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Alternative Measures for Chinese Productivity Growth

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1. Introduction

- A problem with most measures of national Total Factor Productivity (TFP) is that land inputs are omitted. For the most part, this is because national and international statistical offices have not been able collect and organize **data on the price and quantity of land inputs** into production.
  - Due to the efforts of the Asian Productivity Organization and the work of Koji Nomura at Keio University, data on **the price and quantity of land used in production for 25 or so Asian countries** has been constructed.
  - We use these data for the People's Republic of China for the years 1970-2020. This augmented data base has national annual price and quantity estimates for four types of land: **agricultural, industrial, commercial and residential.**
  - In all, there are data on **16 capital stock components**.
  - We will use this data base to construct estimates of China's TFP for these years.

2. User Cost Theory and Data Construction

- We use the **APO Augmented Database** to construct estimates of China's TFP for the years 1970-2020 using the methodology developed by Jorgenson and his coworkers.

- 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.

- 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:

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

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

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

This is the method used by Diewert (1973) 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_{Kn}^{t}) and benefits (the selling price of the used asset at the end of year $(1-\delta_n^{t})P_{Kn}^{t+1}$) 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 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_{Kn}^{t} by $(1+r^{t})$.**

- **(3) $U_n^{t} \equiv (1+r^{t})P_{Kn}^{t} - (1+i_n^{t})(1-\delta_n^{t})P_{Kn}^{t} = [r^{t} - i_n^{t} + \delta_n^{t}(1+i_n^{t})]P_{Kn}^{t}$.**

- 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 is ***not*** **P_{Kn}^{t} but $(1+r^{t})P_{Kn}^{t}$.**

- In many countries, land and structure assets are taxed. **These property taxes need to be added to the corresponding user costs**. Thus let τ_n^t 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:

- **(4)** $U_n^t \equiv (1+r^t + \tau_n^t)P_{Kn}^t - (1+i_n^t)(1-\delta_n^t)P_{Kn}^t = [r^t + \tau_n^t - i_n^t + \delta_n^t(1+i_n^t)]P_{Kn}^t.$

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

- **(5)** $Q_{Kn}^{t+1} = (1-\delta_n^t)Q_{Kn}^t + Q_{In}^t$

  where Q_{In}^t 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 APO's Augmented data base**.
- 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 is denoted by P_C^t, P_G^t, P_I^t, P_X^t and P_M^t and Q_C^t, Q_G^t, Q_I^t, Q_X^t and Q_M^t 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_C^t, V_G^t, V_I^t, V_X^t and V_M^t where $V_C^t = P_C^t Q_C^t$ and so on.

- The APO Augmented Database 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, …, 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 APO data base 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, …, 12.
- The APO database 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, …, 11 and t = 1970, …, 2020.

- The APO Augmented Data base follows standard System of National Accounts (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 Augmented APO Database), 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 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:

- **(6)** $Q_{In}^{t} \equiv Q_{Kn}^{t+1} - Q_{Kn}^{t}$ **;**
  n = 13, …, 16 ; t = 1970, …, 2020.

- In this paper, we will follow APO conventions and set the beginning of the year *t* asset prices equal to the corresponding year *t* investment price for assets 1-11.
- For assets 12-16, we do not have APO investment prices so we will simply set the year *t* investment price equal to the corresponding APO beginning of the year asset price.
- For asset 12, inventory stocks, the asset price does not exactly equal the corresponding inventory change price so we will take the inventory stock price and quantity data, $P_{K12}{}^{t}$ and $Q_{K12}{}^{t}$ as the "truth" and define $Q_{I12}{}^{t}$ as the year *t* difference in inventory stocks, $Q_{K12}{}^{t+1} - Q_{K12}{}^{t}$.
- The year *t* price of inventory change, $P_{I12}{}^{t}$, will be set equal to the corresponding beginning of the year inventory stock price, $P_{K12}{}^{t}$.
- **The depreciation rates for inventory stocks and the land assets are set equal to 0; i.e., we have:**

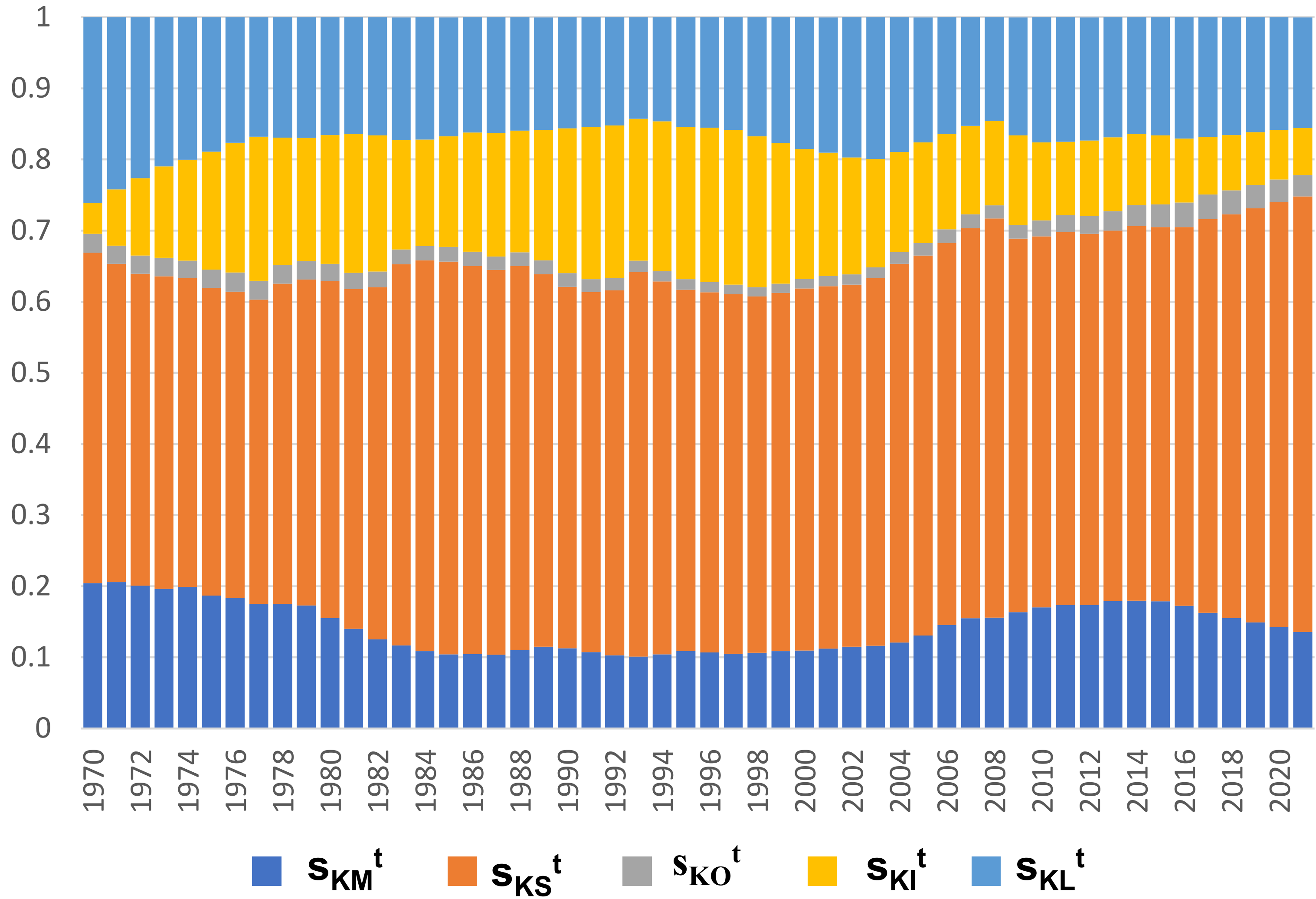
- **(7) $\delta_n{}^t \equiv 0$;**
  $n = 12, \ldots, 16$; $t = 1970, \ldots, 2020$.

- 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*** (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, …,2021. The aggregation is done using chained Törnqvist 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 following equalities:

- **(8)** $$V_K^t \equiv \Sigma_{n=1}^{16} V_{Kn}^t = V_{KM}^t + V_{KS}^t + V_{KO}^t + V_{KI}^t + V_{KL}^t\ ;$$
  $t = 1970, \ldots, 2020.$

The Shares in the Total Value of the Capital Stock



- We use Törnqvist 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 Tornqvist 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 Törnqvist 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 Gross Domestic Product 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:

- **(9)** $\mathbf{KY^t \equiv Q_K^t/Q_Y^t \; ; \; VKY^t \equiv V_K^t/V_Y^t \; ;}$

  $\mathbf{t = 1970, \ldots, 2020.}$

- 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 rats i_n^t and on specific property taxes on assets τ_n^t for n =1, …, 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:

- **(10)** $V_Y^t = V_L^t + \Sigma_{n=1}^{16} [r^t + \tau_n^t - i_n^t + \delta_n^t(1+i_n^t)]P_{Kn}^t Q_{Kn}^t$ **;**

  $t = 1970, \ldots, 2020.$

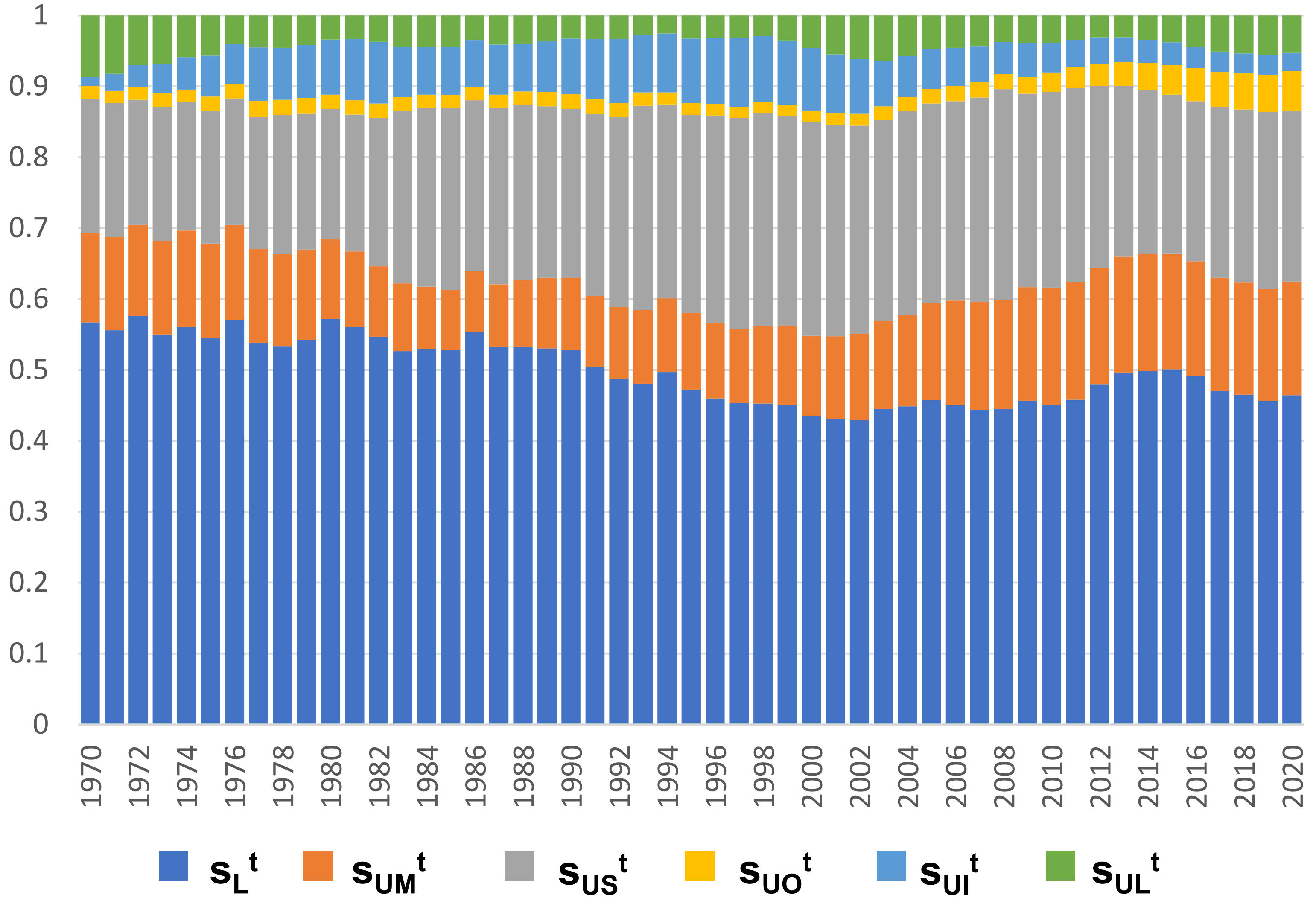
- We assumed that **property taxes fell on industrial land, commercial land and residential land in a proportional manner**. The sample average property tax rate on the three land assets was 1.138%. Since the average rate of return on assets was so high in China, the use of these poorly estimated property tax rates will not materially affect user costs and waiting costs.

3. Total Factor Productivity Estimates for China using Gross Output as the Measure of Output

- Following Jorgenson and Griliches (1967), year *t Gross Output Total Factor Productivity* for the Chinese economy, TFP^t, is defined as the output quantity index $Q_Y{}^t$ divided by the input quantity index $Q_Z{}^t$:
- **(11)** $TFP^t \equiv Q_Y{}^t/Q_Z{}^t$;
  $t = 1970, \ldots, 2020$.

- Year *t Total Factor Productivity Growth* (relative to year t−1), $TFP_G{}^t$, is defined as follows:
- **(12)** $TFP_G{}^t \equiv TFP^t/TFP^{t-1}$;
  $t = 1971, \ldots, 2020$.
- Define the input shares in year *t* GDP for labour and the 5 types of capital services for t = 1970, …, 2020 as follows:
- **(13)** $s_L{}^t \equiv V_L{}^t/V_Y{}^t$; $s_{UM}{}^t \equiv V_{UM}{}^t/V_Y{}^t$; $s_{US}{}^t \equiv V_{US}{}^t/V_Y{}^t$; $s_{UO}{}^t \equiv V_{UO}{}^t/V_Y{}^t$; $s_{UI}{}^t \equiv V_{UI}{}^t/V_Y{}^t$; $s_{UL}{}^t \equiv V_{UL}{}^t/V_Y{}^t$.

The Input Shares of Gross Output



- **The arithmetic average of the TFP growth rates over the years 1971-2020 was 1.13% per year which is quite good by international standards. The average share of labour and the 5 types of capital services was 0.498, 0.127 (Machinery and Equipment), 0.246 (Structures), 0.024 (Other Capital Services), 0.061 (Inventories) and 0.044 (Land).**

- There are some big changes in these shares over time. The relatively low average share of labour 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.

- The share of labour in GDP has dropped from 0.567 in 1970 to 0.464 in 2020. There are other large shifts in GDP shares over the 5 decades. The average share of land is only 0.044 but it has grown during the past 5 years.

- **The average TFP grow rates by decade are as follows: 0.9874 or –1.26% per year during the 1970s; 1.0132 or 1.32% per year during the 1980s; 1.0259 or 2.59% per year during the 1990s; 1.0268 or 2.68% during the 2000s and 1.0086 or 0.86% per year during the 2010s.**

- Thus from 1980 on, the TFP performance of the Chinese economy has been very good by international standards.

- **What is very interesting is that the Chinese rate of productivity growth has not declined to very low levels during he past two decades as has been the case for many OECD countries.**

- We excluded the year 2020 from this average due to extraordinary Covid problems.

4. The Decomposition of Chinese Real Gross Income Growth into Explanatory Factors.

- 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 product generated by the Chinese production sector. Since 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 notation for prices and quantities. **Define the vectors of *real output prices* p^t and *real input prices* w^t for year *t* as follows for t = 1970, …, 2020:**

- **(14)** $p^t \equiv [p_1^t, \ldots, p_5^t] \equiv (1/P_C^t)[P_C^t, P_G^t, P_I^t, P_X^t, P_M^t]$;

  $w^t \equiv [w_1^t, .., w_6^t] \equiv (1/P_C^t)[P_L^t, P_{UM}^t, P_{US}^t, P_{UO}^t, P_{UI}^t, P_{UL}^t]$.

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

- Define the vector of year *t* outputs y^t and the year *t* vector of inputs z^t as follows for all years *t*:
-
- **(15)** $\mathbf{y^t \equiv [y_1{}^t,..,y_5{}^t] \equiv [Q_C{}^t,Q_G{}^t,Q_I{}^t,Q_X{}^t,-Q_M{}^t]}$; $\mathbf{z^t \equiv [z_1{}^t,..,z_6{}^t] \equiv [Q_L{}^t,Q_{UM}{}^t,Q_{US}{}^t,Q_{UO}{}^t,Q_{UI}{}^t,Q_{UL}{}^t]}$.
- Using the above definitions, we see that *year t real income* is equal to $RI^t \equiv V_Y{}^t/P_C{}^t = p^t \cdot y^t = V_Z{}^t/P_C{}^t = w^t \cdot z^t$ for all years t. Define (one plus) *real income growth* going from year t−1 to year t, $RI_G{}^t$, as follows:
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- **(16)** $\mathbf{RI_G{}^t \equiv p^t \cdot y^t/p^{t-1} \cdot y^{t-1}}$;

  t = 1971, …, 2020.

- ***Real gross income*** in China grew 39.5 fold over the 50 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 22.4 fold over the sample period.
- ***Real wages*** grew much slower; an 8.8 fold increase over the sample period. The real user cost growth factors were 0.14 for Machinery and Equipment, 0.44 for Structures, 0.29 for Other Capital Services, 0.37 for Inventory and 4.7 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 9.78 fold over the sample period and this is approximately equal to real wage growth.
- We note that government output prices are typically set equal to a government input price index, where government primary input consists mostly of labour. The real price levels for gross investment, exports and imports in 2020 (relative to the corresponding 1970 levels) were 0.63, 0.59 and 0.53 respectively.

- A problem with the current SNA is that only labour input and depreciation of government structures is counted as an input cost for the government sector.

- Typically, government sector output is measured by input cost. **But there is no imputation in the SNA for the cost of capital that is associated with the use of government land and structures.**

- Thus **the existing SNA methodology greatly undervalues government sector output** for most if not all countries.

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

- **(17)** $\ln P_T(p^{t-1},p^t,y^{t-1},y^t) \equiv \Sigma_{n=1}^{5} (1/2)[(p_n^t y_n^t/p^t \cdot y^t) + (p_n^{t-1} y_n^{t-1}/p^{t-1} \cdot y^{t-1})]\ln(p_n^t/p_n^{t-1})$;
  t = 1971, …, 2020;

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

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

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

- Comparing (17) and (19), it can be seen that the product over n of the year *t* output price growth factors $\alpha_n{}^t$ is equal to the year *t* Törnqvist output price index; i.e.:

- **(20)** $P_T(p^{t-1},p^t,y^{t-1},y^t) = \Pi_{n=1}{}^5\ \alpha_n{}^t$;
  t = 1971, …, 2020.

- Define the year *t input n growth factor*, $\beta_n{}^t$, as follows:

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

- Comparing (18) and (21), it can be seen that the product over n of the year t input growth factors $\beta_n{}^t$ is equal to the year t Törnqvist input quantity index; i.e.:

- **(22)** $Q_T(w^{t-1},w^t,z^{t-1},z^t) = \Pi_{n=1}{}^6 \beta_n{}^t$;
  t = 1971, …, 2020.

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

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

- Using the fact that $\mathbf{P_T(p^{t-1},p^t,y^{t-1},y^t)}$ is homogeneous of degree 1 in the components of p^t and homogeneous of degree -1 in p^{t-1} as well as the fact that $\mathbf{Q_T(w^{t-1},w^t,z^{t-1},z^t)}$ is homogeneous of degree 0 in the components of w^t and homogeneous of degree 0 in the components of 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*.
- Rearrange equations (23) to give us the following expression for year t *real income growth* over the prior year, $\mathbf{RI_G{}^t = p^t \cdot y^t / p^{t-1} \cdot y^{t-1}}$:
- **(24)** $\mathbf{RI_G{}^t = \tau^t P_T(p^{t-1},p^t,y^{t-1},y^t) Q_T(w^{t-1},w^t,z^{t-1},z^t)}$ **;**

  t = 1971, …, 2020

  $= TFP_G{}^t (\Pi_{n=1}{}^5\, \alpha_n{}^t)(\Pi_{n=1}{}^6\, \beta_n{}^t)$

  using (20) and (22).
- 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, $\alpha_2{}^t$-$\alpha_5{}^t$, and year t input growth factors, $\beta_1{}^t$-$\beta_6{}^t$.

- On average, **real gross income growth generated by the Chinese economy was 7.72% 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: **1.13% (TFP change); 0.39% (government real price change); –0.35% (real investment price change); –0.18% (export price change); 0.27% (import price change); 1.34% (quality adjusted labour growth); 1.51% (manufacturing and equipment capital services growth); 2.37% (structures services growth); 0.31% (other capital services growth); 0.60% (inventory growth services) and 0.14% (land services growth)**.
- Real export prices fell over the sample period which lessened overall real gross income growth but real import prices fell even more which increased overall growth. Thus, terms of trade effects were positive for China over the sample period. Note that since population growth is turning into population decline for China, it is unlikely that quality adjusted labour 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 Total Factor Productivity* 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. We use the 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:
- **(25)** $TFP^0 \equiv 1$; $TFP^t \equiv TFP^{t-1}\, TFP_G^t$;

  $t = 1971, \ldots, 2020$;
- **(26)** $A_n^0 \equiv 1$; $A_n^t \equiv A_n^{t-1}\alpha_n^t$;

  $n = 2, 3, 4, 5$; $t = 1971, \ldots, 2020$;
- **(27)** $B_n^0 \equiv 1$; $B_n^t \equiv B_n^{t-1}\beta_n^t$;

  $n = 1, 2, 3, 4, 5, 6$; $t = 1971, \ldots, 2020$.
- This type of levels presentation of the data is quite instructive when presented in graphical form. It was suggested by Kohli (1990) and used extensively by him; see Kohli (1991), (2003) (2004a) (2004b) and Fox and Kohli (1998).

- 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:

- **(28) $RI^t/RI^{1970} = TFP^t A_2{}^t A_3{}^t A_4{}^t A_5{}^t B_1{}^t B_2{}^t B_3{}^t B_4{}^t B_5{}^t B_6{}^t$;**
  t = 1970, …, 2020.

- ***Real gross income*** grew 39.518 fold over the sample period. The growth factors for 2020 that contributed to this overall growth of real income are as follows: 1.710 (TFP growth); 1.213 (Government real price growth); 0.833 (Gross Investment real price growth); 0.906 (Export real price growth); 1.132 (Import real price growth) ; 1.940 (Quality Adjusted Labour Input growth); 2.113 (Machinery and Equipment services growth); 3.223 (Structure Services growth); 1.165 (Other Capital Services growth); 1.350 (Inventory Services growth); **1.072 (Land Services growth).**

- Multiplication of all of these 2020 sample growth factors equals real gross income sample period growth of 39.518.

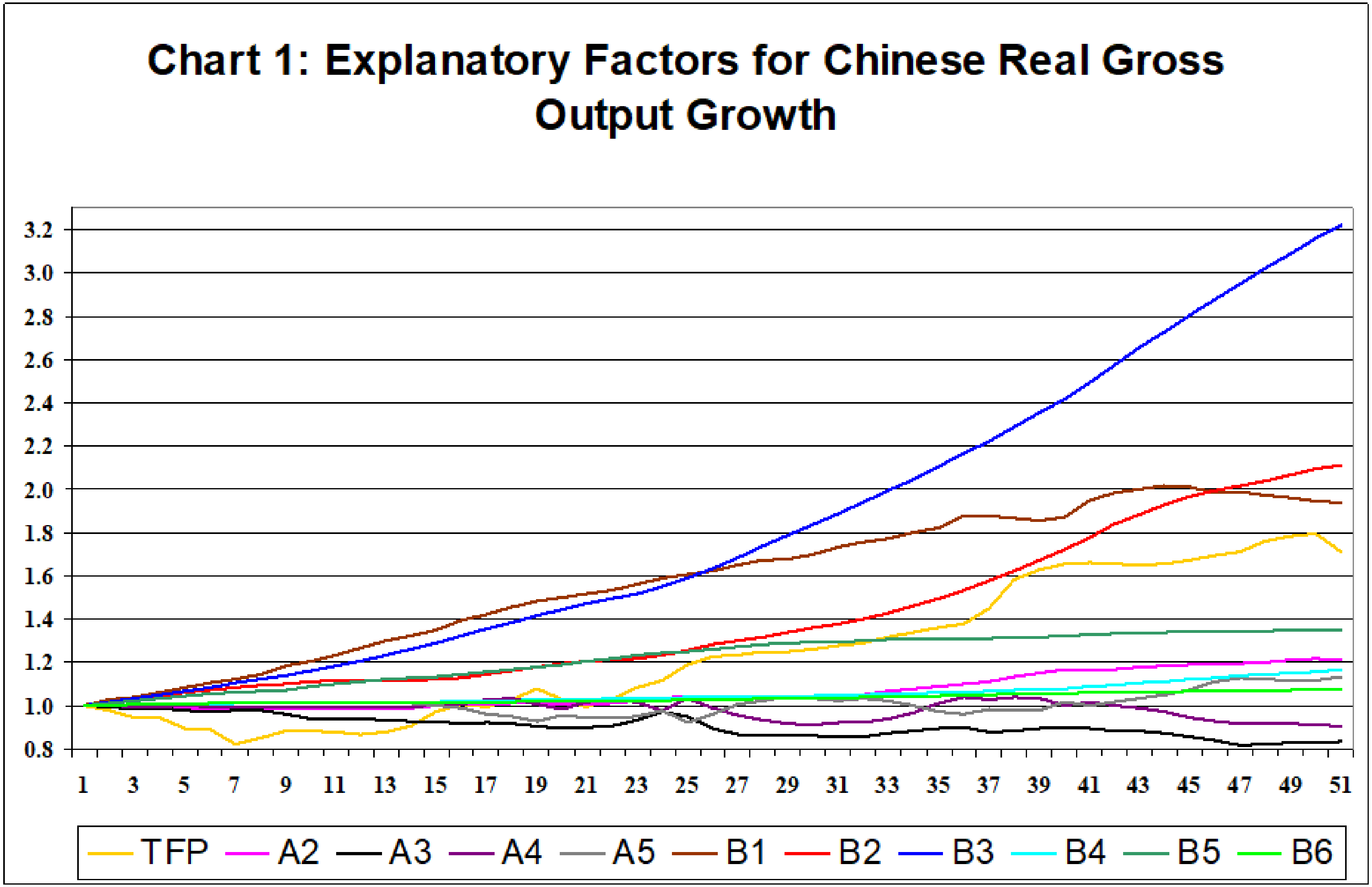
Chart 1: Explanatory Factors for Chinese Real Gross Output Growth
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51
TFP A2 A3 A4 A5 B1 B2 B3 B4 B5 B6

5. A Nonparametric Decomposition of Gross Output Growth for China

- The analysis in this section is based on Diewert and Fox (2018). 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, y^t, and the corresponding primary input vector x^t.
- Instead of letting t = 1970, …, 2020, we let t = 1, …, 51 to reduce the size of the notation. However, in this section, we will work with nominal gross output and income and nominal prices. The year t real price vectors, p^t and $w^{t,}$ in the previous section are now nominal price vectors.

- The basic assumption that Diewert and Fox make is that the year *t* technology set can be approximated by assuming it consists of past observed output and input vectors, (y^s,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 $S^1 \equiv \{(y,x) : y = \lambda y^1, x = \lambda x^1; \lambda \geq 0\}$, $S^2 \equiv \{(y,x) : y = \lambda_1 y^1, x = \lambda_1 x^1; \lambda_1 \geq 0,\ y = \lambda_2 y^2, x = \lambda_2 x^2; \lambda_2 \geq 0\}$, …, $S^t \equiv \{(y,x) : y = \lambda_s y^s, x = \lambda_s x^s; \lambda_s \geq 0,\ s = 1, 2, ..., t\}$.

- These definitions for the S^t mean that we are assuming a constant returns to scale technology for each period.

- The year t *cost constrained value added function* for the Chinese economy, $R^t(p,w,x)$, is defined as follows:

- **(29)** $\mathbf{R^t(p,w,x) \equiv \max_{y,z}\{p\cdot y : (y,z)\in S^t ;\ w\cdot z \le w\cdot x\};}$

$$t = 1, \ldots, 51$$
$$= \max_s \{p\cdot y^s\, w\cdot x/w\cdot x^s : s = 1,2,\ldots,t\}$$
$$= w\cdot x\ \max_s \{p\cdot y^s/w\cdot x^s : s = 1,2,\ldots,t\}.$$

  - Given nominal output prices p, nominal input prices w and the constraint that primary input costs should not exceed observed cost $w\cdot x$, we assume that producers should choose the output vector y and input vector z to maximize national value added, $p\cdot y$, subject to total primary input cost $p\cdot z$ to be equal to or less than observed input cost $w\cdot x$. Due to our assumptions on the year t national production possibilities set S^t, the year t cost constrained value added function $R^t(p,w,x)$ can be calculated for a hypothetical p, w and x by solving the very simple maximization problem, $\max_s \{p\cdot y^s/w\cdot x^s : s = 1,2,\ldots,t\}$, which involves taking the maximum of t numbers. In the definitions which follow, we will list t as going from 1970 to 2020 instead of going from 1 to 51.

- Following the example of Balk (1998; 143), we define the *value added efficiency* of the sector for year t, e^t, as follows:
- **(30)** $e^t \equiv p^t \cdot y^t / R^t(p^t, w^t, x^t) \leq 1$;

  t = 1970, …, 2020.
- where the inequality in (30) follows using definition (29). 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) cost based measure of *overall efficiency*.

- Define an index of the *change in value added efficiency* ε^t for the sector over the years t−1 and t as follows:
- **(31)** $\varepsilon^t \equiv e^t/e^{t-1} = [p^t \cdot y^t / R^t(p^t, w^t, x^t)] / [p^{t-1} \cdot y^{t-1} / R^{t-1}(p^{t-1}, w^{t-1}, x^{t-1})]$;

  t = 1970, …, 2020.
- Thus if $\varepsilon^t > 1$, then 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 *output price change* going from year t−1 to t. Following the example of Konüs (1939) in his analysis of the true cost of living index, it is natural to single out two special cases of a family of output price indexes: one choice is $\alpha_L{}^t$ where we use the year t−1 technology and set the reference input prices and quantities equal to the year t−1 input prices and quantities w^{t-1} and x^{t-1} (which gives rise to a *Laspeyres type output price index*) and another choice is $\alpha_P{}^t$ where we use the year t technology and set the reference input prices and quantities equal to the year t prices and quantities w^t and x^t (which gives rise to a *Paasche type output price index*). We then define an overall measure of price change α^t by taking the geometric mean of these two indexes. These indexes are defined as follows:
- **(32)** $\alpha_L{}^t \equiv R^{t-1}(p^t,w^{t-1},x^{t-1})/R^{t-1}(p^{t-1},w^{t-1},x^{t-1})$;
  t = 1971, …, 2020;
- **(33)** $\alpha_P{}^t \equiv R^t(p^t,w^t,x^t)/R^t(p^{t-1},w^t,x^t)$;
  t = 1971, …, 2020;
- **(34)** $\alpha^t \equiv [\alpha_L{}^t \alpha_P{}^t]^{1/2}$;
  t = 1971, …, 2020.

- Two natural measures of *input price change* are the Laspeyres and Paasche input price indexes. Denote these year t indexes as cases $\beta_L{}^t$ and $\beta_P{}^t$. Again it is natural to take the geometric average of these two indexes which gives rise to the Fisher ideal input price index, β^t. These indexes are defined as follows:

- **(35)** $\beta_L{}^t \equiv w^{t-1}\cdot x^t/w^{t-1}\cdot x^{t-1}$ **;**
  $t = 1971, \ldots, 2020;$
- **(36)** $\beta_P{}^t \equiv w^t\cdot x^t/w^t\cdot x^{t-1}$ **;**
  $t = 1971, \ldots, 2020;$
- **(37)** $\beta^t \equiv [\beta_L{}^t \beta_P{}^t]^{1/2}$ **;**
  $t = 1971, \ldots, 2020.$

- We now consider indexes which measures the effects on cost constrained value added of a change in input prices going from period t−1 to t. Thus we consider measures of the change in cost constrained value added of the form $R^s(p,w^t,x)/R^s(p,w^{t-1},x)$.
- Since $R^s(p,w,x)$ is homogeneous of degree 0 in the components of w, it can be seen that we cannot interpret $R^s(p,w^t,x)/R^s(p,w^{t-1},x)$ as an input price index. If there is only one primary input, $R^s(p,w^t,x)/R^s(p,w^{t-1},x)$ is equal to $R^s(p,1,x)/R^s(p,1,x) = 1$ 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 $R^s(p,w^t,x)/R^s(p,w^{t-1},x)$ 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 a Case 2**.

- The first case index $\gamma_1{}^t$ will use the period t cost constrained value added function and the period t−1 reference vectors p^{t-1} and x^{t-1} while the second case index $\gamma_2{}^t$ will use the use the period t−1 cost constrained value added function and the period t reference vectors p^t and 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.

- **(38)** $\gamma_1{}^t \equiv R^t(p^{t-1},w^t,x^t)/R^t(p^{t-1},w^{t-1},x^t)$;

  t = 1971, …, 2020;
- **(39)** $\gamma_2{}^t \equiv R^{t-1}(p^t,w^t,x^{t-1})/R^{t-1}(p^t,w^{t-1},x^{t-1})$;

  t = 1971, …, 2020;
- **(40)** $\gamma^t \equiv [\gamma_1{}^t\gamma_2{}^t]^{1/2}$;

  t = 1971, …, 2020.

- 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 p, w and x constant and only change the technology from the period t−1 technology to the period t technology.

- Thus, these measures are of the form $R^t(p,w,x)/R^{t-1}(p,w,x)$. 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 $R^t(p,w,x)$ will be equal to or greater than $R^{t-1}(p,w,x)$ 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 $\tau_L{}^t$ and a Paasche measure $\tau_P{}^t$. However, the Laspeyres case $\tau_L{}^t$ will use the period t input vector x^t as the reference input vector and the period t−1 reference output price and input price vectors p^{t-1} and w^{t-1} while the Paasche case $\tau_P{}^t$ will use the use the period t−1 input vector x^{t-1} as the reference input and the period t reference output and input price vectors p^t and w^t. 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.**
- **(41)** $\tau_L{}^t \equiv R^t(p^{t-1},w^{t-1},x^t)/R^{t-1}(p^{t-1},w^{t-1},x^t)$; $t = 1971, \ldots, 2020$;
- **(42)** $\tau_P{}^t \equiv R^t(p^t,w^t,x^{t-1})/R^{t-1}(p^t,w^t,x^{t-1})$; $t = 1971, \ldots, 2020$;
- **(43)** $\tau^t \equiv [\tau_L{}^t \tau_P{}^t]^{1/2}$; $t = 1971, \ldots, 2020.$;
- In our case where the reference technology is subject to constant returns to scale, $\tau_L{}^t$ turns out to be independent of x^t and $\tau_P{}^t$ turns out to be independent of x^{t-1}.

- We define $I_G{}^t$ to be year t *nominal gross income growth* instead of real income growth since our explanatory price factors are nominal prices in this section instead of real prices. Thus define $I_G{}^t$ as follows:

- **(44)** $\mathbf{I_G{}^t \equiv p^t \cdot y^t / p^{t-1} \cdot y^{t-1}}$ **;**
  t = 1971, …, 2020.

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

- **(45)** $\mathbf{I_G{}^t = \varepsilon^t \alpha^t \beta^t \gamma^t \tau^t}$ **;**
  t = 1971, …, 2020.

- A new measure of *Total Factor Productivity growth* for the economy going from period t−1 to t can be defined (following Jorgenson and Griliches (1967)) as an index of output growth divided by an index of input growth. An appropriate index of output growth is the value added ratio divided by the value added price index α^t. An appropriate index of input growth is β^t. Thus define the new *year t TFP growth rate*, TFP_G^{t*}, for the Chinese economy as follows:

- **(46)** $\mathbf{TFP_G^{t*} \equiv \{[p^t \cdot y^t / p^{t-1} \cdot y^{t-1}]/\alpha^t\}/\beta^t = \varepsilon^t \gamma^t \tau^t}$ **;**
  t = 1971, …, 2020.

- where the last equality in (46) follows from (45). Thus in general, the nonparametric period t TFP growth, TFP_G^{t*}, is equal to the product of period t value added 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. TFP_G^{t*} and our old index number measure of TFP growth, TFP_G^t,

- Our nonparametric estimate of average **TFP growth rates is 1.14% per year** whereas our index number estimate of average **TFP growth rates was 1.13%.**.
- On average, **nominal GDP grew at 12.88% per year**. Output price inflation averaged 4.85% per year so real GDP grew at a very rapid rate over the sample period. 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 1971-1983, 1986, 1989-1991 and 2011.
- The inefficiency in the early years of our sample reflect the problems that **China faced in going from a command economy to a market economy in the 1970s and early 1980s**. The inefficiencies in later years correspond to recessions.
- **Aggregate input growth averaged 6.42% per year** which is remarkable. The input mix growth factor, γ^t, was on average equal to 0.9990 which indicates a very small negative contribution to GDP growth over the sample period.
- **The average rate of technical progress τ^t was 1.30% per year** which is quite good. **As the population of China starts to decline more noticeably, we can expect input growth to slow down in the future.**

- We again follow the example of Kohli (1990) and obtain a levels decomposition for the observed level of nominal Gross Domestic Product in year t, $p^t \cdot y^t$, relative to its observed value in year 1 of our sample, $p^1 \cdot y^1$. Define the cumulated explanatory variables as follows:

- **(47)** $E^1 \equiv 1;\ A^1 \equiv 1;\ B^1 \equiv 1;\ C^1 \equiv 1;\ T^1 \equiv 1.$

- For t = 2,3,...,51, define the above variables recursively as follows:

- **(48)** $E^t \equiv \varepsilon^t E^{t-1};\ A^t \equiv \alpha^t A^{t-1};\ B^t \equiv \beta^t B^{t-1};\ C^t \equiv \gamma^t C^{t-1};\ T^t \equiv \tau^t T^{t-1};$
  $t = 1971, \ldots, 2020.$
- Using the above definitions, it can be seen that we have the following *levels decomposition* for the level of period t observed nominal GDP or nominal gross income I^t to its level in 1970:
-
- **(49)** $I^t/I^{1970} \equiv p^t \cdot y^t / p^{1970} \cdot y^{1970} = A^t B^t C^t E^t T^t;$
  $t = 1970, \ldots, 2020.$

- Define the period t level of Total Factor Productivity, TFP^t, as follows:

- **(50) $TFP^{1*} \equiv 1$; for t = 2,...,T, define $TFP^{t*} \equiv (TFP_G{}^{t*})(TFP^{t-1*})$;**
  t = 1971, …, 2020

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

-

- **(51) $TFP^{t*} = [p^t \cdot y^t / p^1 \cdot y^1]/[A^t\, B^t] = C^t\, E^t\, T^t$;**
  t = 1970, …, 2020.

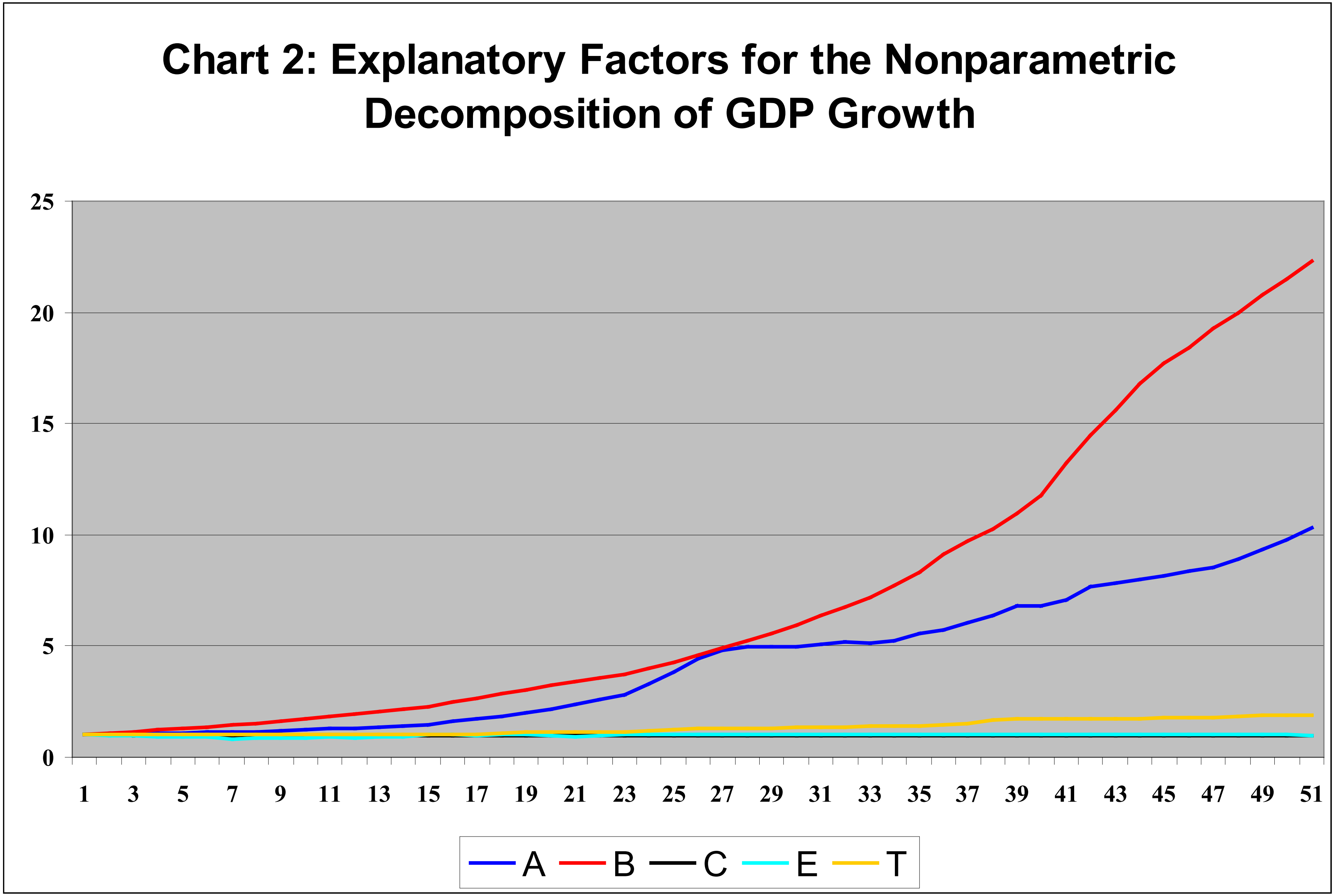
Chart 2: Explanatory Factors for the Nonparametric Decomposition of GDP Growth
25
20
15
10
5
0
1
3
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7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
A
B
C
E
T

- It can be seen that input growth (the top red line) explains most of nominal GDP growth over the sample period followed by output price growth (the blue line) followed by technical progress (the gold line). The remaining two growth factors, input mix changes induced by changes in input prices and inefficiency are so close to 1 that they are difficult to distinguish in the above Chart.
- The nonparametric decomposition can measure inefficiency but can only provide the aggregate contributions of output price change and input quantity change. Both decompositions give the same measures of TFP growth to a high degree of approximation.
- 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 into Explanatory Factors

- In this section, we attempt to define a more realistic income concept that does not count depreciation as income but does allow 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).
- 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).

- 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 sector.
- 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 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**}:

- **(52)** $$\mathbf{P_C{}^tQ_C{}^t + P_G{}^tQ_G{}^t + P_X{}^tQ_X{}^t - P_M{}^tQ_M{}^t + \Sigma_{n=1}^{16} P_{Kn}{}^{t+1}Q_{Kn}{}^{t+1} - \Sigma_{n=1}^{16} P_{Kn}{}^t Q_{Kn}{}^t = P_L{}^tQ_L{}^t + \Sigma_{n\text{-}=1}^{16} P_{Kn}{}^t (r^{t**}+\tau_n{}^t)Q_{Kn}{}^t \,;}$$
  t = 1970, …, 2020.

- We use ex ante or expected prices to value the end of year capital stocks. Recall that i_n^t is the year t smoothed asset *n* inflation rate for n = 1, …, 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*:

- **(53)** $P_{Kn}^{t+1} \equiv (1+i_n^t)P_{Kn}^t$;
  n = 1, …, 16 ; t = 1970, …, 2020.

- 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, …, 2020. These new rates of return are listed on Table 11 below.
- These new rates of return on assets will differ somewhat from our smoothed balancing rates of return r^{t*} because we are valuing gross investment at end of year prices instead of beginning of the year prices.
- In this new model of production, year t user costs U_n^t are replaced by year t *waiting costs*, P_{Wn}^t, defined as follows:

- **(54)** $\mathbf{P_{Wn}^t \equiv (r^{t**} + \tau_n^t)P_{Kn}^t}$ **;**

  $\mathbf{n = 1, \ldots, 16\ ;\ t = 1970, \ldots, 2020.}$
-
- 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.
- Rymes (1968) (1983) appears to have introduced this terminology. He was a strong advocate for replacing user costs by waiting costs.

- In this new model of production, year t user costs U_n^t are replaced by year t *waiting costs*, P_{Wn}^t, defined as follows:
- **(54) $P_{Wn}^t \equiv (r^{t**} + \tau_n^t)P_{Kn}^t$;**

  $n = 1, \ldots, 16$; $t = 1970, \ldots, 2020$.
- 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, …, P_{W16}^t, along with the data on the beginning of the year asset stocks, Q_{K1}^t, …, Q_{K16}^t, to form *five waiting services aggregates* for our five types of aggregate capital. Denote the prices and quantities for these aggregate capital 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 capital services aggregates are listed in Table 12 below along with the corresponding values. 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.

- The average of the **new balancing rates of return r^{t**} is 18.49%,** which is somewhat higher than our previous average rate of return for the gross output model which was **17.95%**.

- There is **an 88.1 fold increase in quality adjusted wage rates over the sample period and an 87.0 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 values.

- 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:

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

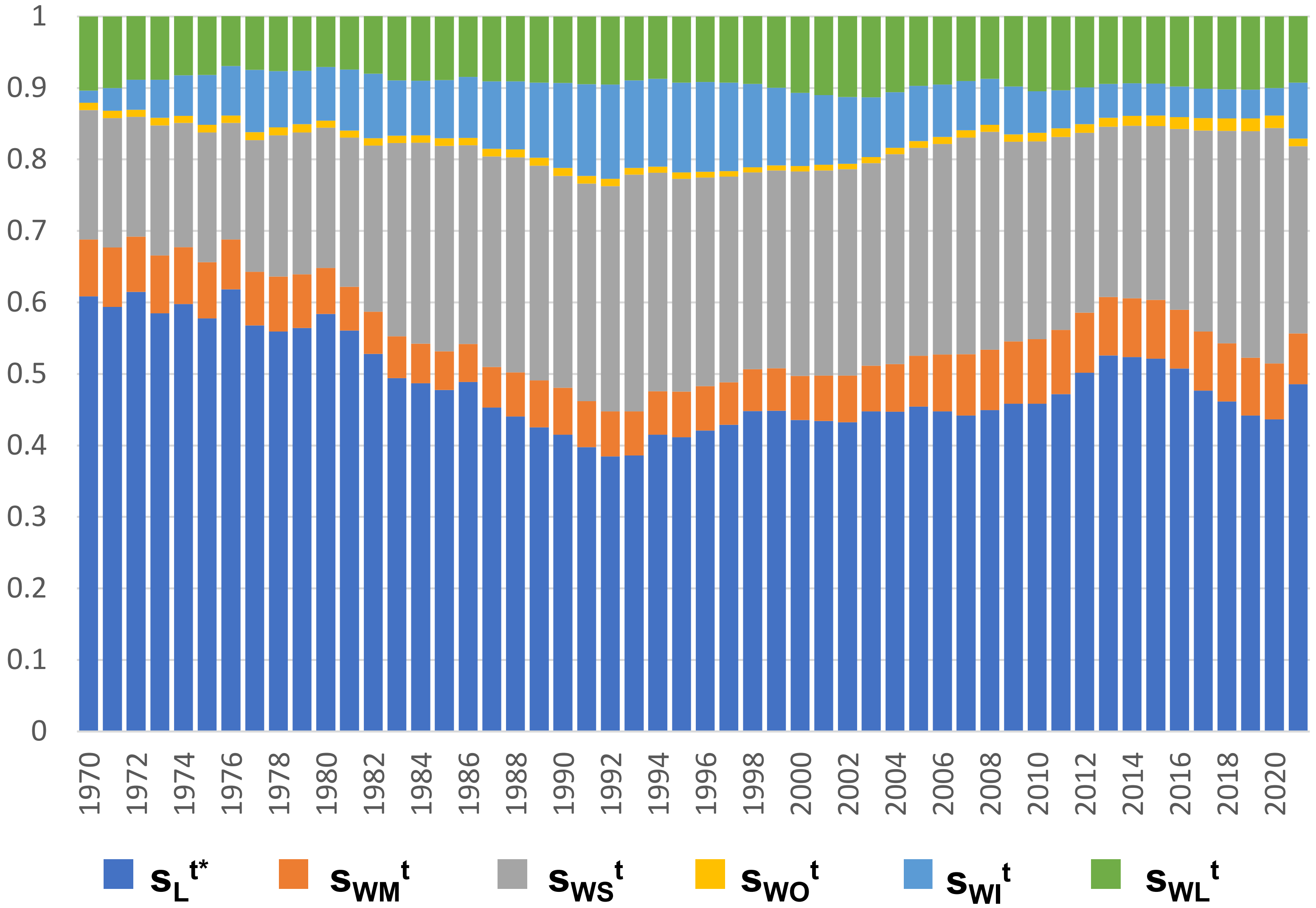
- The year t price index for this net investment aggregate is P_I^{t*} which is calculated as the direct Törnqvist price index of the 32 components of this aggregate. The Q_{Kn}^{t+1} enter the index number formula with plus signs and the Q_{Kn}^t enter the index formula with minus signs. The new year 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:

- **(56)** $V_Y^{t*} \equiv P_C^tQ_C^t + P_G^tQ_G^t + P_I^{t*}Q_I^{t*} + P_X^tQ_X^t - P_M^tQ_M^t$;
  t = 1970, …, 2020.

- It can be seen that switching from a gross output measure to a net output measure makes a big difference. **Net investment value is 52.3 trillion yuan in 2020 while gross investment value is only 46.1 trillion yuan.** Our net investment aggregate adds 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.
- The price of net investment ends up much higher at 14.25 whereas the price of gross investment ends up at 5.73. Conversely, the quantity or volume of net investment ends up much lower at 2.96 while the quantity or volume of gross investment ends up much higher at 7.24.
- What is important for measuring the real income generated by the production sector is the fact that net nominal income V_Y^{2020*} ends up at 103.85 and gross nominal income V_Y^{2020} ends up at 97.59 trillion yuan.
- Both of these measures can be converted into measures of real income generated by the production sector by dividing them by the price of consumption in 2020. Thus ,the net measure of real income ends up 6.4% higher than the corresponding gross measure. **This is not a huge difference but it is not negligible either.**

- The shares of labour and the five types of waiting services in net income in year t are defined as follows:
- **(57)** $s_L^{t*} \equiv V_L^t/V_Z^{t*}$; $s_{WM}^t \equiv V_{WM}^t/V_Z^{t*}$; $s_{WS}^t \equiv V_{WS}^t/V_Z^{t*}$; $s_{WO}^t \equiv V_{WO}^t/V_Z^{t*}$; $s_{WI}^t \equiv V_{WI}^t/V_Z^{t*}$;
  $s_{WL}^t \equiv V_{WL}^t/V_Z^{t*}$;
  t = 1970, …, 2020.
- Having defined new measures of year t net output and input, Q_Y^{t*} and Q_Z^{t*}, a new measure of (Net Output) *Total Factor Productivity* for year t, TFP^{t*}, can be defined by dividing Q_Y^{t*} by Q_Z^{t*}:
- **(58)** $TFP^{t*} \equiv Q_Y^{t*}/Q_Z^{t*}$;
  t = 1970, …, 2020.
- A new measure of *Net Output TFP growth* is defined as follows:
- **(59)** $TFP_G^t \equiv TFP^{t*}/TFP^{t-1*}$
  t = 1971, …, 2020.

The Input Shares



- **Net Output TFP^{t*} finished at 1.6322** which is somewhat lower than **the final value for Gross Output TFP^{t} which was 1.7102**. On average, Net Output TFP was 1.04% per year whereas the average growth rate for Gross Output TFP was 1.13% per year.
- The labour share of net income, $s_L{}^{t*}$, was quite variable. It started at **60.84% in 1970, decreased to 38.54% in 1993, increased to 52.56 in 2013 and then declined to 43.64% in 2020**. Thus over the entire sample period, the income share of capital increased enormously which is perhaps not surprising given the very large rates of gross investment for the Chinese economy. **The income share of Manufactures was roughly constant around 7% and the Land share was also roughly constant around 9%.**
- However, the income share of structures increased from 18.10% in 1970 to 32.90%, which is a very large increase. The share of inventories started at 1.70%, increased to 13.19% in 1992 and then decreased steadily to end up at 7.80% in 2020. The average share of Other Capital was 1.09% and it was roughly constant as well.

- The sample average Net Real Income growth was 8.02% per year which is somewhat greater than the corresponding average Gross Real Income growth which was 7.72% 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 –0.35% to +0.47% per year) and in manufacturing input services (the average contribution factor changed from 1.51% to 0.82% per year).

- **The contribution of land services almost doubled from 0.14% to 0.23% per year).** Thus moving from the gross output measurement framework to the net output framework did lead to some substantial changes.

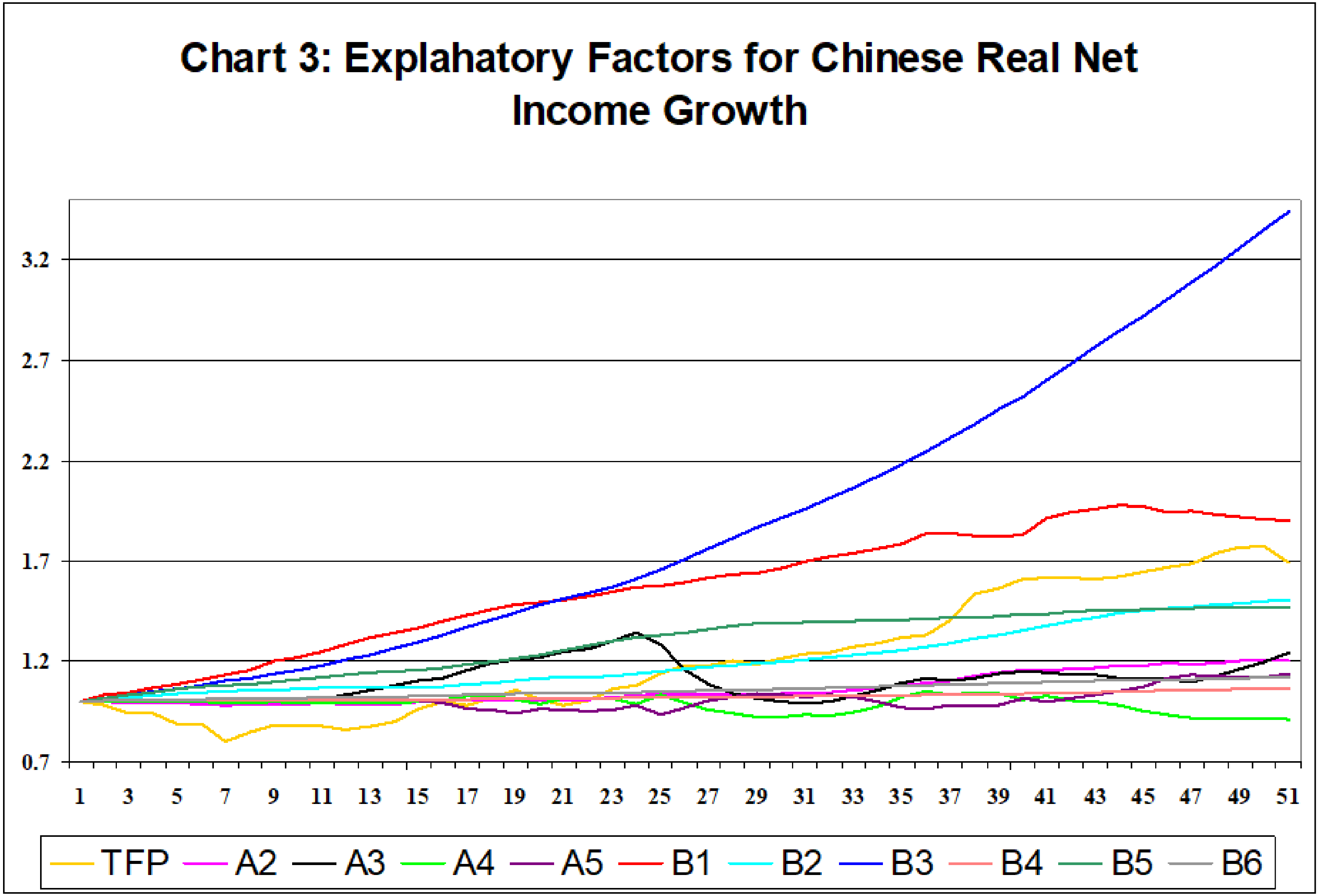


Chart 3: Explahatory Factors for Chinese Real Net Income Growth
3.2
2.7
2.2
1.7
1.2
0.7
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
TFP
A2
A3
A4
A5
B1
B2
B3
B4
B5
B6

- It can be seen that the main factors which explain real net income growth are:
  - (i) Structure Waiting Services (the blue line),
  - (ii) Labour Services (the red line),
  - (iii) Total Factor Productivity Growth (the gold line) and
  - (iv) Manufacturing and Equipment Waiting Services (the bright blue line) and
  - (v) Inventory Waiting Services (the green line).
- The growth in real net investment prices (the black line) was significant in the first half of the sample period. Real export prices (the bright green 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.
- As was mentioned earlier, **Chinese per capita real gross income grew 23.2 fold over our 50 year sample period. It turns out that per capita real net income grew 26.5 fold over the same period, which is a significant difference from the gross rate of growth.**

7. Conclusion

- A big problem with many macroeconomic models is that they ignore land. Some possible reasons for this omission are:
  - The current System of National Accounts does not assign **much of a role to changes in land use in the flow accounts and while Land appears in the Balance Sheet accounts of many countries**, the data are sparse and typically do not break down land into alternative categories.
  - It is difficult to decompose market prices for properties **into their land and structure components**. 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 does not play much of a role as a contributor to economic growth**. As we have seen using the Chinese data, land usage changes significantly over time. In general, agricultural land is converted into other land uses.

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- The work of the Asian Productivity Organization (and augmented by the work of Koji Nomura) has led to the development of a useful data base on national stocks of 4 types of land for about 25 Asian countries. We utilized this data base for China to develop alternative measures of Total Factor Productivity Growth.

- The current international System of National Accounts focuses on the measurement of Gross National Product 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 develop income accounts which would supplement the usual gross output accounts.

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- 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 can 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**?

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