.444777
2001	4.461582	5.933626	0.094370	74.202322	3.589409	1.713529	1.545073	17.462147
2002	5.210438	6.914454	0.105647	79.495823	3.560164	1.720669	1.553530	17.478814
2003	6.187686	8.622882	0.121216	84.054266	3.516277	1.748058	1.579986	17.685814
2004	7.361757	10.544486	0.166286	91.473233	3.472275	1.774830	1.605380	17.876285
2005	8.889424	12.994729	0.254763	98.386875	3.463510	1.800743	1.629847	18.051375
2006	10.786619	16.101788	0.426949	103.591037	3.456450	1.830036	1.657373	18.252555
2007	13.031960	19.514568	0.733135	114.491464	3.454259	1.857319	1.683056	18.429702
2008	15.834781	24.133791	1.191221	132.962473	3.452555	1.882464	1.706695	18.584084
2009	19.278163	33.422063	1.669187	149.517215	3.512900	1.986731	1.802095	19.486067
2010	24.054083	47.835417	2.264003	166.436382	3.573350	2.126383	1.929085	19.827030
2011	29.431971	67.357839	2.917677	190.514668	3.628889	2.240425	2.031594	20.043596
2012	35.654722	96.691307	3.356911	213.797655	3.685051	2.319871	2.106519	20.132439
2013	43.026826	139.652246	4.030358	234.820142	3.740813	2.358151	2.152635	20.090818
2014	51.467378	194.634016	4.756766	258.100299	3.762291	2.392295	2.207640	20.237314
2015	59.614623	261.018812	5.473188	278.723010	3.783244	2.417584	2.226628	20.133623
2016	68.304269	337.642472	6.102772	295.292963	3.780779	2.452047	2.267716	20.321342
2017	77.601698	411.376874	6.853755	313.302427	3.778313	2.479617	2.295409	20.499949
2018	87.510336	487.384982	7.538445	331.356858	3.690629	2.623473	2.430707	21.620492

2019	97.789802	576.276955	7.934788	343.896855	3.603230	2.747763	2.547920	22.587405
2020	109.358293	676.716384	8.228396	356.596904	3.603227	2.750546	2.551690	22.593924
2021	122.021367	765.054930	8.432172	375.129205	3.603219	2.752862	2.554751	22.599373

It can be seen that there are very large growth rates in the capital stocks for many of the assets.

Table A3 lists the depreciation rates δ_n^t for the produced assets, $n = 1, \ldots, 11$. Assets 12-16 have 0 depreciation rates.

Table A3: Annual Geometric Depreciation Rates for Produced Assets

Year t	δ_1^t	δ_2^t	δ_3^t	δ_4^t	δ_5^t	δ_6^t	δ_7^t	δ_8^t	δ_9^t	δ_{10}^t	δ_{11}^t
1970	0.35828	0.29515	0.15961	0.13420	0.03692	0.05552	0.01760	0.18170	0.18957	0.41396	0.33381
1971	0.36693	0.29844	0.15752	0.13181	0.03692	0.05552	0.01760	0.18405	0.18719	0.42487	0.32704
1972	0.37540	0.29865	0.15540	0.13001	0.03692	0.05552	0.01760	0.18211	0.18402	0.43296	0.31460
1973	0.38377	0.30851	0.15668	0.12980	0.03692	0.05552	0.01760	0.18039	0.18246	0.43575	0.31248
1974	0.38994	0.31323	0.15750	0.12874	0.03692	0.05552	0.01760	0.18191	0.18326	0.45176	0.30895
1975	0.38832	0.32049	0.15794	0.13053	0.03692	0.05552	0.01760	0.18129	0.18404	0.44190	0.31297
1976	0.38525	0.31628	0.16466	0.13834	0.04710	0.06570	0.02778	0.18801	0.18067	0.44007	0.30330
1977	0.38327	0.30171	0.15331	0.12689	0.03692	0.05552	0.01760	0.17680	0.18010	0.44029	0.30222
1978	0.38252	0.31364	0.15595	0.12828	0.03692	0.05552	0.01760	0.18097	0.18091	0.44255	0.31600
1979	0.38474	0.29720	0.15207	0.12569	0.03692	0.05552	0.01760	0.17909	0.18235	0.44064	0.31240
1980	0.38575	0.29501	0.15131	0.12473	0.03708	0.05568	0.01776	0.17970	0.18186	0.45226	0.30939
1981	0.39043	0.28832	0.14971	0.12496	0.03917	0.05777	0.01985	0.18011	0.17974	0.44416	0.29618
1982	0.40127	0.30469	0.15088	0.12480	0.03692	0.05552	0.01760	0.18173	0.17980	0.43888	0.31198
1983	0.42753	0.31298	0.15396	0.12606	0.03692	0.05552	0.01760	0.18401	0.18314	0.44296	0.31948
1984	0.45017	0.34367	0.16024	0.12936	0.03692	0.05552	0.01760	0.18818	0.18490	0.45401	0.33159
1985	0.45161	0.35754	0.17592	0.13272	0.03766	0.05626	0.01834	0.19246	0.18376	0.46014	0.35118
1986	0.43970	0.32351	0.16847	0.13620	0.03992	0.05852	0.02060	0.19536	0.18270	0.46739	0.35025
1987	0.41073	0.33516	0.16301	0.13516	0.03703	0.05563	0.01771	0.19233	0.18142	0.46310	0.35043
1988	0.38812	0.32060	0.16306	0.13604	0.03868	0.05728	0.01936	0.19329	0.17980	0.45949	0.34124
1989	0.37776	0.28949	0.15448	0.13055	0.03926	0.05786	0.01994	0.18284	0.17913	0.45249	0.31671
1990	0.37005	0.28705	0.15317	0.12882	0.03892	0.05752	0.01960	0.18381	0.17810	0.45285	0.31196
1991	0.37264	0.30022	0.16018	0.13442	0.04301	0.06161	0.02369	0.19275	0.17867	0.44538	0.31819
1992	0.38442	0.32306	0.16008	0.13298	0.03791	0.05651	0.01859	0.18761	0.17938	0.43694	0.32972
1993	0.39312	0.35099	0.18230	0.13705	0.04066	0.05926	0.02134	0.19663	0.17858	0.42725	0.34241
1994	0.39936	0.35731	0.17639	0.13871	0.04201	0.06061	0.02269	0.19823	0.17976	0.44633	0.34386
1995	0.40075	0.34924	0.16116	0.13584	0.03999	0.05859	0.02067	0.19290	0.18009	0.44214	0.33603
1996	0.39373	0.33343	0.16434	0.14022	0.04449	0.06309	0.02517	0.19523	0.18154	0.44053	0.33398
1997	0.38702	0.34178	0.15855	0.13521	0.03877	0.05737	0.01945	0.19229	0.18460	0.43753	0.33050
1998	0.38694	0.30706	0.15987	0.14544	0.04579	0.06439	0.02647	0.19355	0.18461	0.43436	0.33323
1999	0.39935	0.31969	0.15532	0.13644	0.03935	0.05795	0.02003	0.18932	0.18727	0.42651	0.32979
2000	0.43645	0.35968	0.15458	0.13287	0.03707	0.05567	0.01775	0.18606	0.19111	0.42605	0.33000
2001	0.48464	0.35569	0.16027	0.13251	0.03780	0.05640	0.01848	0.18649	0.19110	0.42787	0.33101
2002	0.50900	0.33167	0.16345	0.13269	0.03779	0.05639	0.01847	0.19015	0.19283	0.44403	0.33537
2003	0.50326	0.32176	0.16797	0.13698	0.03949	0.05809	0.02017	0.18712	0.19303	0.43924	0.37043
2004	0.46781	0.31055	0.16614	0.13604	0.03750	0.05611	0.01818	0.18202	0.19459	0.44112	0.39546
2005	0.42486	0.30590	0.16775	0.13808	0.03823	0.05683	0.01891	0.18134	0.19511	0.44245	0.41792
2006	0.39761	0.30174	0.16642	0.13750	0.03779	0.05639	0.01847	0.18010	0.19465	0.43709	0.42437
2007	0.38221	0.30010	0.16643	0.13785	0.03753	0.05613	0.01821	0.18048	0.19526	0.44198	0.40995
2008	0.37352	0.30431	0.17183	0.14216	0.04223	0.06084	0.02292	0.20038	0.19547	0.47126	0.37502
2009	0.37092	0.30063	0.16803	0.13761	0.03711	0.05571	0.01779	0.20096	0.19814	0.48042	0.36801
2010	0.36933	0.30134	0.16836	0.13781	0.03780	0.05640	0.01848	0.19739	0.19601	0.47585	0.35745
2011	0.36887	0.29978	0.16248	0.13343	0.03733	0.05594	0.01802	0.18688	0.19494	0.48126	0.33586
2012	0.36726	0.30142	0.16368	0.13378	0.03748	0.05608	0.01816	0.18403	0.19453	0.48300	0.34368
2013	0.36355	0.29756	0.15954	0.13227	0.03778	0.05638	0.01846	0.17922	0.19359	0.47300	0.34050
2014	0.35916	0.29130	0.15617	0.13028	0.03743	0.05603	0.01811	0.17617	0.19026	0.46260	0.33587

2015	0.35619	0.28644	0.15339	0.12849	0.03721	0.05582	0.01789	0.17333	0.18915	0.45321	0.33031
2016	0.35522	0.29002	0.15477	0.12965	0.03769	0.05629	0.01837	0.17067	0.18830	0.43836	0.33157
2017	0.35504	0.29096	0.15480	0.12963	0.03718	0.05578	0.01786	0.16870	0.18756	0.43172	0.32795
2018	0.35222	0.28950	0.15460	0.12952	0.03712	0.05572	0.01780	0.16975	0.18666	0.43125	0.32056
2019	0.34895	0.28572	0.15343	0.12872	0.03718	0.05578	0.01786	0.17058	0.18673	0.42965	0.31813
2020	0.34537	0.28088	0.15160	0.12744	0.03699	0.05559	0.01767	0.17163	0.18651	0.42100	0.31621
Mean	0.39412	0.31198	0.16037	0.13285	0.03850	0.05710	0.01918	0.18494	0.18625	0.44553	0.33623

In the main text, we worked with a more aggregated model where there are only 5 types of capital: (i) *Aggregate M&E* (an aggregate of assets 1-4), with year t price, quantity and value indexes equal to P^t_{KM}, Q^t_{KM} and $V^t_{KM} \equiv P^t_{KM}Q^t_{KM}$; (ii) *Aggregate Structures* (an aggregate of assets 5-7) with year t price and quantity indexes equal to P^t_{KS} and Q^t_{KS}; (iii) *Aggregate Other Capital* (an aggregate of assets 8-11) with year t price and quantity indexes equal to P^t_{KO} and Q^t_{KO}; (iv) *Inventory Stocks* (equal to asset 12) which we label as P^t_{KI}, Q^t_{KI} and $V^t_{KI} \equiv P^t_{KI}Q^t_{KI}$ and (v) *Land Assets* (an aggregate of assets 13-16) with price and quantity indexes P^t_{KL} and Q^t_{KL} for $t = 1970, \ldots, 2021$. The aggregation is done using chained Törnqvist price indexes. Table A4 below lists these aggregate beginning of the year capital stocks and their corresponding aggregate prices. The units of measurement for the quantity indexes are now in units of trillions of 1970 yuan.

Table A4: Prices and Quantities for Five Beginning of the Year Aggregate Capital Stocks

Year t	P^t_{KM}	P^t_{KS}	P^t_{KO}	P^t_{KI}	P^t_{KL}	Q^t_{KM}	Q^t_{KS}	Q^t_{KO}	Q^t_{KI}	Q^t_{KL}
1970	1.00000	1.00000	1.00000	1.00000	1.00000	0.09164	0.20841	0.01194	0.04817	0.22097
1971	0.99523	1.01537	0.99385	1.00460	1.05944	0.10633	0.22639	0.01327	0.05670	0.22148
1972	0.97362	1.02161	1.01445	1.01260	1.10733	0.11945	0.24869	0.01475	0.06153	0.22201
1973	0.98975	1.06311	1.08364	1.01388	1.15779	0.13075	0.27265	0.01596	0.06625	0.22269
1974	1.00731	1.06348	1.05510	1.01542	1.20755	0.14300	0.29585	0.01699	0.07069	0.22346
1975	0.97761	1.07449	1.15008	1.01778	1.25476	0.15441	0.32493	0.01829	0.07122	0.22434
1976	0.97491	1.08772	1.23035	1.01510	1.28785	0.17092	0.35890	0.01974	0.06850	0.22506
1977	0.97092	1.10035	1.29704	1.02004	1.31484	0.18069	0.38909	0.02047	0.06671	0.22587
1978	0.98060	1.11574	1.31940	1.01637	1.37809	0.18928	0.42727	0.02114	0.07389	0.22670
1979	0.99535	1.14210	1.37393	1.03707	1.49736	0.20294	0.46832	0.02235	0.08472	0.22756
1980	0.99603	1.22075	1.35637	1.11218	1.66321	0.20878	0.51842	0.02369	0.09864	0.22833
1981	1.00089	1.24951	1.36945	1.15681	1.86524	0.21118	0.57664	0.02509	0.10761	0.22910
1982	1.00619	1.28709	1.39903	1.19240	2.08287	0.20627	0.63815	0.02599	0.11160	0.22995
1983	0.98611	1.35204	1.33978	1.20395	2.33875	0.20942	0.70288	0.02734	0.11243	0.23107
1984	1.00057	1.43289	1.36768	1.22330	2.64320	0.21754	0.76949	0.02969	0.11933	0.23228
1985	1.03583	1.54922	1.47369	1.26567	2.97237	0.23903	0.84619	0.03314	0.14484	0.23359
1986	1.08186	1.69009	1.55674	1.36066	3.35570	0.27925	0.93402	0.03719	0.17585	0.23492
1987	1.09756	1.81148	1.58373	1.47084	3.82668	0.32397	1.02195	0.04162	0.19955	0.23591
1988	1.21005	2.04708	1.76452	1.57062	4.39993	0.38343	1.11470	0.04634	0.20971	0.23684
1989	1.30867	2.19193	1.95455	1.80004	5.08785	0.44739	1.22014	0.05110	0.24381	0.23775
1990	1.43049	2.34325	2.15959	1.89167	5.85954	0.47458	1.30951	0.05371	0.28314	0.23867
1991	1.52738	2.57119	2.22004	2.01635	6.91039	0.49401	1.38920	0.05649	0.31020	0.23962
1992	1.68667	3.00677	2.39978	2.08677	8.16248	0.52592	1.47649	0.06067	0.36829	0.24064
1993	1.98345	3.95798	2.78515	2.18251	9.94609	0.59509	1.60196	0.06548	0.41257	0.24162
1994	2.12913	4.36897	2.97883	2.44500	11.89559	0.71317	1.75477	0.07180	0.44035	0.24271
1995	2.23844	4.57578	3.19442	3.06527	14.63838	0.84870	1.93126	0.08029	0.47611	0.24383
1996	2.24980	4.80546	3.32095	3.47716	16.87101	0.96999	2.15057	0.08914	0.53461	0.24468
1997	2.22518	4.94671	3.26482	3.63135	19.05552	1.09732	2.38096	0.09878	0.59463	0.24545
1998	2.19641	4.95261	3.08259	3.61790	21.09164	1.25981	2.62102	0.11257	0.63253	0.24615
1999	2.13590	4.95994	2.99188	3.45890	23.21959	1.44953	2.87532	0.12465	0.65838	0.24678
2000	2.09188	5.01014	3.01756	3.38314	25.79735	1.65383	3.15294	0.14082	0.69394	0.24720
2001	2.08030	5.08671	3.13983	3.44118	28.87673	1.89237	3.46014	0.16112	0.74202	0.24762
2002	2.04585	5.19774	2.96618	3.44693	32.30022	2.17194	3.79590	0.18436	0.79496	0.24808

2003	2.00551	5.42639	3.08906	3.44314	36.19518	2.52574	4.16372	0.21779	0.84054	0.25110
2004	2.01384	5.88369	3.26398	3.56920	41.00481	3.02784	4.58897	0.25198	0.91473	0.25397
2005	2.02599	6.21055	3.37694	3.91015	47.98145	3.64686	5.07592	0.29079	0.98387	0.25684
2006	2.05587	6.46321	3.48598	4.07068	57.15174	4.43971	5.56149	0.33650	1.03591	0.26014
2007	2.06153	6.88012	3.46833	4.21174	68.10783	5.35991	6.07942	0.38964	1.14491	0.26319
2008	2.08562	7.48038	3.41441	4.47583	81.95295	6.48988	6.66854	0.45922	1.32962	0.26596
2009	2.05627	7.20747	3.31161	4.80467	96.89788	7.82703	7.29278	0.57355	1.49517	0.27936
2010	2.07390	7.56077	3.48283	4.56415	110.28328	9.56505	8.16115	0.74096	1.66436	0.29122
2011	2.11567	8.26007	3.63302	4.91113	122.74774	11.64206	9.10495	0.93432	1.90515	0.30029
2012	2.11000	8.39396	3.58583	5.22963	135.59666	13.44432	10.26086	1.14334	2.13798	0.30619
2013	2.09609	8.41794	3.61187	5.20190	149.00218	15.63092	11.43201	1.39840	2.34820	0.30875
2014	2.08704	8.46522	3.62677	5.16334	166.48889	17.58159	12.80729	1.67555	2.58100	0.31267
2015	2.06596	8.23614	3.62824	5.07224	189.30753	19.22536	14.32535	1.95540	2.78723	0.31319
2016	2.05205	8.18637	3.77568	4.82652	213.40473	20.47612	15.96074	2.23955	2.95293	0.31688
2017	2.06377	8.84016	3.82779	4.77608	236.02159	22.05321	17.62759	2.50162	3.13302	0.31991
2018	2.08660	9.47743	3.89201	5.00407	256.95912	23.93408	19.33865	2.76790	3.31357	0.33685
2019	2.09391	9.74584	3.87597	5.15396	274.74561	25.93155	21.16348	3.06822	3.43897	0.35145
2020	2.08611	9.72195	3.83591	5.20142	291.88865	27.70354	23.08055	3.41796	3.56597	0.35170
2021	2.10400	10.52849	3.86678	5.16729	308.67003	29.06211	25.03494	3.76773	3.75129	0.35191

The aggregate price of land grew 308.7 fold over the sample period while the price of M&E capital grew only 2.1 fold. The price of structures grew 10.5 fold.

We turn our attention to the components of output and investment.

The investment quantity indexes Q_{In}^t, the capital stock quantity indexes Q_{Kn}^t and the non zero depreciation rates δ_n^t are all consistent with equations (A1) above for assets $n = 1, \ldots, 11$. For the zero depreciation assets, we define the corresponding investments by differencing the beginning and end of year capital stocks listed above in Table A2. Thus define the investments for the non-depreciable assets 12-16 as follows:

$$Q_{In}^t \equiv Q_{Kn}^{t+1} - Q_{Kn}^t; \qquad n = 12, \ldots, 16; t = 1970, \ldots, 2020. \tag{A2}$$

Differencing the stock of inventories to obtain an estimate for investment in inventories is acceptable from the viewpoint of the international SNA. The same logic should apply to land stocks; i.e., estimates for investment in the different types of land can be obtained by differencing the stocks as we have done in definitions (A2) above. However, the current SNA does not follow the inventories example and ignores changes in land use in the definition of aggregate investment. It may be that the logic behind this decision is that land as a whole does not change from year to year and hence there is no investment in land by definition. But it can be seen that when we decompose land use into different components, agricultural land is frequently converted into more valuable types of land and hence investment in land should be included in aggregate investment. Thus, the definition of aggregate investment used in this paper will differ from the APDB estimate for aggregate investment because we have included land investment (as defined above) in our investment aggregate.

We can now construct a new investment aggregate that includes land investment. Use chained Törnqvist price indexes to construct the new aggregate investment price P_I^t and the corresponding implicit quantity index Q_I^t by aggregating over all 16 types of investment that are defined above for the years t = 1970-2020. Define the corresponding year t value of aggregate investment as $V_I^t \equiv P_I^t Q_I^t$. Define a produced-asset investment aggregate that aggregates investments over the first 12 types of investment (call this aggregate $V_{IR}^t \equiv P_{IR}^t Q_{IR}^t$) and a land investment aggregate that aggregates over the 4 types of land (call this aggregate $V_{IL}^t \equiv P_{IL}^t Q_{IL}^t$) using chained Törnqvist price indexes. The aggregate investment price indexes P_I^t, P_{IR}^t and P_{IL}^t are listed in Table A5 below and the corresponding quantity indexes and the values V_I^t, V_{IR}^t and V_{IL}^t are listed in Table A6 below.

Table A5 also lists the APDB price indexes for P_C^t (private consumption),*[54] P_G^t (government consumption), P_X^t (exports of goods and services), and P_M^t (imports of goods and services). The corresponding quantity or volume indexes are defined as Q_C^t, Q_G^t, Q_X^t and Q_M^t and they are listed in Table A6 below. The Q_M^t are listed with a negative sign since they are a cost to producers whereas the other outputs are a source of revenue.

Table A5: Output Price Indexes for the Main Aggregates for China

Year t	P_Y^t	P_C^t	P_G^t	P_I^t	P_X^t	P_M^t	P_{IR}^t	P_{IL}^t
1970	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
1971	1.02349	1.03608	0.99747	1.00580	0.95639	0.96080	1.00551	1.04252
1972	1.04080	1.06323	1.00779	1.00098	0.95979	0.93897	1.00024	1.08833
1973	1.07132	1.09222	1.03036	1.02818	0.98814	0.90767	1.02725	1.13395
1974	1.09169	1.12047	1.01970	1.03654	1.04008	0.91877	1.03523	1.17671
1975	1.11309	1.15099	1.04194	1.03921	1.01496	0.90542	1.03761	1.20744
1976	1.12501	1.17481	1.00902	1.04917	0.99847	0.90555	1.04741	1.23505
1977	1.15348	1.21158	1.04876	1.05743	1.00875	0.92117	1.05517	1.29827
1978	1.19274	1.25179	1.12691	1.07297	1.06379	0.94093	1.06988	1.41602
1979	1.25659	1.32738	1.20165	1.10165	1.10905	0.94428	1.09761	1.57814
1980	1.32344	1.39805	1.28851	1.15150	1.14236	0.97690	1.14650	1.77465
1981	1.36446	1.45523	1.31149	1.17814	1.16111	1.01995	1.17186	1.99247
1982	1.40871	1.50559	1.35207	1.20829	1.19303	1.03943	1.20026	2.24743
1983	1.45357	1.55458	1.42371	1.24524	1.24388	1.12138	1.23506	2.54333
1984	1.52416	1.61955	1.60331	1.30377	1.38048	1.31589	1.29163	2.86429
1985	1.67304	1.80019	1.83235	1.39476	1.64960	1.58567	1.38072	3.23762
1986	1.77156	1.90747	1.98296	1.50057	2.19902	2.07980	1.48439	3.71183
1987	1.88602	2.06215	2.16937	1.57812	2.43231	2.41163	1.55962	4.30274
1988	2.05099	2.38008	2.51194	1.77069	2.33080	3.28409	1.74937	5.00471
1989	2.26006	2.66032	2.71340	1.89925	2.10688	2.98095	1.87515	5.77493
1990	2.48125	2.82836	2.90713	2.04501	2.84982	3.37102	2.01660	6.94983
1991	2.68849	3.02186	3.22856	2.20465	3.15007	3.60527	2.17131	8.34148
1992	2.91526	3.14228	3.68045	2.49411	3.20211	3.63753	2.45372	10.47340
1993	3.40814	3.53616	4.44964	3.11813	2.88861	3.53593	3.06802	12.91596
1994	3.92350	4.12808	5.64244	3.43106	4.44760	5.44525	3.37424	15.09292
1995	4.53683	5.11522	6.69272	3.62411	4.59739	5.61425	3.56260	16.91573
1996	4.94646	5.71058	7.38566	3.75794	4.28679	5.04536	3.69358	18.04752
1997	5.07617	5.93707	7.77536	3.80767	4.01903	4.79466	3.74182	18.92105
1998	5.07357	5.94350	7.94103	3.77944	3.64947	4.29620	3.71281	20.19709
1999	5.04825	5.99265	8.08759	3.74438	3.67225	4.53721	3.67669	22.58290
2000	5.15854	6.17686	8.35536	3.74342	3.97211	4.89489	3.67389	26.42950
2001	5.28871	6.24542	8.70718	3.77160	3.98435	4.69097	3.69966	30.98631
2002	5.24309	5.94724	8.93715	3.78724	4.08306	4.66571	3.70910	35.42878
2003	5.34515	5.88654	9.55389	3.85971	4.47608	5.04929	3.77131	40.29172
2004	5.66732	5.99407	10.50233	4.06712	5.18544	5.65189	3.96546	47.43810
2005	5.93931	5.99945	11.19282	4.21174	5.60178	5.79651	4.09370	56.97516
2006	6.32681	6.35680	12.67250	4.34228	5.77391	5.82752	4.20650	68.31841
2007	6.70192	6.46716	14.94353	4.51188	6.01178	5.95700	4.35783	82.31227
2008	7.07901	6.72202	16.98209	4.76619	6.16888	6.19197	4.57578	97.24520
2009	7.09178	6.63570	17.90795	4.68188	5.53661	5.30869	4.44340	109.89207
2010	7.41909	7.00233	18.85678	4.85773	6.12620	5.90382	4.59619	119.74306
2011	8.00466	7.64068	21.08981	5.15761	6.25829	6.01539	4.87642	129.28951

*[54] The consumption price has been adjusted downward by the amount of indirect taxes paid on outputs and the imports price has been adjusted upward by indirect taxes on imports in APDB. The required tax information is also available in the APDB. Thus, we adjust the APDB final demand prices to obtain prices that producers actually pay for inputs and obtain revenues for the outputs that they produce. Jorgenson and Griliches (1972)[44] noted the importance of making these tax adjustments when constructing productivity estimates for the economy.

2012	8.22139	7.82815	22.62962	5.19425	6.12927	5.79792	4.90420	138.34387
2013	8.38706	8.05662	24.00824	5.19204	5.94955	5.58114	4.89497	149.74721
2014	8.54454	8.40516	25.43431	5.19714	5.61211	5.33526	4.89474	148.05880
2015	8.76067	8.63167	27.10046	5.09062	5.36579	4.74452	4.78678	150.60920
2016	8.96447	9.08031	28.21559	5.07597	5.24147	4.60481	4.76175	166.80831
2017	9.37867	9.50284	30.32434	5.33623	5.46211	4.97119	4.99409	181.86109
2018	9.78896	9.82210	32.45280	5.59530	5.61191	5.18919	5.22661	194.25655
2019	10.17567	10.45015	34.77872	5.70288	5.78946	5.45632	5.31740	208.59258
2020	10.46970	10.94922	35.87764	5.68737	5.82056	5.25754	5.30234	225.16269

The corresponding aggregate quantity indexes are measured in units equal to trillions of 1970 yuan. The product of the price and corresponding quantity indexes listed in Tables A5 and A6 are equal to current yuan values in trillions of current yuan. Thus $V_Y^t = P_Y^t Q_Y^t$ is year t Chinese (Augmented) GDP in trillions of yuan.*[55] Table A6 also includes the year t current yuan value of produced-asset (or "regular") gross investment V_{IR}^t and the year t net investment in land V_{IL}^t in trillions of yuan. It can be seen that net land investment for China is in general not large.

Table A6: Output Quantity Indexes and Current Yuan Values for Gross Output

Year t	Q_Y^t	Q_C^t	Q_G^t	Q_I^t	Q_X^t	Q_M^t	Q_{IR}^t	Q_{IL}^t	V_Y^t	V_{IR}^t	V_{IL}^t
1970	0.23602	0.14673	0.02529	0.06554	0.00636	-0.00790	0.06503	0.00051	0.23602	0.06503	0.00051
1971	0.24557	0.14886	0.02967	0.06744	0.00761	-0.00791	0.06691	0.00053	0.25133	0.06728	0.00055
1972	0.25711	0.15694	0.03077	0.06986	0.00921	-0.00962	0.06916	0.00069	0.26760	0.06918	0.00075
1973	0.26455	0.16302	0.03094	0.07218	0.01297	-0.01492	0.07139	0.00078	0.28342	0.07333	0.00088
1974	0.26973	0.16432	0.03360	0.07630	0.01543	-0.02073	0.07540	0.00088	0.29446	0.07805	0.00103
1975	0.28453	0.16837	0.03445	0.08601	0.01600	-0.02054	0.08529	0.00073	0.31671	0.08850	0.00088
1976	0.28615	0.16727	0.03776	0.08472	0.01510	-0.01839	0.08391	0.00082	0.32192	0.08788	0.00101
1977	0.30795	0.17574	0.03909	0.09732	0.01548	-0.01872	0.09651	0.00083	0.35521	0.10183	0.00108
1978	0.33123	0.18475	0.04211	0.11218	0.01833	-0.02499	0.11138	0.00085	0.39508	0.11917	0.00120
1979	0.35301	0.19493	0.04702	0.12067	0.02234	-0.03111	0.12002	0.00076	0.44359	0.13174	0.00119
1980	0.37410	0.21036	0.04896	0.12397	0.02759	-0.03720	0.12333	0.00076	0.49510	0.14140	0.00135
1981	0.38574	0.22265	0.04961	0.11963	0.03648	-0.04515	0.11886	0.00083	0.52632	0.13929	0.00164
1982	0.41174	0.23212	0.05249	0.12845	0.04080	-0.04264	0.12726	0.00110	0.58002	0.15274	0.00247
1983	0.44979	0.25023	0.05902	0.14541	0.04115	-0.04593	0.14420	0.00117	0.65380	0.17810	0.00298
1984	0.51939	0.27338	0.06843	0.19125	0.04985	-0.06003	0.19022	0.00127	0.79163	0.24570	0.00365
1985	0.56219	0.30287	0.07058	0.23175	0.05848	-0.09693	0.23110	0.00128	0.94057	0.31909	0.00415
1986	0.60441	0.31878	0.07248	0.23966	0.06011	-0.08312	0.23990	0.00095	1.07075	0.35610	0.00353
1987	0.65261	0.33589	0.07357	0.24826	0.07062	-0.07669	0.24878	0.00088	1.23083	0.38800	0.00378
1988	0.74558	0.34998	0.07553	0.30332	0.08744	-0.07138	0.30455	0.00086	1.52918	0.53277	0.00432
1989	0.74049	0.36252	0.08350	0.27341	0.10260	-0.08483	0.27427	0.00086	1.67354	0.51429	0.00497
1990	0.74860	0.37164	0.08866	0.25108	0.11554	-0.08725	0.25157	0.00089	1.85745	0.50732	0.00615
1991	0.83346	0.39549	0.09543	0.31503	0.13446	-0.10555	0.31632	0.00092	2.24077	0.68684	0.00768
1992	0.91797	0.42841	0.10670	0.37326	0.16361	-0.14230	0.37572	0.00086	2.67613	0.92191	0.00903
1993	1.01977	0.46774	0.11507	0.44998	0.20773	-0.19617	0.45343	0.00093	3.47552	1.39113	0.01195
1994	1.16465	0.49633	0.12147	0.52436	0.26979	-0.21372	0.52892	0.00095	4.56950	1.78471	0.01439
1995	1.28228	0.53380	0.12197	0.60705	0.30785	-0.23950	0.61394	0.00076	5.81750	2.18723	0.01279
1996	1.39196	0.58112	0.12833	0.66611	0.34746	-0.27228	0.67421	0.00072	6.88525	2.49026	0.01293
1997	1.50787	0.60863	0.14100	0.68844	0.43979	-0.30127	0.69713	0.00068	7.65419	2.60853	0.01282
1998	1.64211	0.64314	0.16035	0.76833	0.47891	-0.32962	0.77862	0.00064	8.33134	2.89088	0.01300
1999	1.76813	0.69579	0.18326	0.82170	0.51448	-0.37289	0.83417	0.00043	8.92593	3.06699	0.00975
2000	1.93960	0.76256	0.20209	0.91986	0.60460	-0.45727	0.93425	0.00042	10.00548	3.43234	0.01109
2001	2.06234	0.80605	0.20898	1.03535	0.64588	-0.51695	1.05178	0.00044	10.90714	3.89123	0.01371

*[55] The GDP estimate is "augmented" because it includes land investments which are not included in "regular" estimates of GDP.

2002	2.26326	0.86533	0.21887	1.19483	0.76844	-0.62125	1.19279	0.00285	11.86648	4.42417	0.10095
2003	2.48260	0.90558	0.22028	1.45877	0.93248	-0.78618	1.46428	0.00269	13.26985	5.52225	0.10819
2004	2.68920	0.96089	0.22538	1.67066	1.09326	-0.94656	1.68147	0.00268	15.24059	6.66782	0.12696
2005	2.96740	1.02793	0.24765	1.84510	1.27394	-1.07341	1.85579	0.00305	17.62428	7.59705	0.17405
2006	3.31247	1.10209	0.25663	2.10676	1.52534	-1.24511	2.12931	0.00280	20.95739	8.95696	0.19118
2007	3.77957	1.22339	0.26437	2.49761	1.77351	-1.42067	2.53823	0.00252	25.33038	11.06120	0.20772
2008	4.27505	1.32849	0.27231	3.03447	1.86092	-1.49131	2.89906	0.01231	30.26314	13.26547	1.19738
2009	4.72149	1.47183	0.28712	3.67805	1.70704	-1.52502	3.61015	0.01073	33.48379	16.04133	1.17885
2010	5.24481	1.61566	0.31880	4.17556	2.00533	-1.86017	4.19622	0.00833	38.91169	19.28663	0.99715
2011	5.63817	1.76031	0.35257	4.52401	2.25084	-2.18996	4.63852	0.00552	45.13161	22.61933	0.71372
2012	6.04124	1.88236	0.37499	4.86324	2.40148	-2.33431	5.08251	0.00242	49.66738	24.92564	0.33525
2013	6.54914	2.00156	0.39231	5.42973	2.62328	-2.58284	5.63844	0.00395	54.92799	27.60002	0.59135
2014	6.88675	2.17092	0.40022	5.64563	2.86100	-2.80764	5.97993	0.00048	58.84408	29.27020	0.07095
2015	7.31688	2.36706	0.41224	5.99509	2.86642	-2.82473	6.22480	0.00479	64.10079	29.79678	0.72195
2016	7.76279	2.57721	0.43288	6.40989	2.89961	-2.98841	6.69388	0.00397	69.58932	31.87463	0.66183
2017	8.61455	2.76596	0.44792	7.45239	3.13014	-3.20630	7.15515	0.02218	80.79305	35.73347	4.03419
2018	9.04684	2.97231	0.46841	7.81784	3.25507	-3.43918	7.65910	0.01911	88.55911	40.03110	3.71204
2019	9.14580	3.12886	0.47570	7.53519	3.26957	-3.31325	8.06892	0.00032	93.06464	42.90571	0.06659
2020	9.27526	3.05019	0.48394	7.75036	3.34163	-3.26766	8.30201	0.00026	97.10923	44.02010	0.05909

We turn our attention to the construction of annual rates of return on assets used in production and on measuring capital services. Actual ex post asset inflation rates can be calculated using the asset price information listed in Table A1. As noted in the text, if ex post asset inflation rates are used in a user cost formula, the resulting user costs are too volatile to approximate rental prices. Thus, we used smoothed asset inflation rates in our final user costs.*[56] The smoothed asset inflation rates, i_n^t, are listed in Table A7 below.

Table A7: Smoothed Asset Inflation Rates for Assets 1-16

Year t	i_1^t	i_2^t	i_3^t	i_4^t	i_5^t	i_6^t	i_7^t	i_8^t
1970	-0.04722	-0.06976	-0.01369	-0.00621	0.00233	-0.00295	0.01761	-0.00573
1971	-0.05237	-0.06556	-0.01272	-0.00478	0.00558	0.00099	0.02003	-0.00388
1972	-0.05755	-0.06140	-0.01173	-0.00331	0.00900	0.00501	0.02254	-0.00226
1973	-0.06267	-0.05729	-0.01072	-0.00177	0.01259	0.00914	0.02515	-0.00076
1974	-0.06751	-0.05325	-0.00966	-0.00016	0.01632	0.01339	0.02787	0.00075
1975	-0.07187	-0.04925	-0.00849	0.00149	0.02015	0.01775	0.03071	0.00245
1976	-0.07552	-0.04521	-0.00715	0.00318	0.02407	0.02219	0.03363	0.00446
1977	-0.07838	-0.04106	-0.00564	0.00492	0.02805	0.02668	0.03661	0.00676
1978	-0.08066	-0.03670	-0.00393	0.00671	0.03207	0.03119	0.03964	0.00909
1979	-0.08318	-0.03190	-0.00204	0.00853	0.03631	0.03571	0.04280	0.01048
1980	-0.08216	-0.02616	0.00169	0.01258	0.04275	0.04155	0.04742	0.01259
1981	-0.07995	-0.01990	0.00607	0.01787	0.04946	0.04748	0.05217	0.01519
1982	-0.07569	-0.01344	0.01094	0.02419	0.05618	0.05356	0.05718	0.01792
1983	-0.06818	-0.00644	0.01676	0.03121	0.06333	0.06041	0.06315	0.02077
1984	-0.05708	0.00190	0.02430	0.03891	0.07204	0.06884	0.07081	0.02464
1985	-0.04299	0.01135	0.03290	0.04711	0.08200	0.07830	0.07955	0.02956
1986	-0.02854	0.02087	0.04153	0.05518	0.09175	0.08744	0.08812	0.03519
1987	-0.01660	0.02905	0.04918	0.06218	0.09991	0.09501	0.09528	0.04089
1988	-0.00863	0.03472	0.05490	0.06729	0.10552	0.10011	0.10015	0.04555
1989	-0.00475	0.03717	0.05809	0.06991	0.10780	0.10213	0.10218	0.04751
1990	-0.00407	0.03632	0.05864	0.06974	0.10653	0.10085	0.10117	0.04617
1991	-0.00589	0.03253	0.05665	0.06690	0.10243	0.09672	0.09766	0.04219
1992	-0.01008	0.02650	0.05265	0.06187	0.09664	0.09077	0.09254	0.03679
1993	-0.01637	0.01894	0.04740	0.05527	0.09018	0.08385	0.08650	0.03090

*[56] We used the Lowess smoothing option in Shazam with Smooth = 0.4 to smooth the ex post asset inflation rates.

1994	-0.02486	0.01004	0.04124	0.04745	0.08352	0.07633	0.07987	0.02581
1995	-0.03564	0.00000	0.03440	0.03878	0.07689	0.06848	0.07284	0.02229
1996	-0.04801	-0.01068	0.02718	0.02978	0.07029	0.06039	0.06524	0.02078
1997	-0.06016	-0.02124	0.02005	0.02118	0.06364	0.05215	0.05694	0.02102
1998	-0.07047	-0.03114	0.01328	0.01339	0.05703	0.04398	0.04836	0.02144
1999	-0.07848	-0.03974	0.00735	0.00685	0.05115	0.03659	0.04091	0.02034
2000	-0.08437	-0.04632	0.00295	0.00201	0.04677	0.03085	0.03564	0.01789
2001	-0.08804	-0.05025	0.00080	-0.00062	0.04481	0.02783	0.03336	0.01616
2002	-0.08962	-0.05167	0.00084	-0.00104	0.04530	0.02783	0.03394	0.01637
2003	-0.08963	-0.05158	0.00221	-0.00010	0.04673	0.02955	0.03584	0.01876
2004	-0.08843	-0.05054	0.00418	0.00140	0.04811	0.03192	0.03789	0.02304
2005	-0.08559	-0.04875	0.00617	0.00286	0.04885	0.03407	0.03931	0.02807
2006	-0.08046	-0.04623	0.00769	0.00392	0.04821	0.03510	0.03948	0.03285
2007	-0.07333	-0.04319	0.00849	0.00447	0.04592	0.03465	0.03833	0.03750
2008	-0.06498	-0.03997	0.00858	0.00456	0.04255	0.03321	0.03660	0.04210
2009	-0.05638	-0.03683	0.00819	0.00434	0.03881	0.03143	0.03492	0.04641
2010	-0.04832	-0.03397	0.00753	0.00394	0.03517	0.02980	0.03347	0.04963
2011	-0.04106	-0.03145	0.00667	0.00337	0.03199	0.02850	0.03225	0.05091
2012	-0.03525	-0.02846	0.00574	0.00320	0.03190	0.02913	0.03248	0.04802
2013	-0.02949	-0.02532	0.00478	0.00302	0.03194	0.02980	0.03268	0.04473
2014	-0.02363	-0.02196	0.00375	0.00280	0.03203	0.03041	0.03281	0.04171
2015	-0.01773	-0.01845	0.00269	0.00260	0.03224	0.03104	0.03294	0.03883
2016	-0.01189	-0.01486	0.00163	0.00244	0.03267	0.03179	0.03321	0.03586
2017	-0.00614	-0.01123	0.00058	0.00236	0.03339	0.03272	0.03370	0.03253
2018	-0.00054	-0.00763	-0.00043	0.00235	0.03440	0.03388	0.03445	0.02860
2019	0.00488	-0.00406	-0.00138	0.00243	0.03568	0.03523	0.03543	0.02391
2020	0.01009	-0.00056	-0.00229	0.00258	0.03721	0.03678	0.03664	0.01840

Year t	i_9^t	i_{10}^t	i_{11}^t	i_{12}^t	i_{13}^t	i_{14}^t	i_{15}^t	i_{16}^t
1970	0.06841	-0.08352	0.07742	-0.00473	0.01804	0.08930	0.08930	0.01804
1971	0.06489	-0.07591	0.07339	-0.00162	0.02294	0.09696	0.09696	0.02294
1972	0.06138	-0.06829	0.06929	0.00155	0.02806	0.10474	0.10474	0.02806
1973	0.05790	-0.06075	0.06515	0.00477	0.03337	0.11260	0.11260	0.03337
1974	0.05447	-0.05336	0.06101	0.00801	0.03878	0.12049	0.12049	0.03878
1975	0.05115	-0.04610	0.05695	0.01124	0.04419	0.12838	0.12838	0.04419
1976	0.04799	-0.03890	0.05308	0.01445	0.04951	0.13627	0.13627	0.04951
1977	0.04504	-0.03165	0.04945	0.01764	0.05465	0.14419	0.14419	0.05465
1978	0.04231	-0.02409	0.04609	0.02082	0.05962	0.15224	0.15224	0.05962
1979	0.03975	-0.01562	0.04286	0.02424	0.06489	0.16080	0.16080	0.06489
1980	0.04017	-0.00650	0.04215	0.02963	0.07122	0.16941	0.16946	0.07123
1981	0.04207	0.00233	0.04274	0.03582	0.07819	0.17737	0.17742	0.07824
1982	0.04515	0.01007	0.04433	0.04204	0.08540	0.18518	0.18445	0.08537
1983	0.04939	0.01667	0.04728	0.04746	0.09230	0.19320	0.19104	0.09189
1984	0.05548	0.02350	0.05241	0.05175	0.09865	0.20158	0.19810	0.09712
1985	0.06307	0.03091	0.05942	0.05556	0.10460	0.21007	0.20552	0.10121
1986	0.07107	0.03842	0.06702	0.06033	0.11058	0.21776	0.21153	0.10610
1987	0.07823	0.04516	0.07381	0.06656	0.11696	0.22310	0.21434	0.11308
1988	0.08343	0.05014	0.07870	0.07358	0.12361	0.22431	0.21280	0.12242
1989	0.08594	0.05258	0.08118	0.07982	0.12979	0.22025	0.20676	0.13346
1990	0.08546	0.05237	0.08102	0.08336	0.13445	0.21113	0.19732	0.14479
1991	0.08206	0.04967	0.07810	0.08323	0.13677	0.19861	0.18633	0.15492
1992	0.07628	0.04492	0.07293	0.07965	0.13654	0.18491	0.17555	0.16276
1993	0.06902	0.03891	0.06620	0.07367	0.13422	0.17202	0.16586	0.16779
1994	0.06076	0.03207	0.05834	0.06669	0.13062	0.16094	0.15706	0.17022
1995	0.05179	0.02473	0.04972	0.06010	0.12659	0.15174	0.14850	0.17096
1996	0.04248	0.01716	0.04077	0.05466	0.12267	0.14430	0.13985	0.17074
1997	0.03351	0.00961	0.03206	0.05017	0.11908	0.13894	0.13138	0.16988

1998	0.02528	0.00212	0.02389	0.04595	0.11573	0.13613	0.12404	0.16826
1999	0.01823	-0.00483	0.01660	0.04132	0.11248	0.13636	0.11946	0.16570
2000	0.01268	-0.01059	0.01087	0.03629	0.10960	0.13976	0.11911	0.16208
2001	0.00935	-0.01439	0.00756	0.03123	0.10781	0.14534	0.12337	0.15758
2002	0.00844	-0.01583	0.00678	0.02759	0.10804	0.15177	0.13081	0.15296
2003	0.00894	-0.01573	0.00746	0.02677	0.11066	0.15749	0.13854	0.14952
2004	0.00993	-0.01505	0.00855	0.02860	0.11526	0.16098	0.14408	0.14824
2005	0.01071	-0.01456	0.00934	0.03138	0.12076	0.16109	0.14685	0.14865
2006	0.01086	-0.01456	0.00948	0.03335	0.12581	0.15717	0.14716	0.15066
2007	0.01027	-0.01487	0.00900	0.03340	0.12923	0.14915	0.14601	0.15384
2008	0.00922	-0.01528	0.00815	0.03147	0.13033	0.13750	0.14456	0.15720
2009	0.00803	-0.01566	0.00722	0.02835	0.12909	0.12321	0.14342	0.15935
2010	0.00692	-0.01597	0.00640	0.02469	0.12595	0.10752	0.14246	0.15890
2011	0.00591	-0.01607	0.00574	0.02092	0.12153	0.09158	0.14110	0.15501
2012	0.00560	-0.01480	0.00562	0.01835	0.11561	0.08127	0.13926	0.14443
2013	0.00512	-0.01348	0.00539	0.01561	0.10986	0.07157	0.13676	0.13340
2014	0.00457	-0.01217	0.00508	0.01265	0.10397	0.06225	0.13402	0.12237
2015	0.00402	-0.01082	0.00475	0.00957	0.09791	0.05340	0.13132	0.11133
2016	0.00353	-0.00938	0.00446	0.00649	0.09170	0.04510	0.12881	0.10016
2017	0.00312	-0.00779	0.00425	0.00354	0.08540	0.03736	0.12656	0.08877
2018	0.00281	-0.00606	0.00412	0.00079	0.07908	0.03023	0.12458	0.07704
2019	0.00259	-0.00416	0.00409	-0.00172	0.07281	0.02372	0.12284	0.06492
2020	0.00244	-0.00208	0.00414	-0.00402	0.06661	0.01781	0.12127	0.05239

The above smoothed asset inflation rates replaced the actual asset inflation rates in equations (10) and the resulting equations were solved for r^t which is a smoothed version of the ex post rates of return. These smoothed r^t are used as an approximation to the Chinese cost of capital for year t. The resulting user costs U^t for assets 1-16 defined by equations (4) in the main text (but using the smoothed asset inflation rates i_n^t and the smoothed rates of return r^t) are listed in Table A8 below.

Table A8: Annual Smoothed User Costs for Chinese Assets used in Production

Year t	U_1^t	U_2^t	U_3^t	U_4^t	U_5^t	U_6^t	U_7^t	U_8^t
1970	0.51300	0.46873	0.29553	0.26399	0.15909	0.18272	0.12471	0.31080
1971	0.50194	0.44065	0.28926	0.25786	0.15635	0.17926	0.12614	0.28646
1972	0.46483	0.41407	0.28362	0.24696	0.15268	0.17153	0.12160	0.27314
1973	0.40962	0.38548	0.27780	0.25203	0.15776	0.17097	0.12120	0.28926
1974	0.41731	0.34363	0.25546	0.25591	0.15046	0.16945	0.12395	0.26093
1975	0.39277	0.34213	0.28236	0.25470	0.15666	0.17824	0.13636	0.30155
1976	0.41628	0.31770	0.27344	0.24432	0.14892	0.16906	0.12762	0.30654
1977	0.43100	0.31123	0.27924	0.25767	0.16443	0.18323	0.14497	0.34082
1978	0.38605	0.31057	0.29094	0.27045	0.17260	0.19189	0.15893	0.33877
1979	0.34865	0.30250	0.29284	0.27884	0.18183	0.19863	0.16667	0.35786
1980	0.26693	0.27881	0.27150	0.27260	0.18194	0.20017	0.16803	0.33007
1981	0.22775	0.26568	0.27095	0.27216	0.18240	0.20569	0.17542	0.31826
1982	0.20943	0.27428	0.28425	0.28453	0.19720	0.22130	0.19388	0.34050
1983	0.19648	0.27356	0.29284	0.29818	0.22903	0.25373	0.22956	0.33987
1984	0.19293	0.29389	0.31183	0.31883	0.25729	0.28405	0.26101	0.36174
1985	0.19120	0.30252	0.33127	0.32966	0.26980	0.29916	0.27202	0.40616
1986	0.18031	0.27484	0.32127	0.32824	0.26522	0.29692	0.26375	0.40169
1987	0.15986	0.27643	0.31877	0.33609	0.28369	0.31438	0.27803	0.40144
1988	0.15259	0.28613	0.35374	0.37922	0.33279	0.36722	0.32833	0.44934
1989	0.15339	0.27431	0.34530	0.38215	0.32311	0.36054	0.31267	0.47033
1990	0.15864	0.28813	0.36190	0.40881	0.33408	0.37498	0.32165	0.50471
1991	0.16630	0.31752	0.40806	0.47688	0.42685	0.46893	0.41772	0.51221
1992	0.17850	0.36386	0.45523	0.52945	0.49665	0.54376	0.48166	0.53586
1993	0.18694	0.44229	0.55954	0.62018	0.65023	0.70127	0.61727	0.56751

1994	0.19740	0.47933	0.59079	0.68441	0.75225	0.80061	0.71230	0.61000
1995	0.19411	0.50894	0.62963	0.76787	0.87631	0.93121	0.84645	0.68405
1996	0.17111	0.46956	0.64921	0.79504	0.96170	1.02162	0.93702	0.73847
1997	0.15678	0.44702	0.63816	0.78448	0.97713	1.03964	0.95512	0.70403
1998	0.15084	0.39759	0.63103	0.80011	1.01254	1.07568	1.01101	0.61972
1999	0.14609	0.37311	0.60796	0.76208	0.98948	1.05631	0.99105	0.57711
2000	0.14677	0.38082	0.60728	0.76546	1.04645	1.08673	1.06782	0.60208
2001	0.13163	0.35646	0.60715	0.74751	1.03499	1.07629	1.05089	0.64732
2002	0.12146	0.31802	0.60360	0.72885	1.05397	1.07337	1.03475	0.57107
2003	0.10140	0.28500	0.58628	0.70686	1.06556	1.06059	1.02622	0.60911
2004	0.08536	0.26663	0.57802	0.69519	1.10635	1.08281	1.04780	0.64816
2005	0.07127	0.25338	0.57717	0.69385	1.16579	1.10962	1.03360	0.67169
2006	0.06525	0.24638	0.59465	0.72063	1.29282	1.18598	1.09004	0.70489
2007	0.06116	0.23563	0.60832	0.73869	1.45975	1.29057	1.19068	0.69128
2008	0.05396	0.22721	0.62216	0.75392	1.60317	1.36760	1.38307	0.64713
2009	0.04576	0.21034	0.61082	0.72687	1.50956	1.27732	1.27469	0.63778
2010	0.04259	0.19450	0.61119	0.71727	1.55426	1.30996	1.29571	0.68896
2011	0.03937	0.17657	0.58723	0.68669	1.55871	1.34813	1.27542	0.67095
2012	0.03581	0.15764	0.55842	0.64814	1.42752	1.25155	1.14698	0.61567
2013	0.03376	0.15036	0.53779	0.61498	1.35323	1.18694	1.06176	0.65015
2014	0.03283	0.14476	0.51066	0.58016	1.25724	1.10148	0.96117	0.65939
2015	0.03302	0.14291	0.50106	0.56695	1.20875	1.05588	0.92431	0.72469
2016	0.03092	0.13959	0.50312	0.57131	1.21378	1.05662	0.93194	0.88716
2017	0.03188	0.14291	0.52993	0.60378	1.42069	1.21969	1.11373	0.97235
2018	0.03143	0.13673	0.52607	0.59985	1.45728	1.25612	1.13576	0.99764
2019	0.02976	0.13014	0.50623	0.57575	1.36399	1.19428	1.04930	0.96878
2020	0.02844	0.12374	0.49171	0.55378	1.27227	1.11432	0.96197	0.86657

Year t	U_9^t	U_{10}^t	U_{11}^t	U_{12}^t	U_{13}^t	U_{14}^t	U_{15}^t	U_{16}^t
1970	0.25854	0.58732	0.40665	0.12914	0.10637	0.03511	0.03511	0.10637
1971	0.27423	0.56151	0.43188	0.12519	0.10517	0.02908	0.02908	0.10517
1972	0.28924	0.53325	0.44760	0.12113	0.10138	0.02028	0.02028	0.10138
1973	0.31271	0.49621	0.47508	0.11906	0.10021	0.01306	0.01306	0.10021
1974	0.32394	0.41077	0.48449	0.11475	0.09582	0.00079	0.00079	0.09582
1975	0.36240	0.39181	0.54741	0.12114	0.10323	0.00309	0.00309	0.10323
1976	0.36742	0.37194	0.57579	0.10133	0.07841	-0.03998	-0.03998	0.07841
1977	0.42864	0.37447	0.65925	0.12592	0.10417	-0.00642	-0.00642	0.10417
1978	0.47380	0.36790	0.74491	0.13252	0.11258	-0.00249	-0.00249	0.11258
1979	0.51246	0.37681	0.77072	0.13971	0.12307	-0.00517	-0.00517	0.12307
1980	0.51213	0.36162	0.76564	0.13925	0.12005	-0.04699	-0.04715	0.12003
1981	0.52738	0.35880	0.78844	0.14067	0.12659	-0.07381	-0.07397	0.12651
1982	0.56346	0.36989	0.86036	0.15691	0.15487	-0.04999	-0.04682	0.15492
1983	0.58554	0.37101	0.90232	0.17982	0.20070	0.01883	0.03007	0.20148
1984	0.62883	0.38847	0.97729	0.20042	0.24586	0.08881	0.11090	0.24906
1985	0.65939	0.40144	1.05014	0.20605	0.25956	0.06380	0.09879	0.26729
1986	0.67005	0.40977	1.07607	0.19951	0.23863	-0.10117	-0.04284	0.24972
1987	0.69188	0.42149	1.12119	0.21927	0.26863	-0.08279	0.01671	0.27969
1988	0.78509	0.46802	1.23681	0.23792	0.30786	0.04282	0.20381	0.31873
1989	0.81997	0.46944	1.28495	0.23579	0.27720	-0.12094	0.12268	0.27336
1990	0.90448	0.48668	1.36875	0.23048	0.27010	-0.08196	0.21465	0.24042
1991	1.04272	0.52075	1.53857	0.27643	0.35784	0.60847	0.88433	0.28644
1992	1.16691	0.53505	1.77560	0.29111	0.39442	1.19747	1.42255	0.27446
1993	1.40964	0.61639	2.17843	0.29201	0.40923	1.58311	1.80439	0.21591
1994	1.54564	0.68591	2.39393	0.34148	0.51109	2.52382	2.77163	0.21920
1995	1.75628	0.74992	2.60363	0.49540	0.77842	4.55914	4.04498	0.43105
1996	1.81352	0.74788	2.63958	0.57097	0.93143	5.37524	4.65630	0.49855
1997	1.84900	0.71805	2.61041	0.59935	1.05952	5.65413	5.14395	0.58184

1998	1.82890	0.69427	2.61079	0.58812	1.11514	5.28494	5.46352	0.62396
1999	1.82849	0.66794	2.56870	0.56316	1.16366	4.90276	5.93959	0.69653
2000	1.89863	0.66169	2.60193	0.58999	1.34055	5.40861	7.23178	0.99088
2001	1.87888	0.64666	2.59957	0.58776	1.31161	4.92700	7.12910	1.00953
2002	1.86768	0.64206	2.61039	0.58793	1.34260	4.87119	6.98893	1.12343
2003	1.83666	0.60437	2.74168	0.55938	1.28989	4.09706	6.07353	1.08798
2004	1.85832	0.59813	2.89666	0.55157	1.24596	3.48532	5.36214	1.08836
2005	1.86490	0.58929	3.02465	0.57295	1.18308	3.40432	5.06414	1.07013
2006	1.95536	0.59279	3.14577	0.61621	1.39901	6.84995	6.94669	1.44023
2007	2.01138	0.59702	3.12347	0.66130	1.67581	12.87016	9.80227	1.84868
2008	2.05358	0.62079	2.96019	0.69556	1.77017	19.21436	12.17043	1.93962
2009	1.95908	0.60251	2.89146	0.74440	1.94500	26.68330	13.82649	1.98558
2010	1.97853	0.58870	2.85414	0.68830	2.05391	31.55521	14.31793	1.92090
2011	1.97155	0.58410	2.76590	0.67966	1.80270	32.89997	11.22786	1.19309
2012	1.87132	0.55455	2.70230	0.64754	1.44399	31.65990	6.98357	0.82767
2013	1.78390	0.51608	2.58672	0.60826	1.38728	33.40836	4.58656	1.10333
2014	1.69778	0.48120	2.48450	0.55989	1.15588	34.39740	0.78091	1.25955
2015	1.65187	0.45375	2.40320	0.56065	1.62631	39.84004	0.94192	2.89859
2016	1.65166	0.43991	2.43712	0.55500	2.34160	45.70172	2.43183	5.62989
2017	1.74601	0.44001	2.50756	0.62271	4.08709	57.20050	12.39550	11.09911
2018	1.76132	0.43359	2.48187	0.64057	4.51717	59.42886	11.15198	13.13515
2019	1.70904	0.41731	2.41583	0.61724	4.48046	59.93490	3.37588	13.84249
2020	1.65619	0.41081	2.38375	0.59966	4.79479	62.59600	-2.77480	15.49885

All of the smoothed user costs are positive except for 11 negative user costs for industrial land and 9 negative user costs for commercial land. Negative user costs for land components are likely to appear in many countries that experience rapid increases in land prices.

References

[1] Balk, B.M. (1998), *Industrial Price, Quantity and Productivity Indices*, Boston: Kluwer Academic Publishers.

[2] APO (2022), *APO Productivity Databook 2022*, Tokyo: Keio University Press.

[3] Baxter, W.T. (1975), *Accounting Values and Inflation*, London: McGraw-Hill.

[4] Böhm-Bawerk, E. V. (1891), *The Positive Theory of Capital*, W. Smart (translator of the original German book published in 1888), New York: G.E. Stechert.

[5] Brandt, N., P. Schreyer and V. Zipperer (2017), "Productivity Measurement with Natural Capital", *Review of Income and Wealth* 61, S7-S21.

[6] Carsberg, B. (1982), "The Case for Financial Capital Maintenance", pp. 59-74 in *Maintenance of Capital: Financial versus Physical*, R.R. Sterling and K.W. Lemke (eds.), Houston: Scholars Book Co.

[7] Christensen, L.R. and D.W. Jorgenson (1969), "The Measurement of U.S. Real Capital Input, 1929-1967", *Review of Income and Wealth* 15, 293-320.

[8] Diewert, W.E. (1974), "Intertemporal Consumer Theory and the Demand for Durables", *Econometrica* 42, 497-516.

[9] Diewert, W.E. (1977), "Walras' Theory of Capital Formation and the Existence of a Temporary Equilibrium', pp. 73-126 in *Equilibrium and Disequilibrium in Economic Theory*, G. Schwödiauer (ed.), Dordrecht: D. Reidel.

[10] Diewert, W.E. (1980), "Aggregation Problems in the Measurement of Capital", pp.433-528 in *The Measurement of Capital*, edited by D. Usher, Studies in Income and Wealth, Vol. 45, National Bureau of Economics Research, University of Chicago Press, Chicago.

[11] Diewert, W.E. (1983), "The Theory of the Output Price Index and the Measurement of Real Output Change", pp. 1049-1113 in *Price Level Measurement*, W.E. Diewert and C.

Montmarquette (eds.), Ottawa: Statistics Canada.
[12] Diewert, W.E. (1976), “Exact and Superlative Index Numbers”, Journal of Econometrics 4, 115-145.
[13] Diewert, W.E., J. de Haan and R. Hendriks (2015), “Hedonic Regressions and the Decomposition of a House Price Index into Land and Structure Components”, *Econometric Reviews* 34, 106-126.
[14] Diewert, W.E. and K.J. Fox (2016), “The User Cost of Nonrenewable Resources and Green Accounting” UBC Discussion Paper 16-01, Vancouver School of Economics, University of British Columbia, Vancouver, B.C., Canada.
[15] Diewert, W.E. and K.J. Fox (2018), “Decomposing Value Added Growth over Sectors into Explanatory Factors”, Chapter 19 in *The Oxford Handbook of Productivity Analysis*, Emile Grifell-Tatje, C.A. Knox Lovell and Robin C. Sickles (eds)., Oxford: Oxford University Press, pp. 625-661.
[16] Diewert, W.E. and K.J. Fox (2022), “Alternative Output, Input and Income Concepts for the Production Accounts”, Discussion Paper 2022-05, School of Economics, University of New South Wales. `https://econpapers.repec.org/paper/swewpaper/2022-05.htm`
[17] Diewert, W.E. and D. Lawrence (2006), *Measuring the Contributions of Productivity and Terms of Trade to Australia's Economic Welfare*, Consultancy Report to the Productivity Commission, Australian Government, Canberra, March.
[18] Diewert, W.E. and C.J. Morrison (1986), “Adjusting Output and Productivity Indexes for Changes in the Terms of Trade”, *The Economic Journal* 96, 659-679.
[19] Diewert, W.E. and A.M. Smith (1994), “Productivity Measurement for a Distribution Firm”, *The Journal of Productivity Analysis* 5, 335-347.
[20] Diewert, W.E. and C. Shimizu (2015), “Residential Property Price Indexes for Tokyo”, *Macroeconomic Dynamics* 19, 1659-1714.
[21] Diewert, W.E. and C. Shimizu (2017), “Hedonic Regression Models for Tokyo Condominium Sales”, *Regional Science and Urban Economics* 60, 300-315.
[22] Diewert, W.E. and C. Shimizu (2019), “Alternative Land Price Indexes for Commercial Properties in Tokyo”, *Review of Income and Wealth* 66:4, 784-824.
[23] Diewert, W.E. and C. Shimizu (2022), Residential Property Price Indexes: Spatial Coordinates versus Neighbourhood Dummy Variables”, *Review of Income and Wealth* 68:3, 770-796.
[24] Edwards, E.O. and P.W. Bell (1961), *The Theory and Measurement of Business Income*, Berkeley: University of California Press.
[25] Eurostat, International Monetary Fund, OECD, United Nations and World Bank (1993), *System of National Accounts* 1993, Luxembourg, New York, Paris, Washington DC.
[26] Eurostat (2013), *Eurostat Handbook on Residential Property Price Indices (RPPIs)*, Luxembourg: Publications Office of the European Union.
[27] Eurostat (2017), *Commercial Property Price Indicators: Sources, Methods and Issues, 2017 edition*, Luxembourg: Publications Office of the European Union.
[28] Eurostat, International Monetary Fund, OECD, United Nations and World Bank (1993), *System of National Accounts 1993*, Luxembourg, New York, Paris, Washington DC.
[29] Farrell, M.J. (1957), “The Measurement of Production Efficiency”, *Journal of the Royal Statistical Society, Series A*, 120, 253-278.
[30] Fox, K.J. and U. Kohli (1998), “GDP Growth, Terms of Trade Effects and Total Factor Productivity”, *Journal of International Trade and Economic Development* 7, 87-110.
[31] Freeman, D., R. Inklaar and W.E. Diewert (2021), “Natural Resources and Missing Inputs in International Productivity Comparisons”, *Review of Income and Wealth* 67:1, 1-17.
[32] George, H. (1935), *Progress and Poverty*, New York: Robert Schalkenbach Foundation.

(First published in 1879).
[33] Haig, R.M. (1921), "The Concept of Income", pp. 1-28 in *The Federal Income Tax.* R.M. Haig (ed.), New York: Columbia University Press.
[34] Hayek, F.A. v. (1941), "Maintaining Capital Intact: A Reply", *Economica* 8, 276-280.
[35] Hicks, J.R. (1939), *Value and Capital*, Oxford: The Clarendon Press.
[36] Hicks, J.R. (1942), "Maintaining Capital Intact: a Further Suggestion", *Economica* 9, 174-179.
[37] Hicks, J.R. (1946), *Value and Capital*, Second Edition, Oxford: Clarendon Press.
[38] Hicks, J.R. (1961), "The Measurement of Capital in Relation to the Measurement of Other Economic Aggregates", pp. 18-31 in *The Theory of Capital*, F.A. Lutz and D.C. Hague (eds.), London: Macmillan.
[39] Hicks, J. (1973), *Capital and Time: A Neo-Austrian Theory*, Oxford: Clarendon Press.
[40] Jorgenson, D.W. (1963), "Capital Theory and Investment Behaviour", *American Economic Review* 53:2, 247–259.
[41] Jorgenson, D.W. (1989), "Capital as a Factor of Production", pp. 1-35 in *Technology and Capital* Formation, D.W. Jorgenson and R. Landau (eds.), Cambridge MA: The MIT Press.
[42] Jorgenson, D.W. (1996), "Empirical Studies of Depreciation", *Economic Inquiry* 34, 24-42.
[43] Jorgenson, D.W. and Z. Griliches (1967), "The Explanation of Productivity Change", *The Review of Economic Studies* 34, 249-283.
[44] Jorgenson, D.W. and Z. Griliches (1972), "Issues in Growth Accounting: A Reply to Edward F. Denison", *Survey of Current Business* 52:4, Part II (May), 65-94.
[45] Jorgenson, D.W. and K. Nomura (2005), "The Industry Origins of Japanese Economic Growth", *Journal of the Japanese and International Economies* 19:4, 482-542.
[46] Kohli, U. (1978), "A Gross National Product Function and the Derived Demand for Imports and Supply of Exports", *Canadian Journal of Economics* 11, 167-182.
[47] Kohli, U. (1990), "Growth Accounting in the Open Economy: Parametric and Nonparametric Estimates", *Journal of Economic and Social Measurement* 16, 125-136.
[48] Kohli, U. (1991), *Technology, Duality and Foreign Trade: The GNP Function Approach to Modelling Imports and Exports*, Ann Arbor: University of Michigan Press.
[49] Kohli, U. (2003), "Growth Accounting in the Open Economy: International Comparisons", *International Review of Economics and Finance* 12, 417-435.
[50] Kohli, U. (2004a), "An Implicit Törnqvist Index of Real GDP", *Journal of Productivity Analysis* 21, 337-353.
[51] Kohli, U. (2004b), "Real GDP, Real Domestic Income and Terms of Trade Changes", *Journal of International Economics* 62, 83-106.
[52] Kumhof, M., N. Tideman, M. Hudson and C.A. Goodhart (2021), "Post-Corona Balanced-Budget Super-Stimulus: The Case for Shifting Taxes onto Land", Discussion Paper DP16652, Centre for Economic Policy Research, 33 Great Sutton Street, London EC1V 0DX, UK.
[53] Konüs, A.A. (1939), "The Problem of the True Index of the Cost of Living", *Econometrica* 7, 10-29.
[54] Marshall, A. (1920), *Principles of Economics*, 8th Edition, London: McMillan. (First Edition; 1890).
[55] Middleditch, L. (1918), "Should Accounts Reflect the Changing Value of the Dollar?", *The Journal of Accountancy* 25, 114-120.
[56] Peasnell, K.V. (1981), "On Capital Budgeting and Income Measurement", *Abacus* 17(1), 52–67.

[57] Pigou, A.C. (1941), “Maintaining Capital Intact”, *Economica* 8, 271-275.
[58] Rymes, T.K. (1968), “Professor Read and the Measurement of Total Factor Productivity”, *The Canadian Journal of Economics* 1, 359-367.
[59] Rymes, T.K. (1983), “More on the Measurement of Total Factor Productivity”, *The Review of Income and Wealth* 29 (September), 297-316.
[60] Salter, W. E. G. (1960), *Productivity and Technical Change*, Cambridge U.K.: Cambridge University Press.
[61] Samuelson, P.A. (1961), “The Evaluation of ‘Social Income: Capital Formation and Wealth”, pp. 32-57 in *The Theory of Capital*, F.A. Lutz and D.C. Hague (eds.), London: Macmillan.
[62] Sterling, R.R. (1975), “Relevant Financial Reporting in an Age of Price Changes”, *The Journal of Accountancy* 139 (February), 42-51.
[63] Sweeney, H.W. (1934), “Approximations of Appraisal Values by Index Numbers”, *Harvard Business Review* 13, 108-115.
[64] Sweeney, H.W. (1935), “The Technique of Stabilized Accounting”, *The Accounting Review* 10, 185-205.
[65] Tweedie, D. and G. Whittington (1984), *The Debate on Inflation Accounting*, London: Cambridge University Press.
[66] Whittington, G. (1980), “Pioneers of Income Measurement and Price-Level Accounting: A Review Article”, *Accounting and Business Research* Spring, 232-240.
[67] World Bank (2021), *The Changing Wealth of Nations*, Washington, DC: The World Bank.