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## The role of factor substitution and technical progress in China's great expansion

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**Abstract**

We offer a macroeconomic assessment of China's Reform Period, highlighting several neglected channels underlining its great expansion. Estimating the supply side of the post-Reform economy reveals the relatively high (above unity) value of the elasticity of factor substitution and the time-varying pattern of factor-saving technical change. The latter we relate to trade, human capital and reallocation factors. We then demonstrate how, in addition to factor accumulation and technical progress, the above-unity elasticity of substitution can be a source of growth (the 'de La Grandville hypothesis'). We then draw upon our estimated framework to rationalize China's high and rising savings ratio as well as the dynamic nature of its convergence path.

**Keywords:** China; Reform Period; Growth; TFP; Factor Substitution; de La Grandville hypothesis; Optimal Savings.
**JEL Classification:** D24, E13, O11

## Non Technical Summary

By any measure, China's recent economic transformation has been extraordinary. Since the start of the 'Reform period' in 1978, real growth has averaged around 9-10% (end, 2012) producing a vast increase in GDP per capita, much of that steered towards savings accumulation, capital deepening and technical improvements. Alongside this, there has been an ongoing restructuring of resources away from the Agricultural sector. Many countries have experienced large economic transitions, but arguably none sustained with the same meaningful size as China. Understanding the reasons behind that rapid growth is a key challenge. Although the reasons behind these transformations are nuanced and granular, here our intention is to provide an 'bigger picture' analysis of the economy – i.e., in an aggregate macro-growth perspective.

We highlight two findings which constitute building blocks for our subsequent analysis. First, China's aggregate elasticity of substitution between aggregate capital and labor is robustly estimated above unity. Second, an interesting pattern for technical progress emerges whereby growth in labor saving slows over time, whilst capital saving, though initially stagnant, accelerates in the last third of the sample. Both features clearly foreshadow the absence of a balanced growth path. Taken together they also shed light on the low and declining labor income share.

Moreover, regarding technical progress, we estimate its growth contributions to be relatively high (around 30%), dispelling the notion that growth has been wholly extensive. In addition, taking our derived paths for technical progress, we suggest that labor-saving technical progress has been driven by reallocation (e.g., urbanization) and external demand for labor-intensive exports. Capital saving technologies, by contrast, have been driven by hi-tech trade which upgraded their global value chain positions, as well as benefitting from R&D. A simple way to characterize this constellation is to say that, TFP-wise, China may have been moving from reallocation growth to an innovation economy. However, persistent enhancement of capital saving technologies continues to ensure that the economy progresses along a growth path that is not balanced.

In the context of a growth model, we demonstrate the startling finding that the degree to which China's economy is outside the balanced growth path has intensified over time; growth in capital intensity rose over time instead of decreasing as might be expected if it were converging to a fixed steady state. At the same time, the distances between equilibrium and actual capital intensity have widened. Hence, although the economy has been moving towards the steady-states, these equilibrium points have moved away even faster reflecting key changes (such as in saving rates, labor force growth and, especially, capital saving technologies). This suggests that, cyclical and political economy constraints aside, ample room for continued expansion exists in the medium run.

Finally, we merge these explanations for China's growth miracle to account for the its high and rising savings. In the context of an optimal growth model, and using our

empirical estimates, we demonstrate that the rising savings rate witnessed over time can be matched and rationalized.

# 1 Introduction

By any measure, China's recent economic transformation has been extraordinary. Since the start of the 'Reform period' in 1978, real growth has averaged around 9-10% (end, 2012) producing a vast increase in GDP per capita, much of that steered towards savings accumulation, capital deepening and technical improvements. Many countries have experienced large economic transitions, but arguably none sustained with the same meaningful size as China.

Although the reasons behind this great expansion are nuanced and granular[1], here our intention is to provide an 'bigger picture' analysis. This focus takes us to the heart of key issues in the macro-growth context: has the economy been characterized by balanced growth; how much of China's growth was intensive versus extensive?; are China's high savings rates 'socially optimal'?

In so doing, compared to the existing literature, we emphasize a number of neglected channels underlying China's great expansion. For instance, we highlight the importance of the aggregate elasticity of factor substitution for China's growth and dynamic convergence process, and the impact of time varying factor augmenting technical progress. Upon that basis, we build our analysis around three main questions.

First, **what are the sources of growth**? Though China experienced rapid development, the composition of that growth needs explaining. If mostly extensive, China's expansion would, Soviet-style, be most likely short lived as diminishing marginal returns, declining saving rates, and demographic slowing set in, leaving the economy in a form of 'middle income trap'. If intensive, China could continue to grow exceptionally until it reaches or defines the technological frontier.[2]

Second, is China on, or at least converging to, an aggregate **balanced growth path** (BGP). If not, what changes would ensure that path? For an economy to be on a balanced growth path requires a unity elasticity of factor substitution or purely labor saving technical progress. China has, however, experienced a continuously rising capital-output ratio and highly non stationary income shares. Moreover, given its profound structural transformation and contrasting factor scarcity (i.e., labor mostly cheaper relative to capital), it is debatable whether all technical progress would have been labor saving. If not, what has shaped the biases in factor-saving technologies? Have technological choices been consistent with China's comparative factor endowment?

Finally, growth has gone hand-in-hand with a remarkably high savings rate (dubbed

[1] For instance, the successful formation of special enterprize zones and growing roles for private entrepreneurship and market pricing. The erosion of barriers to factor mobility and to the expansion of certain sectors were also key elements. As elsewhere in Asia, China's success was also export led. Opening up agricultural trade allowed China to export its new-found surplus and, more generally, exploit its labor intensity (just as the global value chain was lengthening). With access to international markets, came technical transfer, foreign investment and joint ventures and continual deepening in its technical base. References on China's modern and historical economic development and analysis of its transition determinants include, inter alia, Maddison [2007]; Zhu [2012]; Brandt et al. [2014]; Wen [2015]; Curtis [2016]; Kroeber [2016]; Zilibotti [2017] and, especially, the landmark Brandt and Rawski [2008] volume.

[2] On such debates see Krugman [1994, 2013]; Page [1994]; Young [1995].

the "Chinese Savings Puzzle"[3]). According, we leverage our main results (on technology estimation) to account for China's **saving behavior**. Although optimal growth models do predict high (i.e., Golden Rule) savings rates (fortuitously close to China's), they also suggest consumption smoothing which confounds China's experience. Some of this high savings surely reflects financial repression, precautionary motives etc., but in general we also think of savings as reflecting investment opportunities and growth prospects. We demonstrate our estimated framework can help understanding the dynamic profile of savings.

The paper is organized as follows. **Section 2** discusses and motivates our data sources and choices. The quality of official Chinese statistics have been often criticized: many series are only available for a limited time span and/or are affected by breaks in the data. Accordingly, in our analysis we pay close attention to the data sources and data choices. Our principal data sources are the World Bank's World Development Indicators (WDI), China's National Bureau of Statistics (NBS), and China Statistical Yearbook Database (CSYD). Thereafter in **Section 3** we define the key macro stylized facts of interest. These include the high savings rate, labor force and labor income share characteristics, and rapid growth.

In line with our emphasis on economic supply, **Section 4** estimates an aggregate production function and optimal factor demands. We highlight two findings which constitute building blocks for our subsequent analysis. First, China's aggregate elasticity of substitution is robustly estimated above unity. Second, an interesting pattern for technical progress emerges whereby growth in labor saving slows over time, whilst capital saving, though initially stagnant, accelerates in the last third of the sample. Both features foreshadow the absence of a BGP. Taken together they also shed light on China's low and declining labor income share.

Moreover, regarding technical progress, we estimate its growth contributions to be relatively high (around 30%), dispelling the notion that growth has been wholly extensive. In addition, taking our derived paths for technical progress, we suggest that labor-saving technical progress has been driven by reallocation (e.g., urbanization) and external demand for labor-intensive exports. Capital saving technologies, by contrast, have been driven by hi-tech trade which upgraded their global value chain positions (see Kee and Tang [2016]), as well as benefitting from R&D. A simple way to characterize this constellation is to say that, TFP-wise, China may have been moving from reallocation growth to an innovation economy (see also Kee and Tang [2016]). However, persistent enhancement of capital saving technologies continues to ensure that the economy progresses along a growth path that is not balanced.

**Section 5** places this non balanced economy in a Solow-type growth framework (albeit one cast in 'normalized' form, and, crucially, allowing for level shifts in capital saving, which capture non BGP shifts). We demonstrate the startling finding that the degree to which China's economy is outside the BGP has intensified over time; growth in capital intensity rose over time instead of decreasing as might be expected if it were

[3] See Yang et al. [2012] for a comprehensive analysis.

converging to a fixed steady state. At the same time, the distances between equilibrium and actual capital intensity have widened. Hence, although the economy has been moving towards the steady-states, these equilibrium points have moved away even faster reflecting key changes (such as in saving rates, labor force growth and, especially, capital saving technologies). This suggests that, cyclical and political economy constraints aside, ample room for continued expansion exists in the medium run (see also Bosworth and Collins [2008].)

**Section 6** links China's growth patterns specifically to the substitution elasticity (which, to recall, we estimate above unity). This leads us on to the *de La Grandville hypothesis* after La Grandville [1989]. He conjectured that the rapid growth in East Asian countries to a high substitution factor elasticity value in their industrial sectors, and their high savings rate (see also Yuhn [1991]). This echoes Hicks' [1932] argument that a larger substitution value entails high transformation rates between sectors of different factor intensity; when one activity contracts to the benefit of another, the production increase in the second sector can be made larger if the substitution elasticity is high.

Accordingly, the substitution elasticity plays an important role in our analysis. Easier factor substitution – by staving off diminishing returns – can prolong extensive growth (i.e., scare factors can be substituted by abundant ones), and facilitate sectoral reallocations. We also demonstrate that compared to elasticity values typical of developed economies, China's relatively high substitution value has implied a $17\% - 33\%$ per cent gain in the level of production over the second half of the sample (translating into 1-2% higher growth). Moreover, the speed of convergence to a given steady state is a positive function of the elasticity value, which resonates with China's rapid development. However against this, the elasticity value (if sufficiently high or low) can generate disequilibria (where per-capita growth is degenerative or explosive). Although the estimated elasticity does not traverse those regions (in-sample), we discuss parameter changes where such considerations may become relevant.

Finally, in **Section 7**, we merge these explanations for China's growth miracle to account for the its high and rising savings. In the context of an optimal growth model, and using our empirical estimates, we demonstrate that the rising dynamic profile can be matched and rationalized. **Section 8** concludes.

## 2 Data

Before proceeding with the estimation, this section provides a detailed description of the data used.[4]

[4] The data and estimation files for replication purposes are available on request. A full list of the data and their sources are given in Appendix A.

## 2.1 Gross Domestic Product

We use annual GDP series at the national level for China and focus on the economic reform period of 1978 to 2012. Our principal data sources are the World Bank's World Development Indicators (WDI), China's National Bureau of Statistics (NBS), and China Statistical Yearbook Database (CSYD).

The WDI covers nominal and real GDP at the national level starting in 1960, where GDP is defined as the sum of Gross Value Added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.

GDP data is in constant local currency in 2000s prices. The data is similar to the one provided by the NBS, which is available from 1952. Additionally, NBS covers data on nominal and real GDP published at the provincial level, starting in 1978, but there are significant discrepancies between GDP at provincial level and at the national level. For example, provincial data tends to overestimate the level of nominal GDP by around $11\%$ of nominal GDP in 2012.[5] Our choice is to use GDP at the national level as the preferred measure of output.

## 2.2 Labor Share and Employment

Labor share has been defined as the ratio of labor income to GDP at market prices, where the labor income represents the aggregate compensation of employees from GDP decomposition by the income approach. Regarding the sources for GDP by income approach, NBS provides a number of alternatives. First, data on compensation of employees at the national level is provided by Flow of Funds Accounts (FoF) over the period 1992-2012. Second, data is available at the national level in the Input-Output table (I-O table) from 1992. Because NBS is not updating the I-O tables each year, the time series is missing observations, providing only partial information about labor share developments. Thus, FoF data is more suitable for our purpose. However, since the NBS is not providing the FOF data for the earlier period of our sample (1978-1991), we need to turn to the data aggregated across provinces to find a proxy.

NBS provides provincial data for the compensation of employees which covers the full period (1978-2012), but in 2008 the observations of many provinces are missing resulting discontinuity in aggregated figures. However, in Qi [2014] the discontinuity is corrected. We adopt that correction. Thus, in our analysis we use two measures for the labor share: i) based on FOF statistics for 1992-2012 period chained to the provincial data for 1978-1991 and ii) based entirely on the provincial data over 1978-2012 period.

As for the labor input data we use the number of employees published in the Chi-

[5] Different reasons have put forward to explain the discrepancy, most of them indicating errors in the provincial data: provinces double-count cross-provincial economic activities, provinces have an incentive to exaggerate growth rates to gain promotions and to secure additional funding from the central government, provinces used different base year prices for industrial real growth Holz [2014].

nese Statistical Yearbook. The original data of employees contains a break in 1989/1990. In 1997 employment series reported in the Chinese Statistical Yearbook was revised on the basis of the results of the annual Survey of Population Change. While the figures for earlier years were retained, the numbers of from 1990 onwards rose substantially. However, Young [2003] reports overlapping observations of the old and revised series and we utilizing this information in chaining the revised employee series from 1990 backwards.

## 2.3 Capital Stock and Capital Income Share

No capital stock data is reported in the Chinese statistical system. Consequently, we calculated the capital stock using the perpetual inventory method assuming a $\delta = 6.0\%$ depreciation rate following Young [1995].[6] For investment flows, we use Gross Fixed Capital Formation, expressed in constant 2000s prices and available from the WDI.

To minimize the uncertainty related to the choice of the initial stock level we started the accumulation of the capital stock from 1965 (i.e. from the first available investment observation in our data set, $I_0$). We initiate the capital stock in 1965 by assuming the average real investment growth in 1965-1978 (i.e. $g = 10.1\%$) extends into the past. If past investment has grown at that rate then $I_{-s} = I_0(1+g)^{-s}$. Accordingly,

$$K_0 = I_0 + (1-\delta)K_{-1} = \lim_{s\to\infty}\left[I_0\sum_{i=0}^{s}\left(\frac{1-\delta}{1+g}\right)^i + (1-\delta)^s K_{-s}\right] = I_0\frac{1+g}{g+\delta}$$

Now the use of investment data of 13 years *before* the beginning of the analysis makes the observations in the sample period of the analysis quite insensitive with respect to the initial capital stock.[7] Our capital-output is rising throughout the sample. This compares with the OECD and Penn derived series which lie well above our series and appear stationary. However, our derived series is qualitatively and quantitatively similar to the arguably more carefully-constructed Cheremukhin et al. [2015] data (see our figure 2 below).

The capital income share is residually defined from the observed labor share:

$$\varsigma_K = 1 - \varsigma_N = 1 - \frac{wN}{Y}$$

where $w$, $N$ and $Y$ are respectively the real aggregate wage rate, labor input (employees) and real output. Note, the data does not allow us to distinguish an aggregate mark-up. Notwithstanding, it seems unlikely that China's aggregate mark-up value would be internationally remarkable given its strong export orientation [Branstetter and Lardy, 2008]. Moreover, the existence of a large aggregate mark-up would only

[6] A figure which seems consistent with that averaged over other studies, see OECD [2000] and the references therein.

[7] The use of $5\%$ or $15\%$ percent constant investment growth instead of the average growth of 1965-78 would imply $40\%$ higher or $20\%$ lower estimates for the initial capital stock in 1965. However, by 1978 the level differences between the generated series diminished to $5.5\%$ and $2.7\%$, respectively.

further squeeze the labor income share, whose low and declining value is already one of our key concerns.[8] Given our residually-determined capital share, the implicit real user cost of capital can be backed out from,

$$r = \frac{Y - wN}{K}$$

yielding a value of around 20-25% (similar to that reported by Bai et al. [2006]).

## 3 Stylized Facts on China's Growth

We now overview the key stylized facts of China's growth process over 1978-2012. **Figure 1** shows the great rise of the aggregate economy punctuated with only a few periods of 'low' growth. Included among that naturally is the years following the Great Recession and the ensuing global trade slowdown (buttressed, though, by stimulative policy measures).[9,10]

Moreover, by international standards, Chinese investment and saving rates are exceptionally high. Savings were broadly stable until 2000, then accelerated; investment has increased dramatically (the GDP share of gross fixed investment grew by almost $20pp$, i.e. from around $25\%$ in 1978 to around $45\%$ in 2012, **Figure 2**). Accordingly, the capital-output (capital-labor) ratio is almost 1.7 (about 24) times higher in 2012 than in 1978. These developments are coupled with a strongly rising real wage rate and a decreasing real price of capital implying that relative price of capital was decreasing over time.

In addition, the share of resources devoted to research have (for an emerging economy) been high. This has been aided by evolving expenditure patterns (rising demand for more technology-intensive goods, reflecting Engel's Law), the expansion of market-based R&D activities and foreign partnerships and exposure, increased domestic competition, public policies (patent restoration in the mid 1980s, higher expenditures since the mid 1990s) etc.[11]

The labor force has been growing continuously but slowing dramatically from the late 1980s onwards, see **Figure 3**. Alongside this, there has been large reductions in the employment share of primary industries, and ongoing urbanization of labor. Regarding labor income, two facts are clear. First, by the standards of developed economies,

[8] An additional question is whether any such mark-up would be time varying reflecting (positively) say sectoral shifts (towards Services) or (negatively) increasing world trade integration (e.g., reflecting competitiveness pressures following China's WTO participation since 2001). However, experimentation with standard mark-up values (5%, 10%, 20%) had only minor effects on (our later reported) parameter estimates, nor did we find systematic non-stationarity in equation residuals indicative of a time-varying markup.

[9] The depression in the early 1960s was the fallout of the great famine following drought and the failed agricultural policies of the Great Leap Forward. The 1989-91 period reflect internal turbulence and sanctions, and the late 2000s reflects the Great Recession and global slowdown of trade.

[10] For nominal GDP, the discrepancies between data sources are not especially marked and not qualitatively important.

[11] On this, see the comprehensive discussion by Hu and Jefferson [2008].

the labor share (across different data sources) appears unusually low (around 0.45 at the sample end). Second, albeit more in line with developed economies, that share has been trending downwards (at least since the early 2000s). This latter observation suggests that aggregate technology is unlikely to be Cobb Douglas.

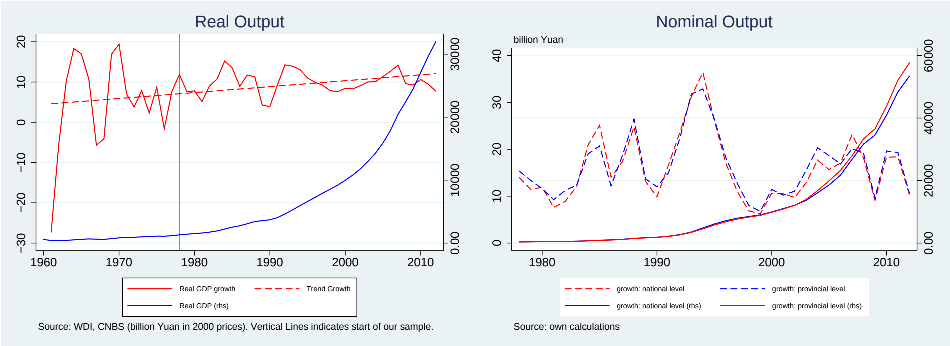
These observations, moreover, are confirmed by all available data sources, i.e. across provinces aggregated compensation of employees and GDP by income approach (period 1978-2012), and at the national level, flow-of-funds accounts on compensation of employees and GDP by income approach (period 1992-2012). However, despite the common downward trend, these two alternative labor share measures contain also large differences, especially since 1998. While since 1998 the labor share shows a strong downward development until 2007 in the provincial data, i.e. the decrease of $8.3pp$, the flow of funds data shows the decrease of only $4.5pp$ coupled with very different time profile in the same period and thereafter. In the flow of funds data the labor share remains stable, or slightly rises, until 2001 and, thereafter, starts decreasing although at a more modest pace than in the provincial data. Perhaps an even more remarkable difference is the strong upward level shift of the labor share in the aggregated provincial data since 2009 whilst, except a modest upward blip in 2009, the labor share continues decreasing in the flow of fund data.

The large discrepancies in the labor shares could be related to changes in the methodological definition of GDP components by income approach and the high degree of inaccuracy of income data at provincial level.[12] The data on GDP by income approach at the provincial level has been subsequently revised. According to Holz [2013], the 2006 benchmark revision (post-economic census 2004 data) revealed that NBS was previously overestimating labor remuneration and underestimating operating surplus[13] with the data being retrospectively revised back to 1993, while the 2010 benchmark revision raised the share of labor compensation in income GDP back to the higher level and the trend exhibited in the data published before the 2006 benchmark revision.

[12] As discussed in Holz [2013] data on rural household income are compiled by three different institutions, namely by the county statistics department through surveys, by the county rural economy committee through complete reporting based on village-level accounts, and by the rural survey teams through surveys and all these source differ

[13] There were two definitional changes introduced by the NBS in 2004. Starting with the 2004 data, first, all income of the owners of individual-owned enterprises (the self-employed) is newly included in operating surplus (rather than in labor remuneration, as before) and, second, the operating surplus of collective- and state-owned agricultural enterprises is newly included in labor remuneration with no further attempt to split operating surplus and labor remuneration (due to the difficulty of obtaining accurate data, as cited in Holz [2013].)

## FIGURE 1: GROWTH AND OUTPUT




## FIGURE 2: INVESTMENT, SAVINGS AND CAPITAL

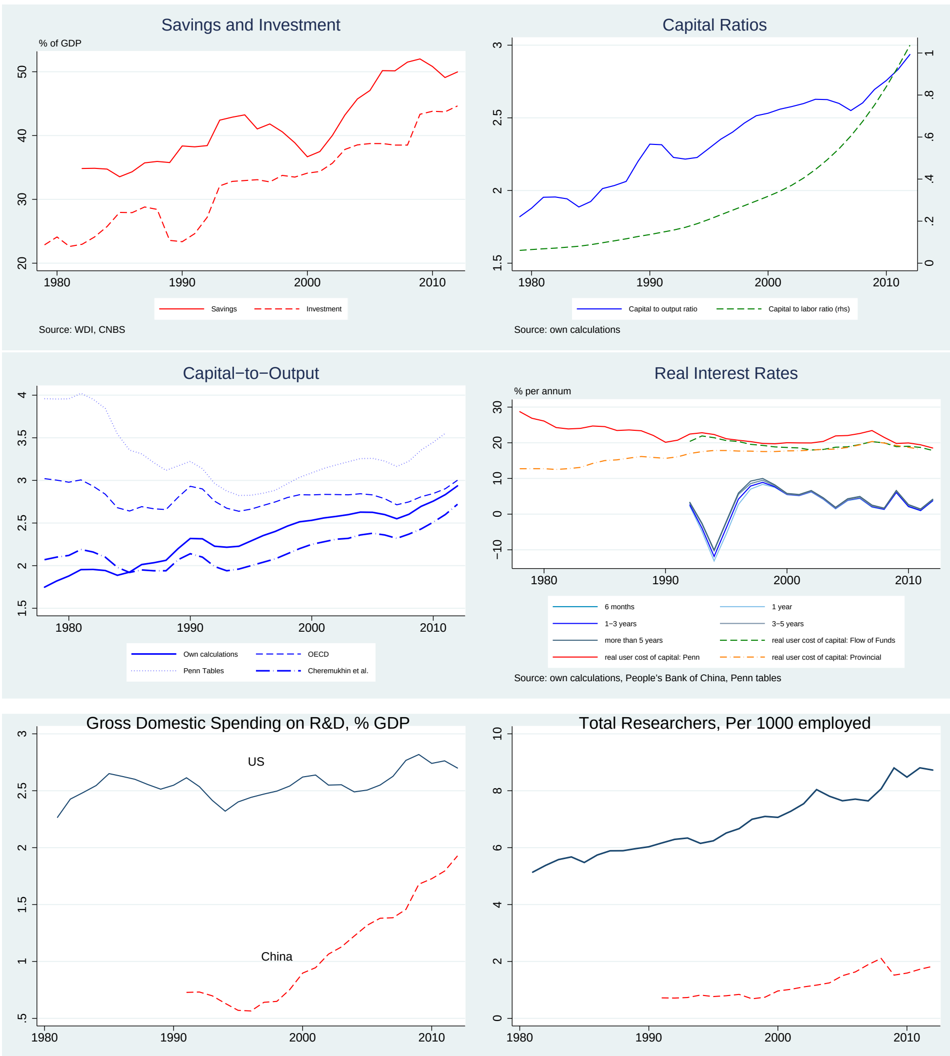
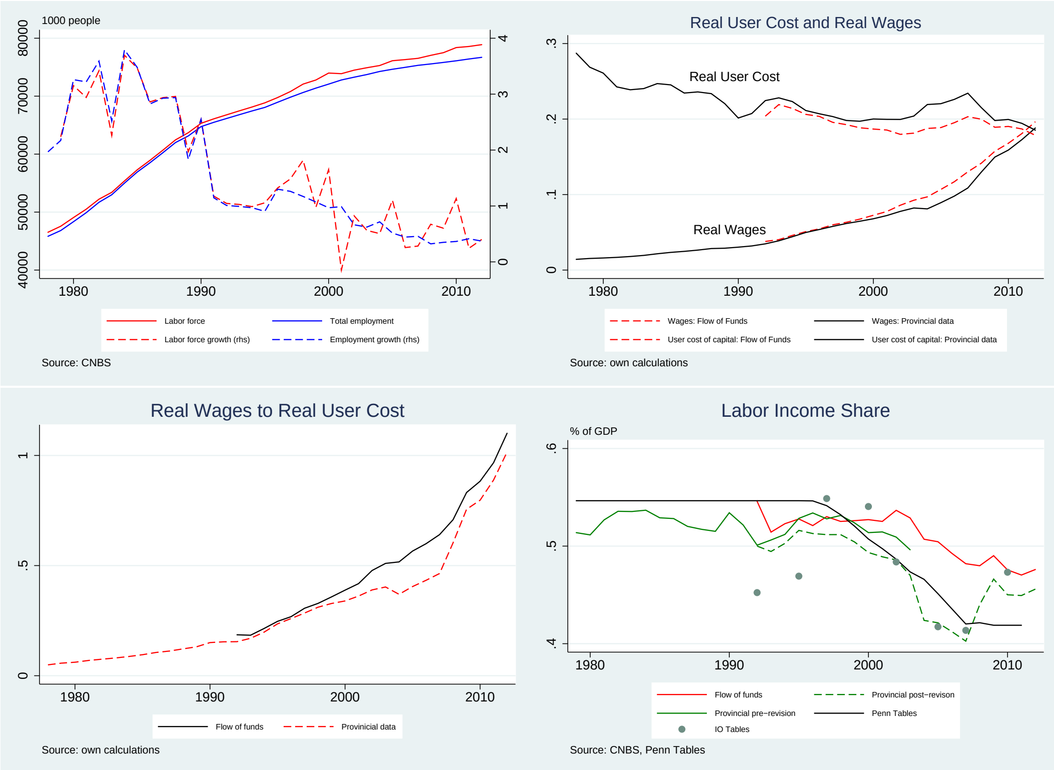


**FIGURE 3: EMPLOYMENT AND FACTOR PRICES**




## 4 The Estimation and Modelling Framework

A key strand of our paper is to characterize the supply side of the Chinese economy. Like Cheremukhin et al. [2015], we study the economy through the lens of a neo-classical production framework. This does not preclude the possibility of frictions or 'wedges' or mark-ups around those conditions, but it does provides us with a relatively simple framework to account for the key quantitative long-run factors behind China's macro economy. Given this focus, like Chirinko and Mallick [2017] for the US aggregate economy, we set aside studying sectoral interactions. Although, to repeat, the rapid sectoral shifts observed in the Chinese economy over the "Reform period", can be mapped to the extent of factor substitutability in the economy (as captured by the aggregate elasticity).

Following León-Ledesma et al. [2010] we model supply determinants as a 'normalized' system of production and factor returns with cross-equation parameter constraints. Consider that real aggregate output $Y$ can be described by the normalized

CES production function,[14]

$$Y_t = Y_z \left[ \pi_z \left( a_t \frac{K_t}{K_z} \right)^{\frac{\sigma-1}{\sigma}} + (1-\pi_z) \left( b_t \frac{N_t}{N_z} \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where $\sigma \in [0, \infty)$ is the elasticity of substitution between the real capital stock $K$ and the labor input $N$. CES function (1) nests Leontief, CD and linear forms, respectively, when $\sigma \to 0, 1, \infty$.[15,16] For a given allocation, the higher is $\sigma$, the greater the similarity (or substitutability) between factors. The substitution elasticity can also be thought of as a measure of how quickly diminishing returns set in and thus how long extensive growth can continue. This parameter will play an important role in our analysis and, indeed since Hicks [1932], has been seen as a deep institutional and structural characteristic of the economy.[17]

Given this, the optimal labor and capital income shares are, respectively,

$$\varsigma_{N,t} = (1-\pi_z) \left( b_t \frac{N_t/Y_t}{N_z/Y_z} \right)^{\frac{\sigma-1}{\sigma}} \tag{2}$$

$$\varsigma_{K,t} = \pi_z \left( a_t \frac{K_t/Y_t}{K_z/Y_z} \right)^{\frac{\sigma-1}{\sigma}} \tag{3}$$

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[14] Normalization essentially implies representing the production relations in consistent indexed number form. Its parameters then have a direct economic and econometrically-identifiable interpretation. Otherwise the estimated parameters can be shown to be scale dependent (i.e., a circular function of $\sigma$ itself), arbitrary and un-robust. Subscripts $z$ denote the specific normalization points: geometric (arithmetic) averages for non-stationary (stationary) variables. See Klump et al. [2012] for a survey, León-Ledesma et al. [2015, 2010] for Monte-Carlo analyses, Growiec [2013] for a discussion of the microfoundations of the normalized CES function, and La Grandville [1989] and Klump and de La Grandville [2000] for the seminal theoretical contributions.

[15] Though there are many plausible data-coherent functional forms to model production, we concentrate on the encompassing CES case. This reflects the power of this functional form in the modern growth literature (e.g., Acemoglu [2009]; La Grandville [2016] ) and allows us to focus on salient features like the unitary/non-unitary value of the substitution elasticity and the nature of factor saving technical change. Under more flexible functional forms, e.g., the Variable Elasticity of Substitution (VES) and translog functions, the substitution elasticity becomes time-varying. Substantial numerical problems can arise from the estimation of these forms, and these problems magnify substantially when incorporating biased technical change. Consequently, the VES appears to have enjoyed limited empirical success, e.g., Genç and Bairam [1998]. Interestingly Yuhn [1991] discussed the validity of the de La Grandville hypothesis in the context of South Korea's growth. However, somewhat confusingly he used a translog function which precisely does not embody the (general mean) interpretation of the growth-elasticity relationship, nor did he find the aggregate elasticity above one. Therefore, we follow the bulk of the literature in assuming that $\sigma$ is time-invariant. Indeed, recursive estimation did not reveal any particular estimation instability, see **Section F**.

[16] When $\sigma < 1\,[> 1]$ factors are 'gross complements' ['gross substitutes']. With gross substitutes, substitutability between factors allows both the augmentation and bias of technological change to 'favor' the same factor (in terms of increasing its factor income share).

[17] Note, we abstract from *human capital.* This was largely done for simplicity since, amongst other things, the introduction of human capital as a separate production factor raises issues of using and discriminating among different hierarchies of multilevel production functions with skilled and unskilled labor and perhaps multiple capital types with corresponding cross elasticities, e.g., León-Ledesma et al. [2012]. One might consider the labor saving technical progress term as capturing some of the effects of human capital on the labor input.

Equations (1) – (3) constitute the non-linear stochastic system of equations to be estimated.[18] In this system, distribution parameter $\pi_z \in (0,1)$ equals the capital income share at the point of normali(**z**)ation: $\pi_z = 1 - \frac{w_z N_z}{Y_z}$, where $w_z$ denotes the real wage rate at the normalization point.

Terms $a_t$ and $b_t$ capture the level of technical progress associated to capital and labor respectively (with $a_{t=z} = b_{t=z} = 1$ with growth rates $d \log a_t = \gamma_a(t)$ and $d \log b_t = \gamma_b(t)$). In the following we omit time subscripts unless necessary for clarity. There is a large body of theory which relates factor-augmenting technologies to R&D resources, technical spillovers and adoptions etc [Acemoglu, 2009; Jones and Williams, 2000]. Here our ambitious is more modest: namely to robust extract measures of time-varying technical progress (from our estimations) and assess plausible determinants and narratives behind their evolution.

Manipulating (2) and (3), the relative factor income share is,

$$\frac{rK}{wN} = \frac{\pi_z}{1-\pi_z}\left(\frac{a}{b}\frac{K/K_z}{N/N_z}\right)^{\frac{\sigma-1}{\sigma}} \tag{4}$$

The latter shows that income shares evolve with capital deepening and/or technical change.[19] The direction of the effect, however, depends on $sgn\ \{\sigma - 1\}$, and, in the case of technical improvements, on their source (e.g., whether or not they augment capital more than labor).

## 4.1 Technical Progress Forms

Aggregate technical progress is not directly observable. To circumvent problems related to Diamond et al. [1978]'s impossibility theorem, researchers typically posit plausible functional forms such as following constant growth. Following theoretical discussion about possible dynamic biases in technical progress (e.g., Acemoglu [2002]; León-Ledesma and Satchi [2018]), however, it is not clear that growth rates of technical progress components should always be constant. This is especially likely for China given its transformation since the Reform Period (e.g., from an Agriculture-based economy to a more modern one). Accordingly, to robustly extract technical progress series we follow three methods:

$\mathbb{M}_1$ Following Klump et al. [2007], we model time-varying technological progress terms using a flexible, normalized Box-Cox transformation: $j = f(t; \gamma_J, \lambda_J)$, where $j = \log(a), \log(b), J = a, b$, and where curvature parameter $\lambda_J$ captures the dynamics of the growth pattern around its central (normalized) value $\gamma_{J,z}$[20] (see Appendix B for further explanation).

[18] Since (1)-(3) represent a system of equations in which shocks to the factor shares are likely to be correlated across the error structure of the model, the system is estimated as a seemingly-unrelated regression. Although for robustness we use many different estimators, as discussed below.

[19] For this ratio to be constant requires: (a) $\sigma = 1$ or (b) $\sigma \neq 1$: i.e., that the bias in technical change exactly offsets accumulation of capital per worker (in growth terms).

[20] For a recent application of this framework see also Chirinko and Mallick [2017].

$\mathbb{M}_2$ As a cross check against these smooth functions of $\mathbb{M}_1$, we additionally solve non-linear system (1)-(3) by iteratively forcing the residual for each equation simultaneously to zero and solving for the resulting time series $\{\log a_t', \log b_t', \sigma_t'\}$ consistent with that outcome.[21]

$\mathbb{M}_3$ Agnostic benchmarks: We drive a standard Solow residual and a Törnqvist index.

## 4.2 Results

León-Ledesma et al. [2010] showed that the estimates of the parameters of the CES production function from the system (1)-(3), containing cross-equation parameter constraints and trend variables, are highly robust. By exploiting Monte Carlo techniques they showed that system estimates were quite insensitive with respect to the sample size and simultaneity bias. In addition and as opposed to the single equation approach, the Diamond-McFadden impossibility theory, lost its importance.

**Table 1** shows the non-linear seemingly unrelated regression (NLS) estimates of our core parameters using Provincial labor share data with the sample 1978 - 2012, and the Box-Cox functions. As a robustness check, though, see Appendix C, we additionally estimate the full-set of system estimations with feasible generalized non-linear least squares (FGNLS) and the iterated feasible generalized least squares (IFGNLS) (which is asymptotically equivalent to maximum likelihood). We also used 2- and 3-stage non-linear least square estimators but suppressed them from brevity.[22] Our central conclusion is that parameter estimates prove highly robust. We also perform a battery of non-linear searches based on different initial parameter conditions.

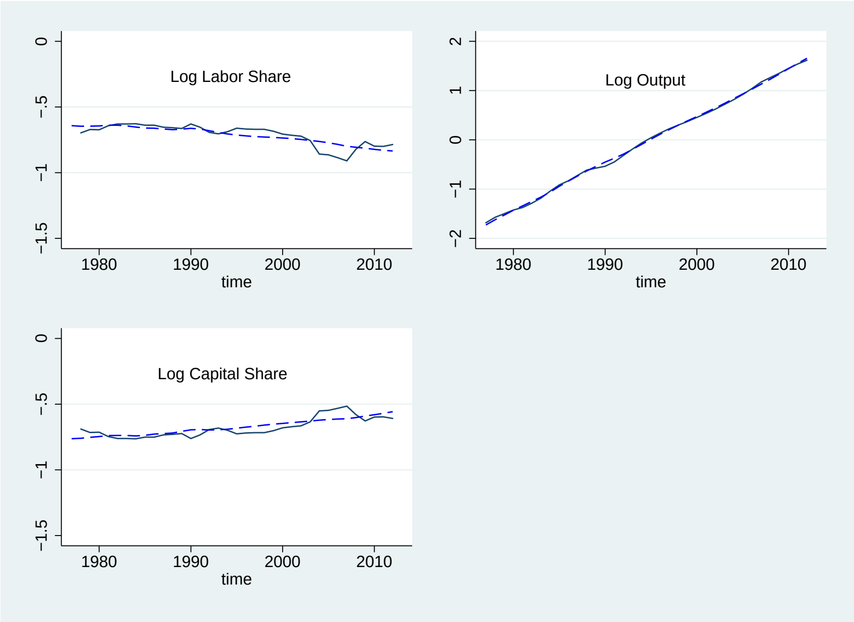
In the table below, we highlight the factor augmenting form since (across all metrics and estimation forms) it was the statistically-dominant form. **Figure 4** shows the fit of the equations and the clear mapping in the trends of factor shares and the close tracking of output. We estimate using the Provincial data for labor share (1978-2012), for the Flow of Funds Physical transactions data (1992-2012) and, for extra robustness, where the latter is backdated to 1978 using growth rates of the former (see **Table C.1**).[23]

[21] The advantages of this approach are two fold: (1) in comparison to the Box-Cox form, there is no parametric constraint on technical progress, (2) in turn, the derived series provides a cross check on the suitability of our estimated parametric forms for the technical progress components. The disadvantage is that the resulting $J_t'$ series will be a mixture of technical progress as well as utilization margins, business-cycle fluctuations, and possible variations in the aggregate mark-up. There are no data on the utilization rates of factors. However, since these other margins are likely to be stationary, the overall remaining trend and qualitative nature is the object of interest. The figure for these statically derived forms are in Appendix F.1.

[22] They are however available on request and, qualitatively, are similar to the ones reported here. We variously used lags of output and capital and the labor input, as well as the output gap and human capital as instruments. See Villacorta [2017] for an interesting application of Bayesian estimation methods to production-technology relationships, and Mućk [2017] for a cross-country panel estimation.

[23] The fit of the estimates in Table 1 can be gauged by figure 4. As we can see the downward (upper) trend in the labor (capital) share is matched well with a low RMSE. Note, using method II, the fit is numerically zero given that this is how we extract $\{\sigma, a, b\}$. Figure F.1 replicates the Figure 1 but additionally show that the $\sigma$ extracted by this method is remarkably stable at around $1.2 - 1.3$ which is of course numerically very close to our central estimated from table 1.

## Figure 4: Production System: Actual and Fitted




Note: Solid denotes data and dashed fitted values.

## Table 1: Production System Estimation

| $\sigma$ | $\gamma_b$ | $\gamma_a$ | $\lambda_b$ | $\lambda_a$ |
|---|---|---|---|---|
| 1.204*** | 0.045*** | 0.020*** | 0.910*** | 1.959*** |
| {1.145:1.263} | {0.036:0.054} | {0.010:0.030} | {0.734:1.086} | {1.210:2.708} |
| $\sigma = 1$ | $\gamma_b = \gamma_a$ | | $\lambda_b = 1$ | $\lambda_a = 1$ |
| [0.000] | [0.009] | | [0.318] | [0.012] |

Note: Joint system estimation of equations (1)-(3). Numbers in {} indicate 95% confidence intervals and in [] denote probability values. Asterisks denotes significance level based on robust standard errors, where *** $< 0.01$.

Results suggest a $\widehat{\sigma}$ significantly different from and above unity. Moreover, to match $\dot{\varsigma}_N/\varsigma_N < 0$ (i.e., decreasing labor share) with gross substitutes, would require (rearranging (4)),[24]

$$\gamma_a + \dot{K}/K > \gamma_b + \dot{N}/N$$

This is precisely what we observe.[25,26]

[24] In the BGP where $\gamma_a = 0$ prevails, the equality $\dot{K}/K = \gamma_b + \dot{N}/N$ guarantees constant factor income shares independently from the size of the substitution elasticity.

[25] Where $\dot{K}/K = 10.960$, $\dot{N}/N = 1.530$ and, from table 1, $\gamma_a = 0.020$; $\gamma_b = 0.045$; although all of these constitute averages of underlying time varying series.

[26] Note that the literature often explains unbalanced growth and a falling share of labor income as a decline of the relative price of investment goods. In our case, however, even leaving aside our aggregate

In terms of the stylized curvature parameters (see **Figure 5**), since $\hat{\lambda}_b \lesssim 1$, the growth of labor saving technical progress is approximately constant but slowing down from above. By contrast, growth in capital saving technologies ends up as a rapidly expanding series since $\hat{\lambda}_a > 1$. The $\mathbb{M}_2$ series $\{\log a'_t, \log b'_t\}$ (superimposed on the Box-Cox functions in figure 5) are consistent with this pattern but in a more striking manner.[27] Growth in capital saving technologies is fairly flat then rapidly accelerates in the last third of the sample. For the labor component, there is rapid acceleration in the first half of the sample, then a stabilization.

Looking across measures $\mathbb{M}_1 - \mathbb{M}_3$, the *overall* TFP growth rate is increasing throughout the sample (**Figure 6**). The $\mathbb{M}_1$ method necessarily only captures the broad upward trend in TFP growth. The other measures – an official NBC measure (beginning in 1995), as well as a Törnqvist index, various Solow-type residuals and the overall $\mathbb{M}_2$ rate – look similar, thus confirming our approach as a general benchmark.[28]

Finally, **Figure 7** shows real growth decomposed into contributions from factors and technical change.[29] The contribution of labor (reflecting slowing labor-force growth) is around 20% at maximum but falling to near zero. Capital accumulation is the dominant contribution (around 50%). Whilst comparing the Solow decomposition (**Panel b**) with our own (**Panel a**), does not reveal any clear cut differences, the latter has the advantage that it distinguishes factor saving types. Notably, over time the contribution of capital saving technical progress becomes around half that of labor (i.e., in the final decade); this is the analogue of the patterns of factor-augmenting technical change described in figure 5. Overall, TFP contributes around 30% to growth (this is above the average of 20% reported by Tian and Yu [2012].)

To conclude, the supply-side estimations suggest two key causes for the falling labor shares: (i) The technological progress has become more capital biased and (ii) a substitution elasticity above 1 combined with the pattern of capital-deepening has amplified firms' incentives to substitute labor for capital, leading to a fall in the labor share. Accordingly, our estimation matches the factor shares and output evolution well, provides an explanation for the falling labor shares and leads to a plausible and (robust across methods) TFP growth path.[30]

---

analysis, an elasticity above one and an investment specific shock would translate as a rising labor share, which is clearly counterfactual.

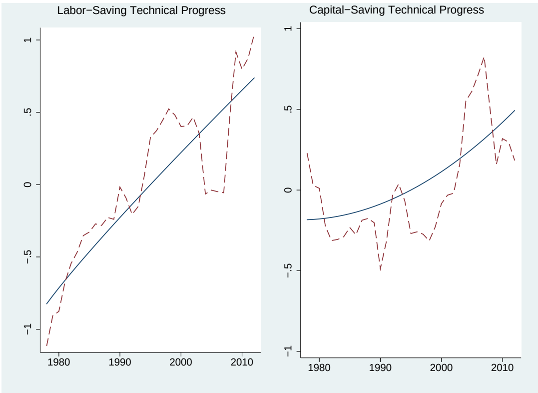
[27] Further $\bar{\sigma}' \approx 1.2$ from the statistically determined system. The parameter is extracted with limited time variation (See **Figure F.1**).

[28] The $\mathbb{M}_2$ series is marginally more volatile, as discussed in footnote 21.

[29] It is always worth bearing in mind that measurement of TFP potentially conflates the impact of market power and factor utilization margins. However since the latter is by definition stationary and the latter (as reflected in our system estimation residuals) does not appear to be trending, we can say that whilst there may be level errors in the level of TFP, there is less likely to be errors in the growth rates and contribution analysis of TFP.

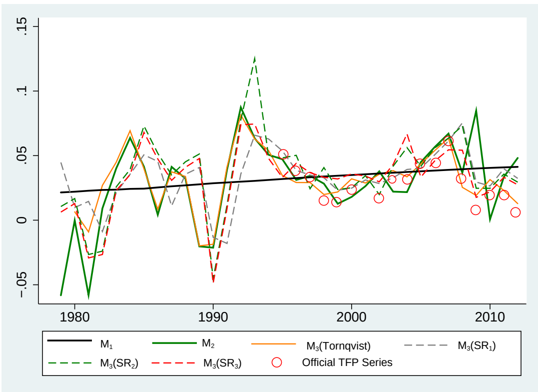
[30] See also Tian and Yu [2012].

## FIGURE 5: TFP LEVELS COMPONENTS



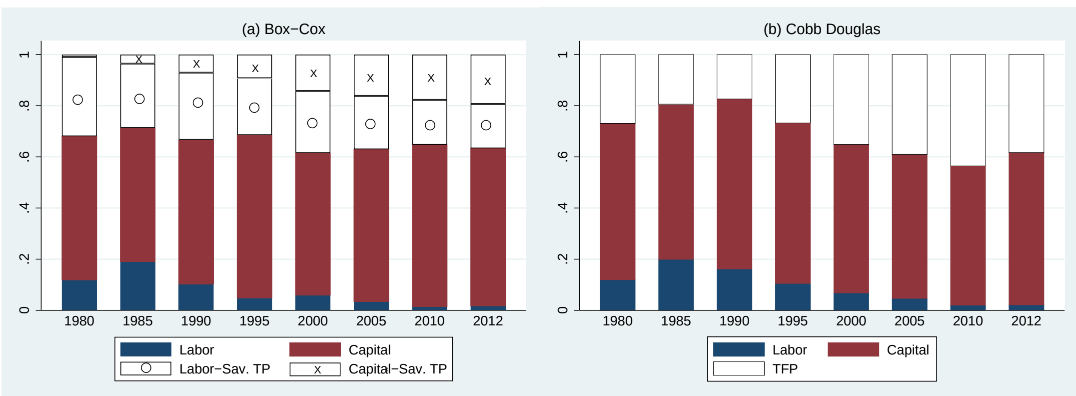

Note: Solid lines indicate the Box-Cox for of technical progress, $\mathbb{M}_1$, the dashed lines indicate the statically derived technical progress forms, $\mathbb{M}_2$.

## FIGURE 6: TFP GROWTH




Note: $SR_1$ is the Solow residual computed by assuming the labor share has been constant over the entire sample (at $0.508$). $SR_2$ and $SR_3$, respectively, are based on the time-varying labor share according the flow of funds data and provincial data. Additionally, we have a Törnqvist index and the official data available from the NBS.

## FIGURE 7: DECOMPOSITION OF REAL OUTPUT GROWTH



### 4.3 Factor Saving Technical Progress: Possible Determinants

The literature on technical change emphasizes many different channels: relative factor scarcity and relative factor prices, profit motives, skill endowments, research effort and patent protection, mis-allocation, proximity to the technical frontier etc (e.g., Gancia and Zilibotti [2009]).

China is an economy influenced by many different constraints and wedges (rural-urban migration, initially large share of SOEs, financial repression etc).[31] Accordingly, given that many such channels may operate and interact, we do not take a stand on any particular channel ex ante. To shed light on them (albeit in reduced form), we regress $a_t'$ and $b_t'$ (viz., capital and labor technical change) on trade variables (i.e., reflecting the entire *market demands* for factors), on *patents and human capital* measures (reflecting factor quality and innovation-protection measures), and on urbanization and scale (reflecting demand for factors and *reallocation mechanisms* across the economy).[32]

**Table 2** shows that whilst there are common factors which boosted *both* components of technical progress, there are also revealing differences. For example whilst increasing trade openness has provided incentives to factor-saving technologies, those gains appear to be decelerating (accelerating) for labor (capital), see the *Open* and *Open*$^2$ coefficients. One interpretation of this is that external trade, reflecting relative factor abundance and the prevalent technology level, initially reflected labor-intensive exports whose gains have over time become increasingly saturated as relative labor costs rose, urbanization and reallocation gains slowed (see the *Urban*/ *Urban*$^2$ coefficients), and other low-wage nations emerged etc.

Capital saving technical progress, by contrast, has been more affected by technology adoption (as reflected in the influence of import content of exports) and impacted by global value chain measures such as a 'high-technology' and ICT components. This chimes with the important analysis of Kee and Tang [2016], who uncover the rising domestic content in exports induced by China's trade and investment liberalization, which deepened its engagement in global value chains. Moreover, with underdeveloped financial markets, limited overseas demand for capital and hi-tech goods, and with investment resources skewed to SOEs, Song et al. [2011], there would likely have been initially limited incentives to bias technology improvements towards capital. However, as access to foreign technologies improved over time (e.g., through openness, integration, and FDI inflows), China would have benefitted from technology catch up and diffusion. The country could thereby consistently improve the contribution of capital saving technical progress over time (moreover, alongside this, the factor price ratio increasing favored capital, further encouraging these developments). Likewise, for human capital indicators: although improvements in such indicators have boosted both technical progress types, there has been an additional boost to capital technologies through R&D advancements (which ostensibly had less

[31] Some of these factors are discussed in Song et al. [2011], Cheremukhin et al. [2015].

[32] A more extensive set of results is shown in Appendix **D**.

impact on labor-saving patterns).

**TABLE 2: TECHNICAL PROGRESS DETERMINANTS**

| | Capital Sav. Technical Progress | | | | Labor Sav. Technical Progress | | | |
|---|---|---|---|---|---|---|---|---|
| **Trade** | | | | | | | | |
| Open | 0.018*** | -0.047*** | | | 0.025*** | 0.135*** | | |
| | (0.004) | (0.011) | | | (0.005) | (0.017) | | |
| $\text{Open}^2$ | | 0.001*** | | | | -0.002*** | | |
| | | (0.000) | | | | (0.000) | | |
| Import Content of Exports | | | 7.105*** | | | | -1.745 | |
| | | | (0.736) | | | | (1.500) | |
| High-Tech. Exports† | | | | 0.032*** | | | | 0.012 |
| | | | | (0.006) | | | | (0.013) |
| Adj. $R^2$ | 0.555 | 0.845 | 0.851 | 0.546 | 0.400 | 0.715 | 0.018 | 0.026 |
| **Patents and Human Capital** | | | | | | | | |
| School Enrollment Secondary‡ | 0.013*** | | | | 0.022*** | | | |
| | (0.002) | | | | (0.004) | | | |
| RnD Expenditure (% GDP) | | 0.559*** | | | | 0.298 | | |
| | | (0.132) | | | | (0.186) | | |
| RnD Workers (per million) | | | 0.0012*** | | | | 1.004e-4 | |
| | | | (0.0002) | | | | (3.26e-4) | |
| Adj. $R^2$ | 0.715 | 0.393 | 0.658 | | 0.195 | 0.079 | 0.061 | |
| **URBANIZATION** | | | | | | | | |
| Urban Population share | 0.021*** | | -0.040 | | 0.044*** | | 0.130*** | |
| | (0.004) | | (0.044) | | (0.004) | | (0.043) | |
| Urban Population share $^2$ | | | 0.0001 | | | | -0.0013** | |
| | | | (0.0001) | | | | (0.0007) | |
| Adj. $R^2$ | 0.418 | | 0.495 | | 0.698 | | 0.754 | |

Notes: Open = sum of exports and imports of final goods as a % of output; † as a % Manufacturing Exports; ‡: % gross measure, years missing (1998, 2004, 2005) were linearly interpolated.
Figures in ()s are bootstrapped standard errors. ***, ** and * denote significance respectively at the 1%, 5% and 10% level. Intercepts not reported in table for brevity.

## 4.4 Robustness

To examine the robustness of these outcomes we undertook a number of checks. We estimated our system under *all* forms of technical neutrality and with several different system estimators (**Table C.1**-**Table C.5**), examining likelihood, information and root mean square error criteria. In all cases, we found $\widehat{\sigma} > 1$ and almost always significantly so (and typically very precisely estimated at around $1.1 - 1.2$). This was also the cases when we statically inverted the system (**Figure F.1**). Since our estimated system is non-linear (and thus sensitive to the setting of the parameter initial conditions), Appendix E additionally systematically varied combinations of parameter initial conditions to ensure trust regions for the parameters. Again, the message is that the parameters found are indeed global maxima and are within economically meaningful regions.

# 5 A Growth Model Perspective

We now try to interpret our results in terms of a Solow-type model. Normally that model is used as a general device to assess convergence and balanced-growth issues, with the assumption of an unique equilibrium. However, one of the benefits of normalization coupled with our specific parameter estimates is that we can express this (otherwise essentially timeless) framework in time-specific terms, plus we show that we can also accommodate factor augmenting technical progress (and thus *non* BGP phenomena).

## 5.1 Preliminaries

We start by transforming production function (1) in terms of efficient labor units,

$$y = f(k) = y_z \left[ \pi_z \left( a \frac{k}{k_z} \right)^{\frac{\sigma-1}{\sigma}} + (1 - \pi_z) \right]^{\frac{\sigma}{\sigma-1}} \tag{5}$$

where $y = \frac{Y}{bN} \Leftrightarrow y_z = \frac{Y_z}{b_z N_z}$ and $k = \frac{K}{bN}$. With $s$ denoting the saving rate and the growth of labor force (population) $n = \frac{\dot{N}}{N}$, the key equation of motion is then,

$$\dot{k} = s y_z \left[ \pi_z \left( a \frac{k}{k_z} \right)^{\frac{\sigma-1}{\sigma}} + (1 - \pi_z) \right]^{\frac{\sigma}{\sigma-1}} - \left( n + \delta + \gamma_{\text{b}} \right) k \tag{6}$$

Equation (6) defines the change of capital intensity $k$ (in efficiency units) as the difference of investment, i.e. $sf(k)$, and the investment required to keep capital intensity constant, i.e., $(n + \delta + \gamma_{\text{b}})k$, at each level of $k$. The intersection of these schedules defines the steady-state capital intensity:

$$\dot{k} = 0 \Rightarrow k^* = \left[ \frac{1 - \pi_z}{\left( \frac{n+\delta+\gamma_{\text{b}}}{s y_z} \right)^{\frac{\sigma-1}{\sigma}} - \pi_z \left( \frac{a}{k_z} \right)^{\frac{\sigma-1}{\sigma}}} \right]^{\frac{\sigma}{\sigma-1}} \tag{7}$$

After the transition dynamics determined by (6) have converged to the steady state and the set of parameters remain constant the economy is on its BGP, where $k = k^*$ and the capital-output ratio is constant.

## 5.2 Application

We utilize this framework to analyze China's economy over 1978-2012. In **Figure 8**, we present the concave and linear schedules in the rhs of (6) corresponding to the $\tau = \{0, z, T\}$ parameter set (laid out in **Table 3**). Their intersection in the three panels, indicated by $k^*_\tau$, represent temporal equilibriums conditional on prevailing parameter values. Actual outcomes are denoted $A_\tau$. To keep the framework implicitly timeless, we treat parameters, including $a$, as temporarily constant. In reality, however, as long as the rate of capital augmentation varies in-sample, it levers the saving function upwards around its fixed hinge point in the vertical axis.[33]

**TABLE 3: PARAMETER VALUES FOR GRAPHICAL ANALYSIS**

| Parameter | Value | Description |
|---|---|---|
| $t_0, t_z, t_T$ | $1978, 1995, 2012$ | Discreet Times Windows† |
| $n_0$ , $n_z$ , $n_T$ | $0.020,\ 0.010,\ 0.004$ | Population Growth Rate |
| $s_0$ , $s_z$ , $s_T$ | $0.304,\ 0.365,\ 0.465$ | Savings Rate |
| $s_z y_z / k_z$ | $0.154$ | Model ratio |
| $\delta$ | $0.060$ | Depreciation Rate |
| $\pi_z$ | $0.508$ | Capital Income Share |
| $\widehat{\gamma}_{b,0}$, $\widehat{\gamma}_{b,z}$, $\widehat{\gamma}_{b,T}$ | $0.056, 0.045, 0.042$ | Labor Saving Technical Growth |
| $\widehat{a}_0$, $\widehat{a}_z$, $\widehat{a}_T$ | $0.834,\ 1,\ 1.638$ | Capital Saving Technical Level |
| $k_0$, $k_z$, $k_T$ | $0.118,\ 0.220,\ 0.580$ | Capital Intensity in Labor Efficiency units |
| $\widehat{\sigma}$ | $1.2$ | Elasticity of Substitution |

Note: † In other words, first-sample, normalized, and end-sample values.

From figure 8, we note the following:

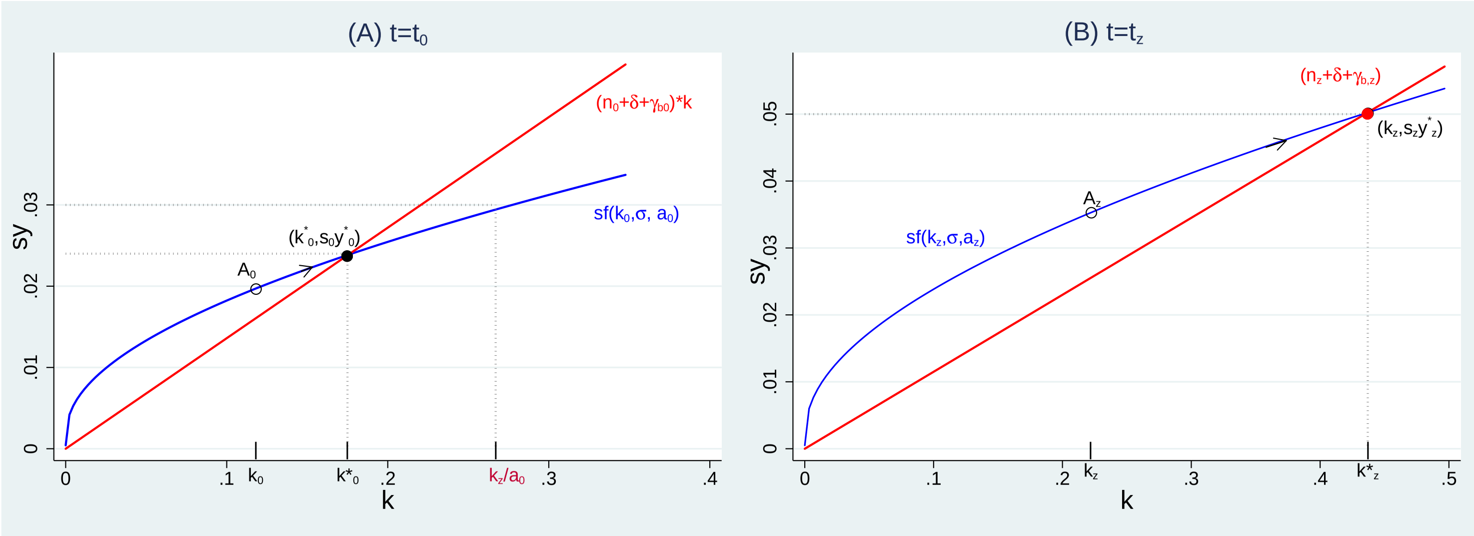
1. All points of $s_\tau f(k, a_\tau)$ moved upwards reflecting (mainly) the rise of capital saving technical change, as well as the rise in the saving rate.[34]
2. Meanwhile, ray $\left(n_\tau + \delta + \gamma_{b,\tau}\right) k$ flattens. This reflects a deceleration in the labor force and in labor saving technical change.
3. Consequently, the intersection points of the schedules in **Panels A-C** have moved continuously northeast.
4. These movements in the temporary equilibrium points are, in both absolute and relative terms, markedly larger than the movements of the actual economy on investment schedules (given by $\mathbf{A_0}$, $\mathbf{A_z}$ and $\mathbf{A_T}$).

[33] With $\sigma > 1$ the hinge point on the vertical axis equals,

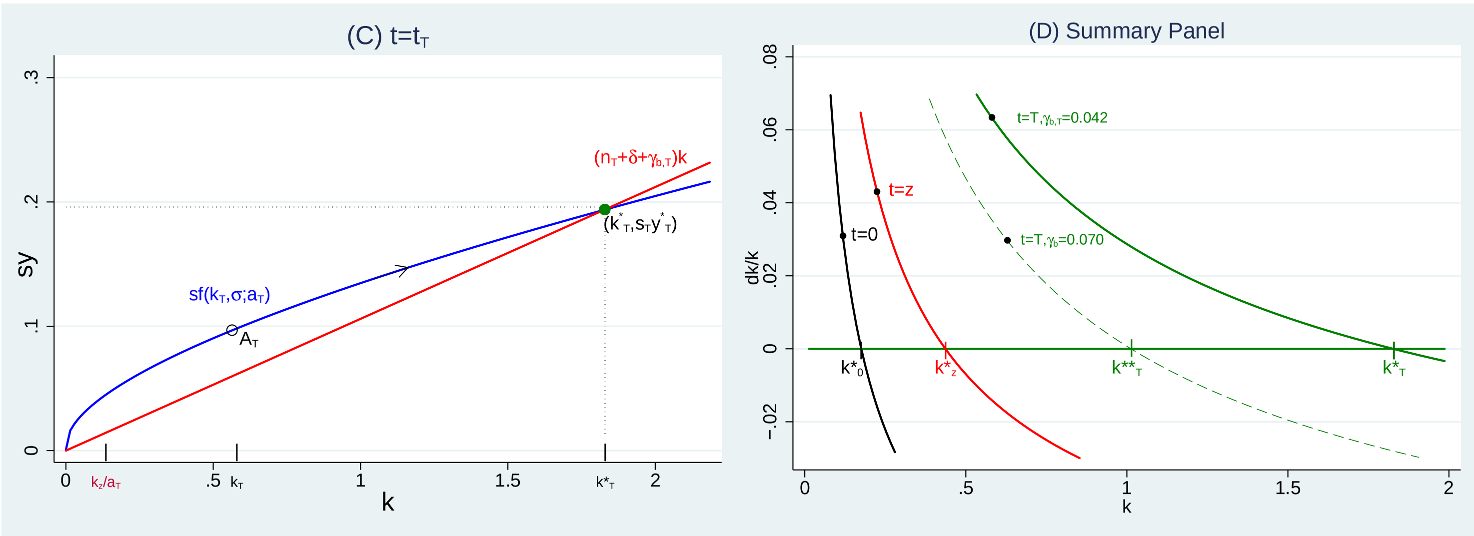
$$\lim_{k \to 0} \left( s y_0 \left[ \pi_z \left( a \frac{k}{k_z} \right)^{\frac{\sigma-1}{\sigma}} + (1 - \pi_z) \right]^{\frac{\sigma}{\sigma-1}} \right) = s y_z (1 - \pi_z)^{\frac{\sigma}{\sigma-1}} > 0 \quad \perp \quad a.$$

[34] This can be seen in the substantial widening of the scales of the axes when moving from **Panel A** to **B** and further to **C**.

## FIGURE 8: DYNAMIC GROWTH OUTCOMES




Note: In **Panel A** the horizontal line ($sy = 0.3$) intersecting the vertical line ($\mathbf{k = k_z/a_0}$) denotes the point where functions $sf(k; a_0)$ for all $\forall\sigma \in [0, \infty)$ have a common tangent. In **Panel A-C**, with $sf(k, \sigma, a_t)$, $\sigma = \widehat{\sigma} = 1.2$, as estimated.



This last aspect is apparent from **Panel D** which plots the implied dynamics of the growth of effective capital intensity. This shows how $\dot{k}/k$ has *risen* from $3.1\%$ to $6.3\%$, *instead of decreasing as one would expect if capital intensity was converging to a fixed steady state*. At the same time, the distances $k^*_\tau - k_\tau$ have widened (i.e., $k^*_T - k_T > k^*_z - k_z > k^*_0 - k_0$). Hence, although the economy has been moving towards the steady-states, these equilibrium points have moved away even faster reflecting parameter changes (especially, in $a$). This suggests that on current trends, rather than slowing down (to some given steady state), there appears to be ample room for China to grow in the medium term.

Movements in temporary equilibrium points will continue as long as capital saving technical change proceeds and, thereby, that equilibrium is never attained. Instead, eventually the economy may move to the regime of 'perpetual growth' (see **Section 6.2** below).

However, if capital-saving technologies stopped growing, there would be an abrupt $\approx 2$ per cent drop in the TFP growth contribution.[35] In converging to the equilibrium $k^*_T$ the growth of output per capita would decelerate further to the balanced growth rate of $4.2\%$ per annum. Accordingly that growth profile would be well below the present target growth rate of about $6.5 - 7\%$ set by the Chinese government. However, to compensate the absence of capital saving technical change (and better in line with the official growth target) labor saving technical change could accelerate and maintain fast TFP growth.

Therefore **Panel D** presents an alternative equilibrium $k^{**}_T = 1.013$ corresponding to a $7\%$ annual growth rate of labor saving technical change. What is happening here is that the resulting steepening of the ray $(n + \delta + \gamma_b)k$ brings the equilibrium point markedly closer to the actual realization of the economy in 2012. As shown in Panel D we see also that the growth of capital intensity starts its adjustment from the $3.5\%$ annual rate to zero when related to equilibrium $k^{**}_T$ as opposed to the $6.3\%$ growth rate when related to equilibrium $k^*_T$. The output growth implied by (8) (see section 4.4) in turn, starts its adjustment from $9\%$ to the balanced growth rate of $7\%$ (as opposed to from $7.8\%$ to $4.2\%$ percent when related to the equilibrium $k^*_T$).

## 6 The Elasticity of Substitution and Growth

Standard analysis identifies factor accumulation and TFP growth as the drivers of growth. Yet, in our context we can highlight another influence. As demonstrated by La Grandville and Solow [2006], the *normalized* CES production function (5) is a general mean of $a\frac{k}{k_z}$ and 1, of order $p = \frac{\sigma-1}{\sigma}$. A general mean is an increasing function of its order. Accordingly, there is a positive relation between output per head and the size of substitution elasticity. A direct implication of this is that $\dot{k}/k$ in (6), defining transitional dynamics, also depends positively on $size\{\sigma\}$, i.e. $\frac{\partial(\dot{k}/k)}{\partial\sigma} > 0$.

This is also true for the growth of per capita production. Output growth is deter-

[35] Also (8) in Section 6 implies $2.2\%$ growth difference when $\gamma_a$ in (8) alternatively equals $0.038$ or $0$.

mined recursively to (6) by,

$$\frac{\dot{y}}{y} = g\left(\sigma\right) \left. \frac{\dot{k}}{k} + \gamma_{\text{a}} \right) \tag{8}$$

where $g\left(\sigma\right) = \frac{\pi_z}{\pi_z + (1-\pi_z)\left(a\frac{k}{k_z}\right)^{\frac{1-\sigma}{\sigma}}}$. Differentiating (8) wrt $\sigma$ gives,

$$\frac{\partial(\dot{y}/y)}{\partial\sigma} = g(\sigma)\frac{\partial(\dot{k}/k)}{\partial\sigma} + \left. \frac{\dot{k}}{k} + \gamma_{\text{a}} \right) \frac{\partial g(\sigma)}{\partial\sigma} > 0 \tag{9}$$

With $\dot{k}/k > 0, \gamma_{\text{a}} \geq 0$ both terms on the rhs of (9) are positive and, hence, the growth rate of output per capita also depends positively on $size\{\sigma\}$.[36] In other words, the higher is the aggregate elasticity, the higher the economy will grow; this observation is in line with China's rapid economic growth in recent decades. This positive relationship can also be demonstrated graphically (see Appendix G).

## 6.1 Data Related Estimates of Positive Effects

Although La Grandville [1989] was the first to systematically explore the relationship between $\sigma$ and growth there is, to our knowledge, no actual empirical estimates of the size of this effect. We measure this conditional on the observed change of (effective) capital intensity. The measure addresses the question: how much lower/higher would activity be if $\widehat{\sigma} \neq 1.2$ and capital intensity rose from its mid-sample to end point level ($k_z = 0.22 \rightarrow k_T = 0.58$).

**Table 4** shows that the effects on relative output differences are asymmetric; the marginal gains in output lessen the more $\sigma > \widehat{\sigma}$ and marginal losses amplify as $\sigma < \widehat{\sigma}$. Hence, in evaluating the elasticity-growth nexus it is essential to define the point of comparison. By international standards, China's aggregate substitution seems high (roughly double of that estimated for many aggregate developed economies, Chirinko and Mallick [2017]; Chirinko [2008]: $0.5 - 0.7$). In comparison to such levels, an substitution elasticity of $1.2$ would imply that the observed rise in capital intensity will result in $16.8 - 33.4$ per cent higher activity over this period.[37]

## 6.2 The Stability of Chinese Growth

The value of factor substitution can thus impart a level effect on production (and hence on transitory growth rates), but it can be shown that it may also have a bear-

[36] In (9) $\frac{\partial g(\sigma)}{\partial\sigma} = \frac{\pi_z(1-\pi_z)\left(a\frac{k}{k_z}\right)^{\frac{1-\sigma}{\sigma}} \ln\left(a\frac{k}{k_z}\right)}{\left(\pi_z + (1-\pi_z)\left(a\frac{k}{k_z}\right)^{\frac{1-\sigma}{\sigma}}\right)^2}\frac{1}{\sigma^2} > 0$, assuming $\frac{ak}{k_z} > 1$.

[37] Although we know that this growth took around 17 years, the measured GDP level differences can not be straightforwardly transformed into differences in average annual growth rates. That is, because, a lower output level implied by lower $\sigma$ would have implied lower investment and slower capital accumulation during transition period and, hence, it would have required a longer time for capital intensity to reach the level $0.58$. Anyway, we may think that the output gain of $17 - 33\%$ for $\sigma$ equalling $1.2$ instead of $0.7 - 0.5$ gives a reasonable lower bound for the estimate of the GDP effect over $1995 - 2012$. In terms of annual growth rates these figures correspond roughly around $1 - 2$ percentage points gain in annual growth rates.

**TABLE 4: OUTPUT RESPONSE WRT $\{\sigma\} - \widehat{\sigma}$ DEVIATIONS AS $k_z \to k_T$.**

| $\sigma$ | $\frac{\Delta y}{y}_{\mid k_z \to k_T}$ | $\sigma$ | $\frac{\Delta y}{y}_{\mid k_z \to k_T}$ |
|---|---|---|---|
| $\infty$ | $-17.90$ | 1.0 | 4.40 |
| 2.0 | $-8.10$ | 0.8 | 11.60 |
| 1.5 | $-4.20$ | 0.7 | 16.80 |
| **1.2** | **0.00** | 0.5 | 33.40 |

Note: This table calculates using the formula:
$\frac{\Delta y}{y}_{\mid k_z \to k_T} = 100 \left[ \frac{f(a_T k_T \mid \widehat{\sigma = 1.2})}{f(a_T k_T \mid \{\sigma\})} - 1 \right].$

ing on the stability of medium and longer run growth. This aspect takes on relevance since we know China is not on an aggregate BGP.

Since Solow [1956], Pitchford [1960], La Grandville [1989] it is known that a sufficiently high value of the substitution elasticity (necessarily above unity) has the potential to generate *perpetual growth* of per-capita output (by curtailing diminishing returns). Similarly, a sufficiently low value (necessarily below unity) may drive the size of the economy towards zero.

Recalling (5), the Chinese economy can be characterized as if adjusting towards a temporary equilibrium that, however, reflecting (mainly) shifts in capital saving technical change, are moving away. The existence of 'temporary' equilibria implies that, although $\widehat{\sigma} > 1$, the economy is not, at least yet, in a perpetual-growth regime. The movement of the economy towards a constantly shifting equilibrium, however, raises the question of whether it is possible that perpetual growth *will become* achievable. Following La Grandville [1989] and Klump and Preissler [2000], we start by presenting conditions for the two disequilibrium regimes (perpetual growth, degenerative output per capita); in our case though we additionally take into account normalization and the role of the capital saving technical change.

## 6.3 Threshold Elasticity

Regarding perpetual growth we can derive an expression for the relevant threshold elasticity, $\sigma^*$. Perpetual growth (resp., convergence to zero) requires that with $k \in (0, \infty)$ the slope of the investment schedule $sf(k)$ lies above (below) the ray $(n + \delta + \gamma_b)\, k$ defining the required level of investment for constant capital intensity. This implies the following condition for the existence of permanent growth,

$$\lim_{k \to \infty} s f'_{\mid \sigma > 1}(k) = \mathcal{S} \pi_z^{\frac{1}{\sigma - 1}} \geq \mathcal{R} \tag{10}$$

where $\mathcal{S} = \pi_z s \frac{y_z}{k_z} a > 0$ and $\mathcal{R} = n + \delta + \gamma_b > 0$.[38] Similarly for $\sigma < 1$ we have the condition for output per capita falling to zero:

$$\lim_{k \to 0} s f'_{|\sigma<1}(k) = \mathcal{S} \pi_z^{\frac{1}{\sigma-1}} \leq \mathcal{R} \tag{11}$$

Note $\lim_{k\to\infty} f'_{|\sigma>1} = \lim_{k\to 0} f'_{|\sigma<1}$.[39] Hence, (10) and (11) imply the *same* expression for threshold elasticities. However since our interest is in the possibility of perpetual growth with $\sigma > 1$ we write its sign dependencies accordingly:[40]

$$\sigma^* \left( \underbrace{n, \delta, \gamma_b}_{+}, \underbrace{\pi_z, s, y_z/k_z, a}_{-} \right) \in (-\infty, \infty) = 1 - \log \pi_z / \log \left( \frac{\mathcal{S}}{\mathcal{R}} \right) \tag{12}$$

**Table 5** shows that at $t_0$, with $\sigma_0^* = 0.24$, there would be a disequilibrium regime of continuously falling income if $\sigma \in [\sigma_0^*, 1)$. By contrast, at time $t_z$ we would have $\sigma > \sigma_z^* < 0 = -0.91$: there exist neither disequilibrium regimes, i.e. $\forall \sigma \geq 0, k \to k^*$ and the economy converges towards the BGP. With the $t_T$ parameter set, there exists a finite above-unity threshold elasticity for permanent growth if $\sigma \geq \sigma_z^* = 2.47$.[41]

**TABLE 5: THRESHOLD ELASTICITIES AND THEIR DYNAMIC OUTCOMES**

| $\tau$ | $\sigma_\tau^*$ | Inequality | | | Outcome |
|---|---|---|---|---|---|
| $t_0$ | $0.24$ | $\mathcal{S} < \mathcal{R}$ | if $\sigma \in [0.24, 1)$ | $\rightarrow$ | Disequilibrium |
| $t_z$ | $-0.91$ | $\mathcal{S} < \mathcal{R}$ | if $\sigma > \sigma^* < 0$ | $\rightarrow$ | Convergence |
| $t_T$ | $2.47$ | $\mathcal{S} > \mathcal{R}$ | if $\sigma \in [2.47, \infty)$ | $\rightarrow$ | Permanent Growth |

### 6.3.1 Could $\sigma^* \rightarrow_+ \widehat{\sigma}$ ?

The Chinese economy does not therefore reside in either disequilibrium region. However $2.47$ (i.e., $\sigma^*_{\tau=T}$) is by no means an unreasonable value for an economy's aggregate substitution. Moreover, given that outside the steady state $\sigma^*$ is a function of time, the threshold elasticity may under some circumstances intersect our given estimate, $\widehat{\sigma}$, implying that the Chinese economy (rather than structurally slowing down) enters a perpetual growth regime.

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[38] Also $\mathcal{S}$ has a clear interpretation; it is the slope of the linear investment function $s y_z [\pi_z a \frac{k}{k_z} + (1 - \pi_z)]$, implied by (5) when $\sigma \to \infty$. Since $\partial \pi_z^{\frac{1}{\sigma-1}} / \partial \sigma > 0$, then with $\sigma > 1$, $\mathcal{S}$ is the maximum of the slope $\mathcal{S} \pi_z^{\frac{1}{\sigma-1}}$ with $\infty \geq \sigma > 1$. Now it is also clear that, if $\mathcal{S} < \mathcal{R}$, a finite $k^*$ always exists and, hence, no disequilibrium region of perpetual growth exists.

[39] La Grandville [2016] labeled this the Pitchford [1960] constant.

[40] Thus $\sigma^*$ is determined not just by conventional deep parameters like savings and population but also the average state of development (as captured by $y_z/k_z$) as well as non-BGP effects (i.e., the presence of capital saving technological change).

[41] This evolution in $\sigma^*$ reflects the continuous rise in marginal saving $s f'(k)$ ($s$ and especially $a$ have risen) on one hand, and the decrease of the slope of the ray $(n + \delta + \gamma_b) \cdot k$ on the other ($n, \gamma_b$ fell).

How realistic is this? Recalling the underset derivatives in (12), we observe the following discussion points:

- Savings. Will savings behavior continue? High savings likely reflect the importance of the internal financing by non-SOEs mirroring underdeveloped financial markets and financial repression (keeping the effective price of capital high). On households' side, it also thought to reflect a limited public safety net, family planning policies, marriage dynamics, worsening income inequality etc. Rapid income growth has enabled a larger portion of households to start accumulating savings for retirement, boosting the aggregate rate. Eventually, however, the increasing share of retirees begin dis-saving and $s$ settles down to a lower level. Likewise, we have the continued decline of the share of SOEs and thus easier access to private credit. This would, ceteris paribus, move the saving function downwards and $k^*$ leftwards.

- Capital Saving Technologies.It is straightforward to verify that $\lim_{a\to\infty} \sigma^* \to 1$. Hence, corresponding to any $\sigma > 1$ , there must exist a finite $a^*$ the attainment of which moves the economy to the perpetual growth regime. Based on (10) it is,

$$a^* = \frac{n + \delta + \gamma_b}{s\frac{y_z}{k_z}} \pi_z^{\frac{\sigma}{1-\sigma}} \; , \; \partial a^* / \partial \sigma < 0 \tag{13}$$

  This in turn raises the question of how high $a^*$ should be and how long it would take to move to the regime of perpetual growth corresponding to $\widehat{\sigma} = 1.2$. Using $\tau = T$ parameters set (13) yields $a^* = 30.5 \gg a_{\mathrm{T}} = 1.64$. If the capital saving technical change continued at the (2012) growth rate of $\approx 3.7\%$, it would take 79 years.

  Hence, this extrapolated regime shift is not a matter for the foreseeable future. Moreover, before that, there may be changes in technical biases, and in the other parameters in (13). Finally, though, a continued rise, ceteris paribus, in $a$ implies that the labor income share will also move below its recent level ($46\%$ in 2012, FoF statistics), which by international comparison is already low.

- Technical bias. According to our results, labor and capital saving technologies are, respectively, slowing down and accelerating. Moreover, recalling table 2, there appears to be a plausible narrative behind this. Future paths are inevitably less clear: biases in technical change reflect a complex interplay of different forces: relative factor scarcity and relative prices, profitability (as reflected in the strength of 'market' and 'price' effects), state dependence in technological choices, political economy constraints, sectoral evolutions, the pace and nature of frontier innovations etc. In a BGP all technical progress though is labor saving reflecting that in an open economy labor is essentially the constraining factor.

  Specifically, Chinese financial markets are developing, lowering the real price of capital (recall figure 3) and the stock of labor resources in inefficient use are depleting (coupled with stabilizing population). Hence, we might expect (subject to consumer preferences, and home and foreign demand patterns) labor to turn to the relatively more scarce factor thus reducing the incentives for the capital saving technical change.[42]

– Labor Force. If the trend decline in labor force continues, $\mathcal{R}$ becomes less steep (ceteris paribus), moving $k^*$ rightwards, and lowering $\sigma^*$. The relaxation of the one-child policy in 2015 holds out the possibility of stabilizing or even reversing the decline, although many doubt this outcome [Whyte et al., 2015]. However, if modest population growth intensives educational attainment efforts, as elsewhere in Asia, the effect could generate an associated offsetting increase in labor-augmenting technical progress.

## 7 Optimal Savings Rate

So far we have kept savings exogenous. Undoing that assumption makes sense given China's unusually high and rising savings ratio (its so-called 'Savings Puzzle'). Whether observed savings mimics its social optimum, moreover, is a natural question in growth theory from Ramsey onwards.

We use the Ramsey-Cass-Koopmans (RCK) framework. The novelty here is (i) as before, we have the entire framework crafted in normalized form facilitating intertemporal comparisons and (ii) we have an estimated and fully specified factor saving CES production framework upon which we can fashion the analysis. Note, we are trying to match the dynamic pattern of savings rather than its level; the Golden Rule will in any case produce a savings rate around the capital income share (fortuitously close to China'actual realized savings).

As before, we define variables of interest in terms of per efficient unit of labor,

$$c = \frac{C}{Nb} \; ; \quad = \frac{cb}{y}\left(\equiv \frac{C}{Y}\right) \; ; \; \omega = \frac{y}{k}$$

Assume that a social planner maximizes the utility of the representative consumer,

$$\int_0^\infty \frac{(cb)^{1-\theta} - 1}{1-\theta} e^{-(\rho - n)t} dt \tag{14}$$

where $\rho > n$ is the rate of time preference, utility is of the constant relative risk aversion form, and $\theta > 0$ is the risk aversion parameter. Note that the savings rate is,

$$s = 1 - \psi \Rightarrow \dot{s} = -\dot{\psi}$$

[42] Moreover, La Grandville [2016] (chp. 7) shows that if factors are gross substitutes and there is permanent capital saving technical progress, the long-run growth path must have the property that the marginal product of capital is unbounded over time (which is not compatible with a competitive equilibrium).

Standard techniques yield the familiar consumption euler equation:

$$\frac{\dot{c}}{c} = \frac{1}{\theta}\left(f'(k) - \delta - \rho - \theta\gamma_{\text{b}}\right) \tag{15}$$

where $\frac{\dot{c}}{c} + \gamma_{\text{b}}$ and $f'(k)$, in our graphs below, can be replaced by their observed quantities. In what follows we assume $\theta = 1.5$[43] which, to preserve the equality of both sides in (15), yields $\rho = 0.02 + n$.

Moreover, when production is defined by equation (5), the conventional intertemporal utility / profit maximizing procedure (under the resource and no Ponzi game constraints) results in the two differential equation system that defines the dynamics of the consumption rate $\psi$ and the output-capital ratio $\omega$[44]:

$$\frac{\dot{\psi}}{} = \pi(\omega)\left[\omega\left(\quad - \frac{\theta - 1}{\theta}\right) + (n + \delta + \gamma_{\text{b}} - \gamma_{\text{a}})\right] - \frac{\rho + \delta + \theta\gamma_{\text{b}}}{\theta} \tag{16}$$

$$\frac{\dot{\omega}}{\omega} = \left[\pi\left(\omega\right) - 1\right]\left[\omega(1 - \psi) - (n + \delta + \gamma_{\text{b}})\right] + \pi(\omega)\gamma_{\text{a}} \tag{17}$$

Using the fact that with the normalized CES, the capital income share is defined by $\pi(\omega) = \frac{kf'(k)}{f(k)} = \pi_z\left(a\frac{\omega_z}{\omega}\right)^{\frac{\sigma-1}{\sigma}}$, we can derive the "steady state",

$$\frac{\dot{\psi}}{} = 0 \Rightarrow \quad = \frac{\theta - 1}{\theta} + \frac{\rho + \delta + \theta\gamma_{\text{b}}}{\theta\pi_z(\omega_z a)^{\frac{\sigma-1}{\sigma}}}\Bigg)\omega^{-\frac{1}{\sigma}} - \frac{n + \delta + \gamma_{\text{b}} - \gamma_{\text{a}}}{\omega} \tag{18}$$

$$\frac{\dot{\omega}}{\omega} = 0 \Rightarrow \psi = 1 - \frac{n + \delta + \gamma_{\text{b}}}{\omega} + \gamma_{\text{a}}\frac{\pi_z\left(\omega_z a\right)\omega^{\frac{1-\sigma}{\sigma}}}{\pi_z\left(\omega_z a\right)\omega^{\frac{1-\sigma}{\sigma}} - 1} \tag{19}$$

## 7.1 Phase Diagram Analysis

We can proceed to represent these two schedules in phase diagrams and identify the equilibrium and the potential stability of the adjustment path. It is worth stressing that the intersection point (if it exists) of schedules (18)-(19) can be interpreted as the steady state level of $\omega$ and $\psi$ iff $\gamma_{\text{a},\tau} = 0, \forall t \geq \tau$.

Moreover, note, we have several *time varying* parameters (e.g., $n_0 \gg n_T$). The effect of this is that the equilibrium is no longer unique; instead the loci shift around, as does their intersection. Essentially, the only way to show that a time-varying phase system is stable is to find a Lyapunov function that holds at all times. This is generally very difficult. Accordingly, we try something simpler, and potentially more instructive.

We first study the movement of the steady state ($\gamma_{\text{a}} = 0$) corresponding to $a$ values over $\tau = t_0, t_z, t_T$. The phase diagrams of **Figure 9** show saddle-path stability, with

[43] This parameter is typically considered to lie in a 1-3 range.

[44] Note, for the capital-saving component, we deliberately express the system in terms of $a$ rather than $\gamma_{\text{a}}$ in order to consider systems embodying deviations from balanced growth.

the area between the loci $d\psi/dt = 0$ and $dw/dt = 0$ defining the saddle path quadrants; the convergence must start from these quadrants in order for convergence to the steady state. The pattern of phase diagram arrows imply that the stable-arm is downward sloping: so with $\omega > \omega^*$ the consumption rate (saving rate) should rise (decrease) when the economy converges to the steady state.

The equilibrium and actual data points are respectively indicated by $\omega^*$, $\psi^*$ and circles labelled $s_0$, $s_z$, $s_T$ (reflecting the realized savings rates). It is striking to note that the $\omega, \psi$ observations in the initial and normalization points (**Panels A and B**) are located *above* the stable arm. This is un-surprising, because unlike the equilibrium characterization, the growth of capital saving technologies is non zero which effects the locations of actual observations in the diagrams. Notwithstanding, for those first two time points, the dynamics of the schedules should result in rising consumption (equivalently, decreasing saving).

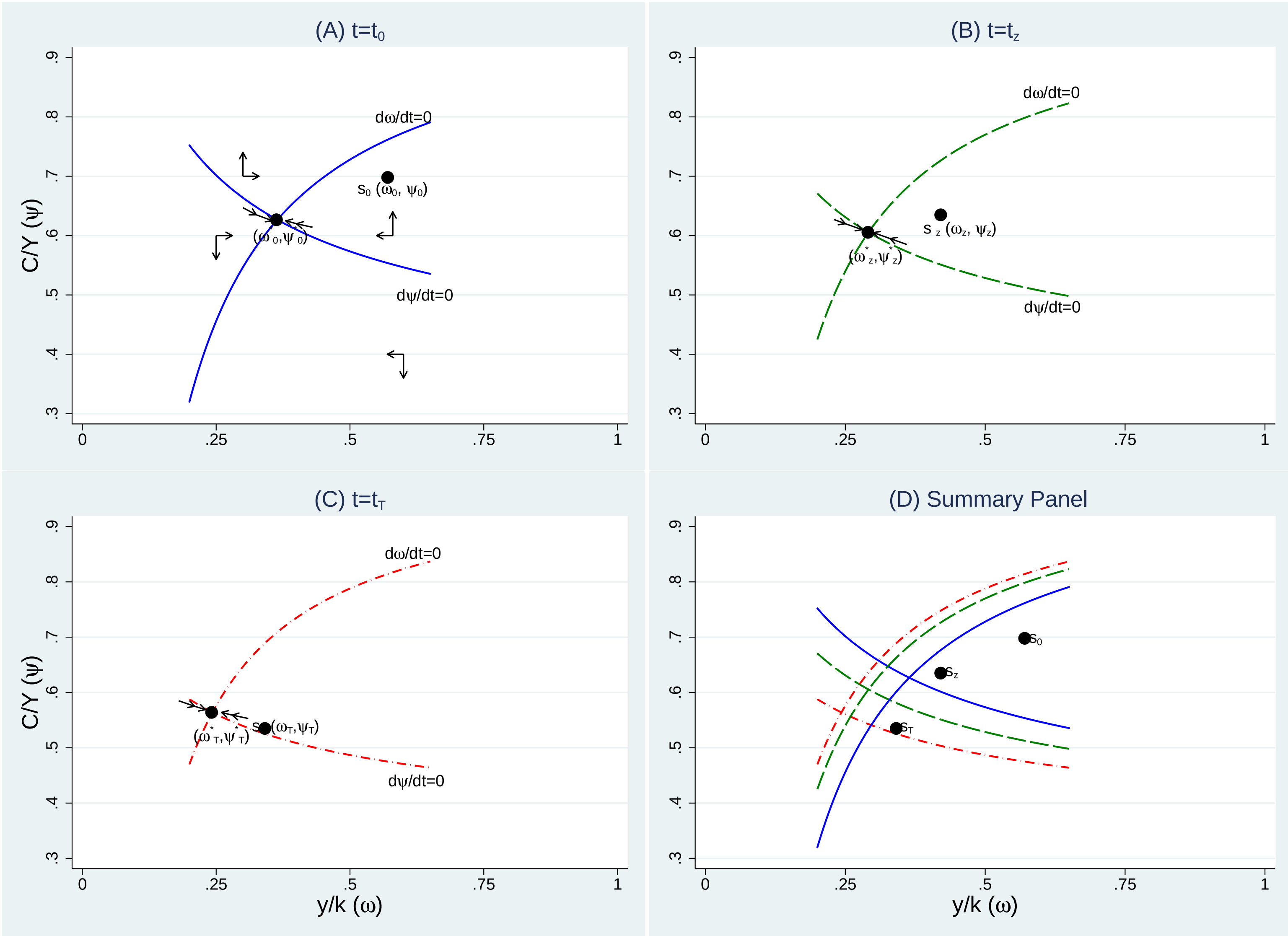
This, though, is *not* what happens. As summary (**Panel D**) shows the consumption rate fell through these two snapshot periods, resulting in a continuously increasing savings rate and a higher capital-output ratio. This happens to such an extent that, by 2012 (**Panel C**), the combinations are located practically on top of the stable arm. Thus our analysis mimics the increasing profile of realized savings as well as (approximately) their quantitative level.

What lay behind these movements? Their explanation can be found with reference to the values in table 3. The increasing level of capital saving technical development, as well as the falling rate of population moves the loci and their intersection points towards origin. This implies a rising steady-state saving rate and rising capital output ratio. Broadly taken, the observed increasing saving rate and the rising capital output ratio are consistent with capital saving technical change; accordingly, when capital saving technical change stops growing the consumption rate (the saving rate) should turn increasing (decreases) when the economy converges to the steady state.[45]

This analysis shows that with some plausible parameter values a simple RCK framework (albeit augmented with our estimates and the realized aggregate data) is able to match equilibrium and actual saving rates (dynamics and levels) and capital output ratios. We also find that the time profile of the equilibrium points as responses to the estimated level shifts of capital saving technologies resembles the developments of the saving rate and the inverse of the capital output ratio. Finally our analysis suggests that, if capital saving technologies continue as estimated in the data, then the equilibrium saving rate may decrease further although at a slower pace than that observed in the historical data. However, if the capital augmenting technical change stops growing, then the equilibrium saving rate implied by the model could be below the observed saving rate in the end of our sample. That is the case especially, if the acceleration of the labor augmenting technical change at least partly compensates the ending of the capital saving.

[45] **Figure F.3** shows the equivalent case for Cobb Douglas. There – given the constant ratio of the marginal to the average product of capital implicit under log-linear technology – the savings profile will be essentially flat (excepting fluctuations in neutral technical progress).

**FIGURE 9: TRANSITIONAL DYNAMICS OF CONSUMPTION AND CAPITAL**



# 8 Conclusions

We offered a macroeconomic assessment of China's great expansion since the Reform Period. Like Cheremukhin et al. [2015], we did so through a neoclassical perspective, though highlighting some neglected channels underlying its great growth pattern. Our analysis starts with the estimation of an aggregate production system. Consistent with the observation of declining labor income shares and a non balanced growth path, we use the framework of the CES production function with a factor saving technical change. This yields estimates of the elasticity of substitution and the rates of factor augmenting, time-varying technical change growth rates. Essentially we view the expansion of the Chinese economy (its growth, its balance, its savings behavior) through the lens of these two features, and hence can conclude on that basis.

- **The aggregate elasticity of substitution** Our first remark is that the aggregate elasticity robustly exceeds one. This is important. A high elasticity of substitution can prolong and accelerate extensive growth, and (following Hicks and de La Grandville) can also facilitate sectoral reallocations (such as we have seen in China in recent decades). We (re-)defined the threshold value of the substitution elasticity for 'perpetual growth' by controlling for normalization and persistent capital saving technologies; our estimated elasticity does not fall within the regions but still we estimated that the growth contribution of the high elasticity to be around $1-2\%$ higher growth than otherwise.

- **Technical progress is markedly time varying and factor augmenting** We tried many different methods to identify individual factor saving technology. When aggregated to an overall TFP measure, the series benchmarked well against other methodologies. Moreover, regarding technical progress, we estimate its growth contributions to be relatively high (around 30%), dispelling the notion that growth has been wholly extensive. How factor saving technologies change over time is a key ingredient in biased endogenous technical change. Although we do not model the ex ante determinants of the derived series, we nevertheless try to understand their time profile in reduced form. Under aggregate balanced growth there should be no capital saving components. In our case, however, we find that in the last half of the sample capital saving technologies dominate. This, coupled with gross complements, can help explain the declining labor share. Taking our derived paths for technical progress, we suggest that labor-saving technical progress has been driven by reallocation (e.g., urbanization) and external demand for labor-intensive exports. Capital saving technologies, by contrast, have been driven by hi-tech trade which upgraded their global value chain positions, as well as benefitting from R&D. A simple way to characterize this constellation is to say that, TFP-wise, China may have been moving from reallocation growth to an innovation economy.

- **Balanced Growth and Convergence** On the issue of balanced growth we demonstrate that the degree to which China's economy is outside the BGP has intensified over time; growth in capital intensity rose over time instead of decreasing as might be expected if the economy was converging to a fixed steady state. At the same time, the distances between equilibrium and actual capital intensity have widened. This suggests that ample room for continued expansion exists in the medium run.

- **Saving** Regarding savings, it is a challenge to represent such changes in technology and underlying parameters in a standard phase diagram. Accordingly, we analysed different points in the economy, consistent with the normalization philosophy. Our framework matches the upward expansion of savings well. Had we stayed in a standard Cobb-Douglas neutral technology world, this would not have been possible. Hence, we may conclude that, suitably modified, at the aggregate level the Chinese economic development looks quite compatible with optimal growth theory.

## References


Acemoglu, D. (2002). Directed technical change. *Review of Economic Studies 69*, 781–809.

Acemoglu, D. (2009). *Introduction to Modern Economic Growth*. MIT Press.

Bai, C.-E., C.-T. Hsieh, and Y. Qian (2006). The Return to Capital in China. *Brookings Papers on Economic Activity 37*(2), 61–102.

Bosworth, B. and S. M. Collins (2008). Accounting for Growth: Comparing China and India. *Journal of Economic Perspectives 22*(1), 45–66.

Box, G. and D. Cox (1964). An analysis of transformations. *Journal of the Royal Statistical Society 26, Series B*, 211–243.

Brandt, L., D. Ma, and T. G. Rawski (2014). From Divergence to Convergence: Reevaluating the History behind China's Economic Boom. *Journal of Economic Literature 52*(1), 45–123.

Brandt, L. and T. G. Rawski (2008). *China's Great Economic Transformation*. Cambridge University Press.

Branstetter, L. and N. Lardy (2008). China's Embrace of Globalization. In L. Brandt and T. G. Rawski (Eds.), *China's Great Economic Transformation*, pp. 633–682. Cambridge University Press.

Cheremukhin, A., M. Golosov, S. Guriev, and A. Tsyvinski (2015). The Economy of People's Republic of China from 1953. NBER Working Papers 21397, National Bureau of Economic Research, Inc.

Chirinko, R. S. (2008). $\sigma$: The Long and Short of It. *Journal of Macroeconomics 30*(2), 671–686.

Chirinko, R. S. and D. Mallick (2017). The Substitution Elasticity, Factor Shares, and the Low-Frequency Panel Model. *American Economic Journal: Macroeconomics 9*(4), 225–53.

Curtis, C. C. (2016). Economic reforms and the evolution of China's total factor productivity. *Review of Economic Dynamics 21*(C), 225 – 245.

Diamond, P. A., D. McFadden, and M. Rodriguez (1978). Measurement of the elasticity of substitution and bias of technical change. In M. Fuss and D. McFadden (Eds.), *Production Economics, Vol. 2*, pp. 125–147. Amsterdam and North Holland.

Gancia, G. and F. Zilibotti (2009). Technological Change and the Wealth of Nations. *Annual Review of Economics 1*(1), 93–120.

Genç, M. and E. I. Bairam (1998). The Box-Cox Transformation as a VES Production Function. In E. I. Bairam (Ed.), *Production and Cost Functions*. Ashgate Press.

Growiec, J. (2013). A microfoundation for normalized CES production functions with factor-augmenting technical change. *Journal of Economic Dynamics and Control 37*(11), 2336–2350.

Hicks, J. R. (1932). *The Theory of Wages*. London: Macmillan.

Holz, C. A. (2013). Chinese statistics: Output data. *SCID Working Paper 473*.

Holz, C. A. (2014). The Quality of China's GDP statistics. *China Economic Review 30 (C)*, 309–338.

Hu, A. G. Z. and G. H. Jefferson (2008). Science and Technology in China. In L. Brandt and T. G. Rawski (Eds.), *China's Great Economic Transformation*, pp. 286–337. Cambridge University Press.

Jones, C. I. and J. C. Williams (2000). Too Much of a Good Thing? The Economics of Investment in R&D. *Journal of Economic Growth 5*(1), 65–85.

Kee, H. L. and H. Tang (2016). Domestic Value Added in Exports: Theory and Firm Evidence from China. *American Economic Review 106*(6), 1402–1436.

Klump, R. and O. de La Grandville (2000). Economic growth and the elasticity of substitution: Two theorems and some suggestions. *American Economic Review 90*(1), 282–291.

Klump, R., P. McAdam, and A. Willman (2007). Factor Substitution and Factor Augmenting Technical Progress in the US. *Review of Economics and Statistics 89*(1), 183–92.

Klump, R., P. McAdam, and A. Willman (2012). The Normalized CES Production Function: Theory And Empirics. *Journal of Economic Surveys 26*(5), 769–799.

Klump, R. and H. Preissler (2000). CES production functions and economic growth. *Scandinavian Journal of Economics 102*(1), 41–56.

Kroeber, A. R. (2016). *China's Economy*. Oxford University Press.

Krugman, P. (1994). The myth of Asia's miracle. *Foreign Affairs 73*(6), 62–78.

Krugman, P. (2013). Hitting China's Wall. (Available at http://www.nytimes.com/2013/07/19/opinion/krugman-hitting-chinas-wall.html), New York Times.

La Grandville, O. de. (1989). In Quest of the Slutzky Diamond. *American Economic Review 79*, 468–481.

La Grandville, O. de. (2016). *Economic Growth: A Unified Approach*. 2nd edition, Cambridge University Press.

La Grandville, O. de. and R. M. Solow (2006). A Conjecture On General Means. *Journal of Inequalities in Pure and Applied Mathematics 7*(3).

León-Ledesma, M. A., P. McAdam, and A. Willman (2010). Identifying the Elasticity of Substitution with Biased Technical Change. *American Economic Review 100*(4), 1330–1357.

León-Ledesma, M. A., P. McAdam, and A. Willman (2012). Aggregation, the Skill Premium and the Two-Level Production Function. In O. de La Grandville (Ed.), *Economic Growth and Development (Frontiers of Economics and Globalization, Volume 11)*, pp. 417–436. CUP.

León-Ledesma, M. A., P. McAdam, and A. Willman (2015). Production technology estimates and balanced growth. *Oxford Bulletin of Economics and Statistics 77*(1), 40–65.

León-Ledesma, M. A. and M. Satchi (2018). Appropriate Technology and the Labour Share. *Review of Economic Studies* (forthcoming).

Maddison, A. (2007). *Chinese Economic Performance in the Long Run.* Development Centre Studies, OECD.

Mućk, J. (2017). Elasticity of substitution between labor and capital: robust evidence from developed economies. Working papers no. 271, National Bank of Poland. Available at www.nbp.pl/publikacje/materialy_i_studia/271_en.pdf.

OECD (2000). *National Accounts for China. Sources and Methods.* Organisation for Economic Cooperation and Development, Paris.

Page, J. (1994). The East Asian Miracle: Four Lessons for Development Policy. In *NBER Macroeconomics Annual 1994, Volume 9*, NBER Chapters, pp. 219–282. National Bureau of Economic Research, Inc.

Pitchford, J. D. (1960). Growth and the elasticity of substitution. *Economic Record 36*, 491–504.

Qi, H. (2014). The Labor Share Question in China. *Monthly Review 65*(8).

Solow, R. M. (1956). A contribution to the theory of economic growth. *Quarterly Journal of Economics 70*(1), 65–94.

Song, Z., K. Storesletten, and F. Zilibotti (2011). Growing Like China. *American Economic Review 101*(1), 196–233.

Tian, X. and X. Yu (2012). The Enigmas of TFP in China: A meta-analysis. *China Economic Review 23*(2), 396 – 414.

Villacorta, L. (2017). Estimating country heterogeneity in capital-labor substitution using panel data. Available at https://sites.google.com/site/luccianovillacorta/.

Wen, Y. (2015). The Making of an Economic Superpower ? Unlocking China's Secret of Rapid Industrialization. Working Papers 2015-6, Federal Reserve Bank of St. Louis.

Whyte, M. K., W. Feng, and Y. Cai (2015). Challenging Myths About China's One-Child Policy. *The China Journal 74*, 144–159.

Yang, D. T., J. Zhang, and S. Zhou (2012). Why Are Saving Rates So High in China? In *Capitalizing China*, NBER Chapters, pp. 249–278. National Bureau of Economic Research, Inc.

Young, A. (1995). The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience. *Quarterly Journal of Economics 110*(3), 641–80.

Young, A. (2003). Gold into Base Metals: Productivity Growth in the People's Republic of China during the Reform Period. *Journal of Political Economy 111*(6), 1220–1261.

Yuhn, K.-h. (1991). Economic Growth, Technical Change Biases, and the Elasticity of Substitution: A Test of the De La Grandville Hypothesis. *Review of Economics and Statistics 73*(2), 340–46.

Zhu, X. (2012). Understanding China's Growth: Past, Present, and Future. *Journal of Economic Perspectives 26*(4), 103–124.

Zilibotti, F. (2017). Growing and Slowing Down Like China. *Journal of the European Economic Association 15*(5), 943–988.

# A Data Sources

## Table A.1: Detailed Description of Data

| Variables | Definitions | Sample | Source |
|---|---|---|---|
| **A. Gross Domestic Product** | | | |
| Real GDP | Billion Yuan (2000 Constant Prices) | 1960-2012 | World Bank |
| Nominal GDP | Billion Yuan | 1960-2012 | World Bank |
| Nominal GDP by Provinces | Income approach, Billion Yuan | 1952-2012 | National Bureau of Statistics |
| Real GDP per Capita | Billion Yuan (2000 Constant Prices) | 1960-2012 | World Bank |
| **B. Value added** | | | |
| Nominal Valued Added by Primary, Secondary and Tertiary Activities | Billion Yuan | 1952-2013 | National Bureau of Statistics |
| Real Valued Added by Primary, Secondary and Tertiary Activities | Index 1978=100 | 1978-2012 | National Bureau of Statistics |
| **C. Investment data** | | | |
| Real Gross Capital Formation | Billion Yuan (2000 Constant Prices) , National Account Data | 1961-2011 | World Bank |
| Nominal Gross Capital Formation | Billion Yuan | 1961-2012 | World Bank |
| Real Gross Fixed Capital Formation | Billion Yuan (2000 Constant Prices) | 1965-2011 | World Bank |
| Nominal Gross Fixed Capital Formation | Billion Yuan | 1965-2012 | World Bank |
| **D. Labor Data** | | | |
| Total Employment | 10,000 persons | 1952-2012 | National Bureau of Statistics |
| Employment by Primary, Secondary and Tertiary activities | 10,000 persons | 1978-2012 | National Bureau of Statistics |
| Employment by Urban/Rural sector | 10,000 persons | 1970-2012 | National Bureau of Statistics |
| Working Age Population | 1000 Persons | 1952-2012 | United Nations |
| Economical Active Population | 10,000 persons | 1952-2012 | National Bureau of Statistics |
| Total Population | 10,000 persons | 1970-2012 | National Bureau of Statistics |
| Population by Urban/Rual sector | 10,000 persons | 1970-2012 | National Bureau of Statistics |
| Compensation of Labor1 | Billion yuan, Total Provincial Data | 1978-2012† | National Bureau of Statistics |
| Compensation of Labor2 | Billion yuan, based on Flow of Funds Physical Transaction | 1992-2011 | National Bureau of Statistics |
| Compensation of Labor3 | Billion yuan, Input-Output Intermediate Use | 1992-2011‡ | National Bureau of Statistics |
| Total Wages | 100 Million Yuan, Employees in Urban Units | 1962-2012 | National Bureau of Statistics |
| Unit Labor Costs | Index 2000=100 | 1978-2012 | National Bureau of Statistics |

Note: † with break in 2008, ‡ only 8 data points available consistent with the publication of Input-Output tables.

## TABLE A.2: DETAILED DESCRIPTION OF DATA (CONT.)

| Variables | Definitions | Sample | Source |
|---|---|---|---|
| **E. Other data** | | | |
| CPI | year/year % chg | 2001-2013 | National Bureau of Statistics |
| Adjusted Gross Savings | % Gross National Income | 1982-2012 | World Bank |
| Lending Rate by Maturity (6 months, 1 year, 1-3 years, 3-5 years, longer than 5 years) | % per annum | 1991-2013 | PBoC |
| US Research and Development Expenditure | % of GDP | 1982-2013 | World Bank |
| China Research and Development Expenditure | % of GDP | 1996-2015 | World Bank |
| Researchers in Research and Development in China | Per Million People | 1996-2012 | World Bank |
| Researchers in Research and Development in US | Per Million People | 1996-2012 | World Bank |
| Patent Applications, Residents | Number | 1985-2015 | World Bank |
| Patent Applications, Nonresidents | Number | 1985-2015 | World Bank |
| Air Transport | Freight (Million Ton-Km) | 1974-2015 | World Bank |
| Railways, Goods Transported | Million Ton-Km | 1980-2015 | World Bank |
| Railways, Passengers Carried | Million Passenger-Km | 1980-2015 | World Bank |
| Import Content of Exports | % of Total Exports | 1996-2011 | based on World Input-Output Tables |
| School Enrollment Secondary | Thousand People | 1970 -2011 | World Bank |
| Urban Population Share | % of Total | 1960-2011 | World Bank |
| ICT Goods Exports | % of Total Goods Exports | 2000-2011 | World Bank |
| High-Technology Exports | Million US dollars | 1992-2011 | World Bank |
| ICT Goods Imports | % of Total Goods Imports | 2000-2011 | World Bank |
| Tariff Rate, most favored nation, all products | %, Weighted Mean | 1992-2011 | World Bank |
| Tariff Rate, most favored nation, manufacturing products | %, Weighted Mean | 1992-2011 | World Bank |
| Tariff Rate, most favored nation, primary products | %, Weighted Mean | 1992-2011 | World Bank |
| Electricity Production from Coal Sources | % of Total | 1971-2014 | World Bank |
| CO2 Emissions | Kt | 1960-2013 | World Bank |
| **F. Other institutions data on potential output and input factors** | | | |
| Physical Capital Stock | Million 2005 US dollars (Current PPPs) , | 1952-2011 | Penn Tables |
| Physical capital stock | Million 2005 US dollars (Constant 2005 National Prices ) | 1952-2011 | Penn Tables |
| Total Factor Productivity | Index USA=1 (Current PPPs) | 1952-2011 | Penn Tables |
| Total Factor Productivity | Index 2005=1, (Constant National Prices) | 1952-2012 | Penn Tables |
| Share of Labor Compensation in GDP | Current National Prices | 1952-2011 | Penn Tables |
| Human Capital Indicator | Index of Human Capital per Person, based on years of schooling | 1952-2011 | Penn Tables |
| Potential Output | Million 2005 US dollars at PPP, Volume | | |
| Output Gap | % of Potential Output | 1992-2012 | OECD |
| Productive Capital Stock | Volume, Billion Yuan) | 1990-2011 | OECD |
| Potential Employment | 1000 Persons | 1991-2012 | OECD |
| Trend Labor Efficiency | Volume, Index, 2005 US dollars at PPP) | 1992-2012 | OECD |
| NAIRU | % | 1991-2012 | OECD |
| Output Gap | % of Potential GDP | 1980-2013 | IMF |

## B Non-Linear Box-Cox Time-Varying Technical Progress Functions

Following recent theoretical discussion about possible biases in technical progress (e.g., Acemoglu [2002]), it is not clear that growth rates of technical progress components should always be constant. Following Klump et al. [2007], we model time-varying technological progress terms using a Box and Cox [1964] transformation (specified in normalized form).[46] This allows deterministic but time-varying technological progress terms where curvature or decay terms could be uncovered from the data in economically meaningful ways.

$$j = f(t; \gamma_J, \lambda_J) = t_z \frac{\gamma_J}{\lambda_J}[\tilde{t}^J - 1], \quad J = a, b \quad \text{and} \quad j = \log J \tag{B.1}$$

where $\widetilde{t} = \mathbf{t}/t_z$ and curvature parameter $\lambda_J \in \mathbb{R}$ determines the shape of the technical progress function. Note, the re-scaling of $\gamma_J$ and $t$ by the fixed point value $t_z$ in (B.1) allows us to interpret $\gamma_a$ and $\gamma_b$ directly as the rates of labor- and capital saving technical change at the fixed-point period, when $\widetilde{t} = 1$, independently from the same of parameter $\lambda_J$ (see equation B.3 below).

For $\lambda_J = 1$, technical progress functions are the (textbook) linear specification; otherwise they are exponential ($\lambda_j \in (0,1)$), log-linear ($\lambda_J = 0$) or hyperbolic functions in time ($\lambda_J < 0$). If $\lambda_J > 1$ then technical progress is rapidly expanding; although essentially at odds with an aggregate BGP it is not impossible to observe such a pattern in a particular data sample.

Asymptotically, function (B.1) would behave as follows:

$$\begin{aligned} &\lim_{t\to\infty} j \to \infty && \lambda_J \geq 0 \\ &\lim_{t\to\infty} j = -\tfrac{\gamma_J}{\lambda_J} t_z && \lambda_J < 0 \end{aligned} \tag{B.2}$$

$$\frac{\partial j}{\partial t} = \gamma_J \widetilde{t}^{\lambda_J - 1} \Rightarrow \begin{cases} \infty \text{ (as } t \to \infty) & \lambda_J > 1 \\ \frac{\partial j}{\partial t} = \gamma_J & \lambda_J = 1 \\ \frac{\partial j}{\partial t} = 0 & \lambda_J < 1 \end{cases} \tag{B.3}$$

This framework allows the data to decide on the presence and dynamics of factor saving technical change rather than it being imposed a priori by the researcher. If, for example, the data supported an asymptotic steady state, this would arise from the estimated dynamics of these curvature functions (i.e., labor saving technical progress becomes dominant (linear), that of capital absent or decaying).

[46] Note, the re-scaling of $\gamma_J$ and $t$ by the fixed point value $t_z$ in (B.1). This allows us to interpret $\gamma_J$ as the rate factor saving technical change at the fixed-point period: $\gamma_{J,z}$.

# C Full Sets of Estimation Results

## C.1 All results

We now show all results from our exercises. This includes the estimation of all neutrality forms over three different estimators: non-linear seemingly unrelated regression, feasible generalized non-linear least squares and the iterated feasible generalized non-linear least squares (which is asymptotically equivalent to maximum likelihood).

These estimators account for cross-equation parameter restrictions as well as cross correlated errors. Of the three, feasible generalized non-linear least squares is the one reported in the main text. We also used two and three stage non-linear least square estimators but suppressed them for brevity. They are however available on request and, qualitatively, are similar to the ones reported here. We used lags of output and capital and the labor input as instruments. 95% confidence intervals based on robust standard errors are presented below the parameter estimates.

Under the main tables, we present some diagnostics, the calculated log likelihood, information criteria and the root mean square error of the labor share equation (3), the capital share equation (4) and the CES production function (2). Under that, we test some relevant parameter constraints. As in the main text we work around three samples, where the labor share is calculated using provincial data (estimation column 1), where it is calculated on the flow-of-funds data (column 3) and where, for benchmarking, the provincial data source is estimated on the same shorted sample size as the flow of funds (column 2) and, finally, where the flow-of-funds data is backdated using the provincial data (column 4).

## TABLE C.1: SUMMARY ESTIMATES OF FACTOR SAVING CASES

| | Prov. Data | | FoF Data | FoF + Prov. |
|---|---|---|---|---|
| | 1978-2012 | 1992-2012 | 1992-2012 | 1978-2012 |
| | (1) | (2) | (3) | (4) |
| $\sigma$ | 1.204*** | 1.099*** | 1.174*** | 1.308*** |
| | {1.145:1.263} | {1.056:1.142} | {1.158:1.191} | {1.276:1.340} |
| $\gamma_b$ | 0.045*** | 0.013 | 0.034*** | 0.055*** |
| | {0.036:0.054} | {-0.057:0.084} | {0.026:0.042} | {0.053:0.058} |
| $\gamma_a$ | 0.020*** | 0.043 | 0.050*** | 0.014*** |
| | {0.010:0.030} | {-0.016:0.102} | {0.033:0.067} | {0.007:0.020} |
| $\lambda_b$ | 0.910*** | 1.285 | 0.622*** | 1.007*** |
| | {0.734:1.086} | {-14.041:16.612} | {0.413:0.831} | {0.919:1.094} |
| $\lambda_a$ | 1.959*** | 1.706 | 1.802*** | 2.312*** |
| | {1.210:2.708} | {-2.109:5.521} | {1.041:2.562} | {1.179:3.445} |
| $ll$ | 264.047 | 166.543 | 221.500 | 316.553 |
| $aic$ | -516.093 | -321.087 | -431.000 | -621.106 |
| $bic$ | -506.761 | -314.819 | -424.733 | -611.774 |
| $rmse(\varsigma_N)$ | 0.045 | 0.055 | 0.017 | 0.021 |
| $rmse(\varsigma_K)$ | 0.042 | 0.047 | 0.024 | 0.034 |
| $rmse(Y)$ | 0.031 | 0.028 | 0.023 | 0.031 |
| $\sigma = 1$ | [0.000] | [0.000] | [0.000] | [0.000] |
| $\gamma_b = \gamma_a$ | [0.009] | [0.657] | [0.197] | [0.000] |
| $\lambda_b = 1$ | [0.318] | [0.971] | [0.000] | [0.884] |
| $\lambda_a = 1$ | [0.012] | [0.717] | [0.039] | [0.023] |

Note: Numbers in parentheses indicates 95% confidence intervals, and those in squared brackets indicate probability values. Asterisks denotes significance level based on robust standard errors, where $^{***} < 0.01, ^{**} < 0.05, ^{*} < 0.1$. The respective normalized capital shares, $\pi_z$, for the Provincial (1978-2012), Provincial (1992-2012) and FoF (1992-2012) data are $0.508$, $0.527$ and $0.490$. The terms $ll$, $aic$ and $bic$ refer to the log likelihood, the Akaike and Bayesian information criteria, respectively, whilst $rmse(\varsigma_N)$, $rmse(\varsigma_K)$ and $rmse(Y)$ refer, respectively, to the root mean square error of the fitted values of equations (1)-(3).

## TABLE C.2: ESTIMATES: PROVINCIAL DATA

| | Harrod | | | Solow | | | Hicks | | | Augmenting | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS |
| $\sigma$ | 1.647*** | 1.622*** | 1.563*** | 1.080*** | 1.073*** | 1.071*** | 1.144*** | 1.128*** | 1.127*** | 1.153*** | 1.146*** | 1.204*** |
| | {1.330:1.964} | {1.520:1.724} | {1.470:1.656} | {1.058:1.103} | {1.053:1.093} | {1.052:1.090} | {1.101:1.187} | {1.094:1.162} | {1.097:1.157} | {0.877:1.428 } | {1.088:1.204} | {1.145:1.263} |
| $\gamma_b$ | 0.068*** | 0.068*** | 0.068*** | | | | | | | 0.034 | 0.034*** | 0.045*** |
| | {0.066:0.070} | {0.066:0.070} | {0.066:0.070} | | | | | | | {-0.045:0.114} | {0.018:0.049} | {0.036:0.054} |
| $\gamma_a$ | | | | 0.065*** | 0.065*** | 0.065*** | | | | 0.031 | 0.031*** | 0.020*** |
| | | | | {0.063:0.067} | {0.063:0.067} | {0.063:0.067} | | | | {-0.046:0.108} | {0.015:0.047} | {0.010:0.030} |
| $\gamma$ | | | | | | | 0.033*** | 0.033*** | 0.033*** | | | |
| | | | | | | | {0.033:0.034} | {0.032:0.034} | {0.032:0.034} | | | |
| $\lambda_b$ | 1.198*** | 1.131*** | 1.138*** | | | | | | | 0.924* | 0.835*** | 0.910*** |
| | {1.118:1.279} | {1.056:1.206} | {1.061:1.216} | | | | | | | {0.171:1.677} | {0.584:1.086} | {0.734:1.086} |
| $\lambda_a$ | | | | 1.144*** | 1.097*** | 1.012*** | | | | 1.611 | 1.680*** | 1.959*** |
| | | | | {1.026:1.261} | {0.982:1.212} | {0.897:1.127} | | | | {-0.030:3.252} | {1.108:2.251} | {1.210:2.708} |
| $\lambda$ | | | | | | | 1.217*** | 1.141*** | 1.013*** | | | |
| | | | | | | | {1.117:1.317} | {1.046:1.236} | {0.914:1.112} | | | |
| $\xi$ | 0.975*** | 0.984*** | 0.984*** | 0.981*** | 0.986*** | 0.994*** | 0.982*** | 0.989*** | 1.000*** | 0.963*** | 0.967*** | 0.972*** |
| | {0.960:0.991} | {0.968:1.000} | {0.968:1.001} | {0.973:0.989} | {0.979:0.993} | {0.988:1.000} | {0.974:0.989} | {0.983:0.995} | {0.994:1.005} | {0.948:0.978 } | {0.951:0.983} | {0.956:0.988} |
| $ll$ | 255.638 | 257.668 | 257.798 | 253.412 | 255.741 | 257.058 | 248.645 | 253.934 | 257.055 | 263.152 | 263.724 | 264.047 |
| $aic$ | -503.276 | -507.336 | -507.595 | -498.824 | -503.483 | -506.115 | -489.289 | -499.869 | -506.111 | -514.305 | - 515.448 | -516.093 |
| $bic$ | -497.055 | -501.115 | -501.374 | -492.602 | -497.261 | -499.894 | -483.068 | -493.647 | -499.889 | -504.972 | - 506.116 | -506.761 |
| $rmse(\varsigma_N)$ | 0.050 | 0.049 | 0.050 | 0.047 | 0.048 | 0.048 | 0.048 | 0.048 | 0.047 | 0.046 | 0.046 | 0.045 |
| $rmse(\varsigma_K)$ | 0.050 | 0.050 | 0.050 | 0.043 | 0.043 | 0.044 | 0.043 | 0.044 | 0.045 | 0.042 | 0.042 | 0.042 |
| $rmse(Y)$ | 0.031 | 0.033 | 0.033 | 0.029 | 0.029 | 0.034 | 0.029 | 0.030 | 0.038 | 0.029 | 0.030 | 0.031 |
| $\sigma = 1$ | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.277] | [0.000] | [0.000] |
| $\gamma_b = \gamma_a$ | – | – | – | – | – | – | – | – | – | [0.969] | [0.848] | [0.009] |
| $\lambda_b = 1$ | [0.000] | [0.000] | [0.000] | – | – | – | [0.000] | [0.004] | [0.791] | [0.843] | [0.198] | [0.318] |
| $\lambda_a = 1$ | – | – | – | [0.016] | [0.098] | [0.836] | – | – | – | [0.466] | [0.020] | [0.012] |

## TABLE C.3: ESTIMATES: PROVINCIAL DATA, 1992-2012

| | Harrod | | | Solow | | | Hicks | | | Augmenting | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS |
| $\sigma$ | 2.224*** | 2.132*** | 1.490*** | 1.096*** | 1.084*** | 1.019*** | 1.169*** | 1.145*** | 1.150*** | 1.105*** | 1.144*** | 1.099*** |
| | {1.183:3.266} | {1.914:2.351} | {1.405:1.574} | {1.058:1.133} | {1.050:1.118} | {1.009:1.028} | {1.100:1.238} | {1.088:1.203} | {1.107:1.193} | {0.739:1.471 } | {1.084:1.204} | {1.056:1.142} |
| $\gamma_b$ | 0.061*** | 0.058*** | 0.058*** | | | | | | | 0.004 | 0.035* | 0.013 |
| | {0.051:0.072} | {0.049:0.067} | {0.050:0.066} | | | | | | | {-0.177:0.184} | {0.000:0.071} | {-0.057:0.084} |
| $\gamma_a$ | | | | 0.062*** | 0.057*** | 0.059*** | | | | 0.058 | 0.025 | 0.043 |
| | | | | {0.052:0.072} | {0.046:0.068} | {0.051:0.067} | | | | {-0.122:0.239} | {-0.001:0.050} | {-0.016:0.102} |
| $\gamma$ | | | | | | | 0.031*** | 0.028*** | 0.024*** | | | |
| | | | | | | | {0.026:0.036} | {0.022:0.035} | {0.017:0.031} | | | |
| $\lambda_b$ | 1.557*** | 1.733*** | 1.768*** | | | | | | | 2.851 | 0.566 | 1.285 |
| | {1.122:1.992} | {1.318:2.148} | {1.369:2.168} | | | | | | | {-35.383:41.085 } | {-2.886:4.018} | {-14.041:16.612} |
| $\lambda_a$ | | | | 1.152*** | 1.376*** | 1.620*** | | | | 1.017 | 2.273 | 1.706 |
| | | | | {0.680:1.624} | {0.833:1.919} | {1.237:2.003} | | | | {-2.064:4.098} | {-0.403:4.949} | {-2.109:5.521} |
| $\lambda$ | | | | | | | 1.326*** | 1.532*** | 1.848*** | | | |
| | | | | | | | {0.867:1.785} | {0.957:2.107} | {1.039:2.658} | | | |
| $\xi$ | 0.977*** | 0.971*** | 0.965*** | 0.987*** | 0.991*** | 0.980*** | 0.987*** | 0.993*** | 1.006*** | 0.975*** | 0.972*** | 0.961*** |
| | {0.961:0.992} | {0.958:0.984} | {0.953:0.978} | {0.980:0.995} | {0.982:1.000} | {0.973:0.987} | {0.980:0.995} | {0.984:1.002} | {0.997:1.015} | {0.960:0.990 } | {0.958:0.985} | {0.948:0.974} |
| $ll$ | 161.173 | 163.046 | 164.268 | 157.578 | 159.265 | 161.605 | 154.035 | 157.232 | 158.755 | 163.268 | 165.502 | 166.543 |
| $aic$ | -314.345 | -318.091 | -320.536 | -307.156 | -310.530 | -315.209 | -300.071 | -306.463 | -309.510 | -314.536 | - 319.004 | -321.087 |
| $bic$ | -310.167 | -313.913 | -316.358 | -302.978 | -306.352 | -311.031 | -295.893 | -302.285 | -305.332 | -308.269 | - 312.736 | -314.819 |
| $rmse(\varsigma_N)$ | 0.058 | 0.058 | 0.064 | 0.054 | 0.055 | 0.078 | 0.054 | 0.055 | 0.054 | 0.054 | 0.055 | 0.055 |
| $rmse(\varsigma_K)$ | 0.052 | 0.052 | 0.057 | 0.046 | 0.047 | 0.065 | 0.047 | 0.048 | 0.048 | 0.046 | 0.047 | 0.047 |
| $rmse(Y)$ | 0.023 | 0.024 | 0.026 | 0.023 | 0.023 | 0.026 | 0.023 | 0.024 | 0.033 | 0.023 | 0.024 | 0.028 |
| $\sigma = 1$ | [0.021] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.573] | [0.000] | [0.000] |
| $\gamma_b = \gamma_a$ | – | – | – | – | – | – | – | – | – | [0.767] | [0.731] | [0.657] |
| $\lambda_b = 1$ | [0.012] | [0.000] | [0.000] | – | – | – | [0.164] | [0.070] | [0.040] | [0.924] | [0.805] | [0.971] |
| $\lambda_a = 1$ | – | – | – | [0.528] | [0.175] | [0.000] | – | – | – | [0.991] | [0.351] | [0.717] |

## Table C.4: Estimates: Flow of Funds Data

| | Harrod | | | Solow | | | Hicks | | | Augmenting | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS |
| $\sigma$ | 1.037*** | 1.042*** | 1.180*** | 1.060*** | 1.044*** | 1.010*** | 1.121*** | 1.091*** | 1.010*** | 1.165*** | 1.164*** | 1.174*** |
| | {0.964:1.111} | {1.010:1.074} | {1.171:1.189} | {1.039:1.080} | {1.032:1.056} | {1.007:1.012} | {1.092:1.151} | {1.067:1.114} | {1.007:1.012} | {1.128:1.201 } | {1.148:1.180} | {1.158:1.191} |
| $\gamma_b$ | 0.085*** | 0.080*** | 0.062*** | | | | | | | 0.030*** | 0.031*** | 0.034*** |
| | {0.077:0.093} | {0.074:0.086} | {0.058:0.065} | | | | | | | {0.021:0.040} | {0.024:0.038} | {0.026:0.042} |
| $\gamma_a$ | | | | 0.086*** | 0.079*** | 0.062*** | | | | 0.059*** | 0.054*** | 0.050*** |
| | | | | {0.078:0.094} | {0.074:0.084} | {0.058:0.066} | | | | {0.037:0.082} | {0.040:0.069} | {0.033:0.067} |
| $\gamma$ | | | | | | | 0.041*** | 0.038*** | 0.030*** | | | |
| | | | | | | | {0.038:0.045} | {0.036:0.040} | {0.028:0.032} | | | |
| $\lambda_b$ | 1.200*** | 1.156*** | 0.886*** | | | | | | | 0.533*** | 0.554*** | 0.622*** |
| | {1.026:1.373} | {1.016:1.297} | {0.812:0.960} | | | | | | | {0.289:0.777} | {0.383:0.725} | {0.413:0.831} |
| $\lambda_a$ | | | | 1.087*** | 1.013*** | 0.890*** | | | | 2.070*** | 1.930*** | 1.802*** |
| | | | | {0.910:1.264} | {0.901:1.126} | {0.810:0.971} | | | | {1.060:3.080} | {1.282:2.579} | {1.041:2.562} |
| $\lambda$ | | | | | | | 1.121*** | 1.023*** | 0.901*** | | | |
| | | | | | | | {0.953:1.289} | {0.926:1.119} | {0.822:0.981} | | | |
| $\xi$ | 1.315*** | 1.305*** | 1.304*** | 1.146*** | 1.138*** | 1.117*** | 1.144*** | 1.138*** | 1.117*** | 1.303*** | 1.297*** | 1.303*** |
| | {1.295:1.335} | {1.287:1.323} | {1.289:1.319} | {1.136:1.155} | {1.131:1.145} | {1.111:1.123} | {1.135:1.153} | {1.131:1.144} | {1.112:1.123} | {1.277:1.328 } | {1.279:1.315} | {1.286:1.320} |
| $ll$ | 181.749 | 184.514 | 200.136 | 160.198 | 168.534 | 201.218 | 147.933 | 155.367 | 200.498 | 220.266 | 221.051 | 221.500 |
| $aic$ | -355.498 | -361.029 | -392.272 | -312.397 | -329.067 | -394.437 | -287.865 | -302.734 | -392.997 | -428.532 | - 430.102 | -431.000 |
| $bic$ | -351.320 | -356.851 | -388.093 | -308.219 | -324.889 | -390.259 | -283.687 | -298.555 | -388.818 | -422.265 | - 423.835 | -424.733 |
| $rmse(\varsigma_N)$ | 0.043 | 0.042 | 0.038 | 0.025 | 0.028 | 0.041 | 0.026 | 0.027 | 0.042 | 0.017 | 0.017 | 0.017 |
| $rmse(\varsigma_K)$ | 0.045 | 0.045 | 0.057 | 0.035 | 0.034 | 0.042 | 0.029 | 0.031 | 0.044 | 0.023 | 0.023 | 0.024 |
| $rmse(Y)$ | 0.023 | 0.025 | 0.055 | 0.023 | 0.026 | 0.049 | 0.023 | 0.026 | 0.050 | 0.023 | 0.023 | 0.023 |
| $\sigma = 1$ | [0.319] | [0.010] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] |
| $\gamma_b = \gamma_a$ | – | – | – | – | – | – | – | – | – | [0.053] | [0.027] | [0.197] |
| $\lambda_b = 1$ | – | – | – | – | – | – | [0.159] | [0.645] | [0.015] | [0.000] | [0.000] | [0.000] |
| $\lambda_a = 1$ | [0.024] | [0.029] | [0.000] | [0.335] | [0.817] | [0.007] | – | – | – | [0.038] | [0.005] | [0.039] |

## TABLE C.5: ESTIMATES: PROVINCIAL + FLOW-OF-FUNDS DATA

| | Harrod | | | Solow | | | Hicks | | | Augmenting | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS | NLS | FGNLS | IFGNLS |
| $\sigma$ | 1.716*** | 1.697*** | 1.994*** | 1.078*** | 1.083*** | 1.091*** | 1.155*** | 1.151*** | 1.179*** | 1. 309*** | 1.248*** | 1.308*** |
| | {1.420:2.011} | {1.615:1.778} | {1.954:2.035} | {1.065:1.092} | {1.072:1.095} | {1.082:1.099} | {1.125:1.184} | {1.125:1.177} | {1.168:1.190} | {1.110:1.509} | {1.219:1.277} | {1.276:1.340} |
| $\gamma_b$ | 0.068*** | 0.068*** | 0.067*** | | | | | | | 0. 056*** | 0.051*** | 0.055*** |
| | {0.066:0.070} | {0.067:0.069} | {0.066:0.069} | | | | | | | {0. 043:0.068} | {0.047:0.054} | {0.053:0.058} |
| $\gamma_a$ | | | | 0.078*** | 0.079*** | 0.080*** | | | | 0. 013 | 0.019*** | 0.014*** |
| | | | | {0.076:0.080} | {0.077:0.080} | {0.078:0.082} | | | | {-0.003:0.029} | {0.012:0.026} | {0.007:0.020} |
| $\gamma$ | | | | | | | 0.037*** | 0.037*** | 0.037*** | | | |
| | | | | | | | {0.036:0.038} | {0.036:0.038} | {0.036:0.038} | | | |
| $\lambda_b$ | 1.111*** | 1.087*** | 0.864*** | | | | | | | 1.032*** | 0.978*** | 1.007*** |
| | {1.053:1.170} | {1.027:1.147} | {0.804:0.924} | | | | | | | {0. 892:1.171} | {0.871:1.084} | {0.919:1.094} |
| $\lambda_a$ | | | | 1.122*** | 0.986*** | 0.845*** | | | | 2.393** | 2.022*** | 2.312*** |
| | | | | {0.997:1.247} | {0.904:1.068} | {0.779:0.910} | | | | {0.654:4.133} | {1.152:2.892} | {1.179:3.445} |
| $\lambda$ | | | | | | | 1.204*** | 1.089*** | 0.815*** | | | |
| | | | | | | | {1.109:1.299} | {1.023:1.156} | {0.769:0.861} | | | |
| $\xi$ | 0.943*** | 0.942*** | 0.971*** | 0.962*** | 0.970*** | 0.982*** | 0.963*** | 0.972*** | 0.995*** | 0. 930*** | 0.933*** | 0.933*** |
| | {0.928:0.959} | {0.926:0.957} | {0.949:0.992} | {0.954:0.970} | {0.964:0.976} | {0.978:0.986} | {0.955:0.971} | {0.966:0.977} | {0.992:0.997} | {0.917:0.944} | {0.921:0.944} | {0.921:0.945} |
| $ll$ | 283.793 | 285.976 | 293.744 | 276.430 | 284.699 | 290.115 | 260.576 | 268.971 | 287.646 | 316.244 | 316.239 | 316.553 |
| $aic$ | -559.586 | -563.953 | -579.488 | -544.860 | -561.398 | -572.231 | -513.152 | -529.941 | -567.293 | -620.488 | -620.478 | -621.106 |
| $bic$ | -553.365 | -557.731 | -573.267 | -538.638 | -555.177 | -566.009 | -506.931 | -523.720 | -561.071 | -611.156 | -611.146 | -611.774 |
| $rmse(\varsigma_N)$ | 0.026 | 0.024 | 0.031 | 0.026 | 0.026 | 0.027 | 0.026 | 0.025 | 0.023 | 0.021 | 0.021 | 0.021 |
| $rmse(\varsigma_K)$ | 0.048 | 0.048 | 0.045 | 0.035 | 0.036 | 0.039 | 0.035 | 0.036 | 0.040 | 0.034 | 0.034 | 0.034 |
| $rmse(Y)$ | 0.037 | 0.040 | 0.056 | 0.029 | 0.032 | 0.042 | 0.029 | 0.032 | 0.056 | 0.030 | 0.030 | 0.031 |
| $\sigma = 1$ | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.002] | [0.000] | [0.000] |
| $\gamma_b = \gamma_a$ | – | – | – | – | – | – | – | – | – | [0.003] | [0.000] | [0.000] |
| $\lambda_b = 1$ | [0.000] | [0.000] | [0.000] | – | – | – | [0.000] | [0.000] | [0.000] | [0.655] | [0.679] | [0.884] |
| $\lambda_a = 1$ | – | – | – | [0.055] | [0.741] | [0.000] | – | – | – | [0.116] | [0.021] | [0.023] |

# D Regressions Based on Statically Derived Technical Progress Components

## TABLE D.1: TECHNICAL PROGRESS AND TRADE COMPONENTS

| | Capital Saving Technical Progress | | | | | | | | | Labor Saving Technical Progress | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Open | 0.018*** | -0.047*** | | | | | | | | 0.025*** | 0.135*** | | | | | | | |
| | (0.004) | (0.011) | | | | | | | | (0.005) | (0.017) | | | | | | | |
| $\text{Open}^2$ | | 0.001*** | | | | | | | | | -0.002*** | | | | | | | |
| | | (0.000) | | | | | | | | | (0.000) | | | | | | | |
| Import Content of Exports | | | 7.105*** | | | | | | | | | -1.745 | | | | | | |
| | | | (0.736) | | | | | | | | | (1.500) | | | | | | |
| ICT Goods Exports* | | | | 0.057*** | | | | | | | | | -0.019 | | | | | |
| | | | | (0.012) | | | | | | | | | (0.039) | | | | | |
| ICT Goods Imports** | | | | | 0.069* | | | | | | | | | -0.134*** | | | | |
| | | | | | (0.027) | | | | | | | | | (0.023) | | | | |
| Tariff Rate† | | | | | | -0.023* | | | | | | | | | -0.016* | | | |
| | | | | | | (0.010) | | | | | | | | | (0.007) | | | |
| Tariff Rate (Manufacturing) | | | | | | | -0.019* | | | | | | | | | -0.015 | | |
| | | | | | | | (0.009) | | | | | | | | | (0.009) | | |
| Tariff Rate (Primary) | | | | | | | | -0.037*** | | | | | | | | | -0.004 | |
| | | | | | | | | (0.006) | | | | | | | | | (0.010) | |
| High-Tech. Exports‡ | | | | | | | | | 0.032*** | | | | | | | | | 0.012 |
| | | | | | | | | | (0.006) | | | | | | | | | (0.013) |
| Adj. $R^2$ | 0.555 | 0.845 | 0.851 | 0.567 | 0.262 | 0.352 | 0.267 | 0.642 | 0.546 | 0.400 | 0.715 | 0.018 | 0.048 | 0.656 | 0.139 | 0.158 | 0.050 | 0.026 |

Note: Open = sum of exports and imports of final goods as a % of output; * as a % Total Goods Exports; ** as a % Total Goods Imports; †: Tariff rate, most favored nation, weighted mean, all products; ‡ as a % Manufacturing Exports.
Figures in ()s are bootstrapped standard errors. ***, ** and * denote significant respectively at the 1%, 5% and 10% level. Intercepts not reported in tables for brevity.

## TABLE D.2: TECHNICAL PROGRESS AND PATENTS AND HUMAN CAPITAL

| | Capital Saving Technical Progress | | | | | Labor Saving Technical Progress | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| School Enrollment Secondary (% gross)† | 0.013*** | | | | | 0.022*** | | | | |
| | (0.002) | | | | | (0.004) | | | | |
| Patent Applications, Nonresidents (Number) | | 7.206e-6*** | | | | | 6.292e-6*** | | | |
| | | (1.220e-6) | | | | | (1.624e-6) | | | |
| Patent Applications, Residents (Number) | | | 1.34e-6 | | | | | 2.053e-6*** | | |
| | | | (8.36e-7) | | | | | (6.360e-7) | | |
| RnD Expenditure (% GDP) | | | | 0.559*** | | | | | 0.298 | |
| | | | | (0.132) | | | | | (0.186) | |
| RnD Workers (per million people) | | | | | 0.0012*** | | | | | 1.004e-4 |
| | | | | | (0.0002) | | | | | (3.26e-4) |
| Adj. $R^2$ | 0.715 | 0.642 | 0.236 | 0.393 | 0.658 | 0.195 | 0.355 | 0.454 | 0.079 | 0.061 |

Note: †: Years missing (1998, 2004, 2005) were linearly interpolated.

## TABLE D.3: TECHNICAL PROGRESS AND URBANIZATION

| | Capital Saving Technical Progress | | | | | | | Labor Saving Technical Progress | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Urban Population Share | 0.021*** | -0.040 | | | | | | 0.044*** | 0.130*** | | | | | |
| | (0.004) | (0.044 ) | | | | | | (0.006) | (0.043) | | | | | |
| Urban Population Share$^2$ | | 0.0001 | | | | | | | -0.0013** | | | | | |
| | | (0.0001) | | | | | | | (0.0007) | | | | | |
| Air Transport Freight | | | 4.44e-5*** | | | | | | | 7.33e-5*** | | | | |
| | | | (8.91e-6) | | | | | | | (9.98e-6) | | | | |
| Railways Goods Trans | | | | 4.172e-7*** | | | | | | | 5.876e-7*** | | | |
| | | | | (7.66e-8) | | | | | | | (8.4e-8) | | | |
| Railways, Passengers Carried* | | | | | 1.253e-6*** | | | | | | | 1.763e-6*** | | |
| | | | | | (2.44e-7) | | | | | | | (2.270e-7) | | |
| Share of Electricity From Coal | | | | | | 0.017** | | | | | | | 0.047*** | |
| | | | | | | (0.006) | | | | | | | (0.006) | |
| $CO_2$ emissions | | | | | | | 9.16e-8*** | | | | | | | 1.638e-7*** |
| | | | | | | | (2.27e-8) | | | | | | | (2.06e-8) |
| Adj. $R^2$ | 0.418 | 0.495 | 0.456 | 0.575 | 0.576 | 0.189 | 0.439 | 0.698 | 0.754 | 0.490 | 0.581 | 0.581 | 0.603 | 0.555 |

Note: * per Mil.Passenger-Km.

# E Robustness: Trust Regions

Given that the system that we are estimating is non-linear, we took care to ensure that our final parameter estimates are robust to variation in the parameter initial conditions provided. The result of these grid searches are shown below. These indicate *trust regions* where, across a number of metrics and exercises, we can have confidence in which ranges key parameter reside. Thus for a given parameter $\theta$ we have a final realized estimated value, $\widehat{\theta}$, conditional on the range of initial conditions tried: i.e., $\widehat{\theta} \mid \theta_0 \in \left[\underline{\theta}, \overline{\theta}\right]$.

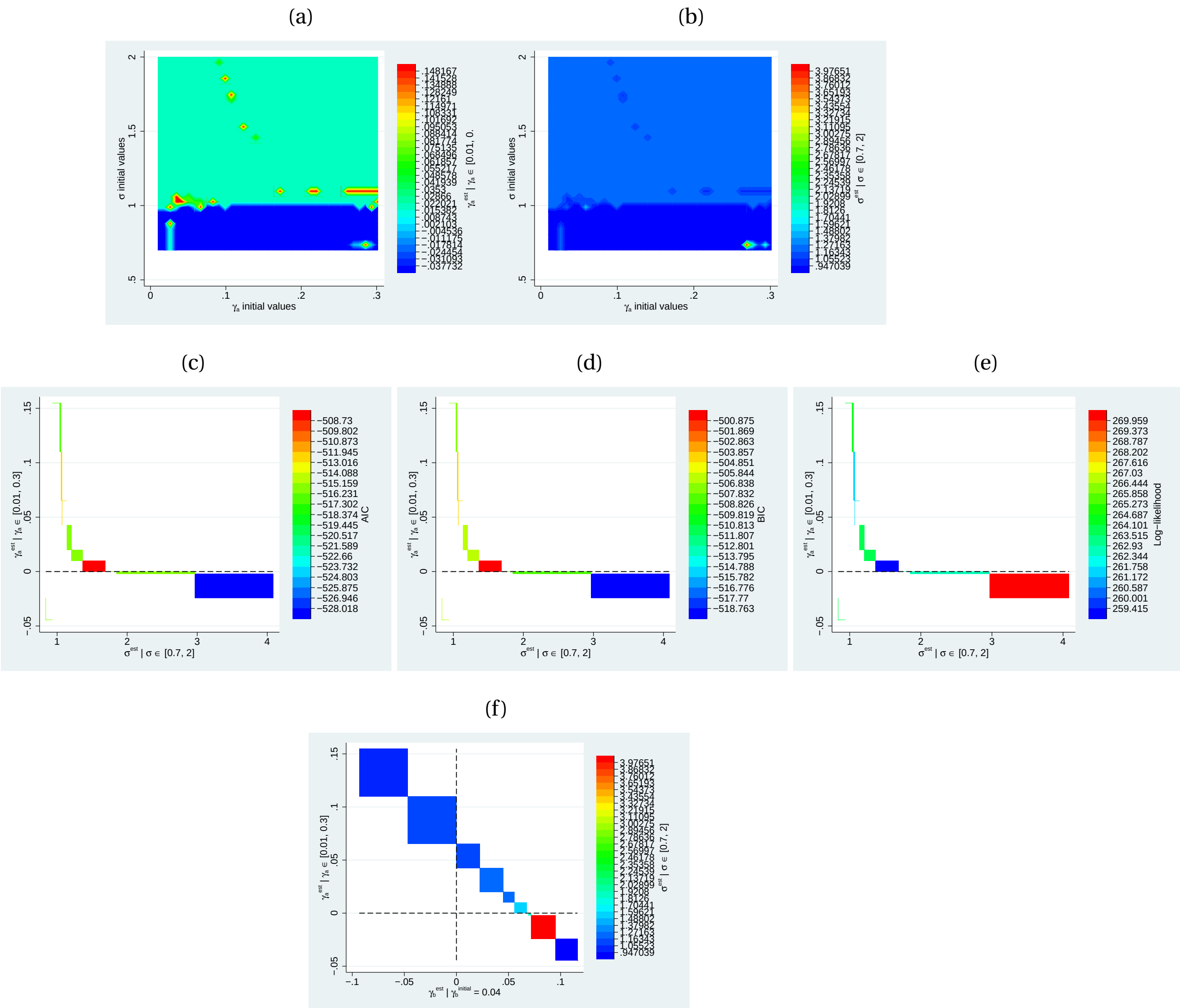
We consider two exercises, reflected in the matching set of plots in **Figure E.1** and **Figure E.2**. In the E.1 the initial condition for parameter $\gamma_{\text{b}}$ is held constant (although not this is only the initial condition, the parameter itself in all these exercises is freely estimated) and we trace outcomes for variations in the other two parameters, $\sigma$ and $\gamma_{\text{a}}$. In E.2 is the $\gamma_{\text{a}}$ whose initial condition is held constant.

The first exercises are the simplest. For example in E.1 panels $a$ and $b$ the initial parameter guesses of $\sigma$ and $\gamma_{\text{a}}$ are being varied between $0.5-2$, and $0-0.3$, and then for a fixed initial condition for $\gamma_{\text{b}}$, we plot the regions for $\widehat{\gamma}_a$. As we can see when $\sigma$ is initially set below 1 we derive negative $\gamma_{\text{a}}$ values irrespective of the initial condition given to $\gamma_{\text{a}}$. In (**Panel b**) we do the same but plot the regions where the estimated value of $\sigma$ ends up. In (**Panels c-e**), we again hold the initial value of $\gamma_{\text{b}}$ fixed and vary the initial conditions of $\sigma$ and $\gamma_{\text{a}}$ and identify their estimation regions. We do so across the log-likelihood, $aic$ and $bic$ criteria; although the inference is identical in each case.

Consider (**Panel c**) when $\widehat{\sigma}$ is around 4 the estimated capital saving growth rate is negative. However prima facie reasoning would reject a growth rate for technical progress of an emerging country to be negative, so such a region is economically implausible. A more trustworthy region is when $\sigma$ is just above unity and $\gamma_{\text{a}}$ is in the $0-0.05$ region.

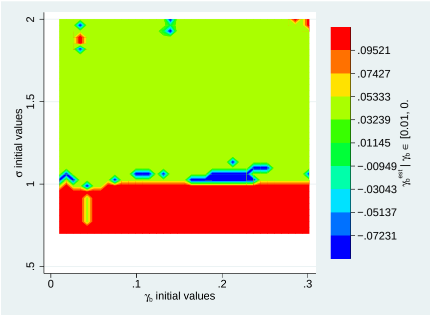
(**Panel f**) is probably the most informative. It again demarcates a zero infeasible region (given by the dotted lines) and shows, for a given $\gamma_{\text{b}}$ initial condition where the estimated values of $\gamma_{\text{a}}$ and $\sigma$ reside. The most plausible region is the upper right quadrant in the small light blue box where $\gamma_{\text{b}}$ estimated is around $0.05$ and $\gamma_{\text{a}}$ is around $0.01$ and $\widehat{\sigma}$ is around $1.4-1.8$.

## Figure E.1: Trust regions I

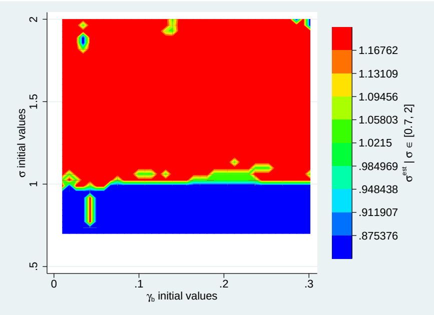


# FIGURE E.2: TRUST REGIONS II

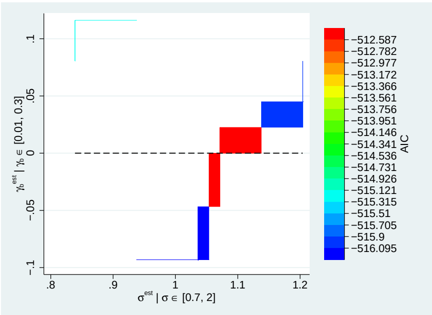
(a)



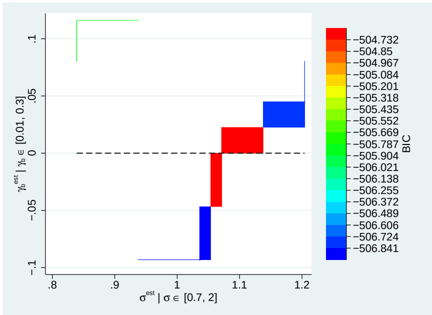

(b)



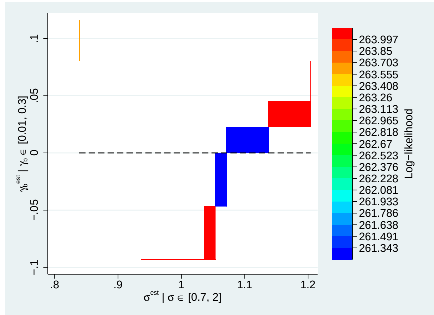

(c)



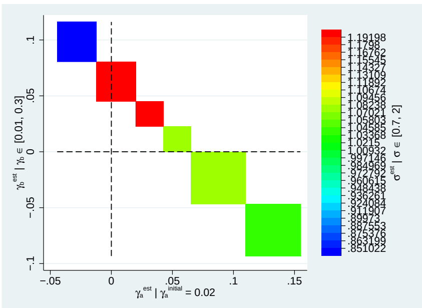

(d)




(e)




(f)



# F Additional Figures

**FIGURE F.1: STYLIZED AND STATICALLY-DERIVED TECHNICAL PROGRESS TERMS**

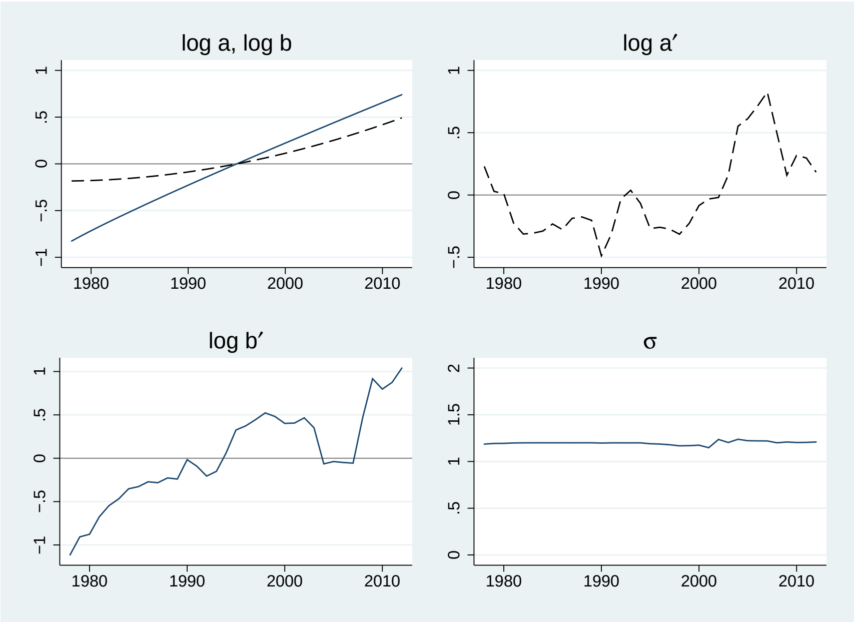



**FIGURE F.2: RECURSIVE ESTIMATION OF AUGMENTING CASE OF TABLE 1**

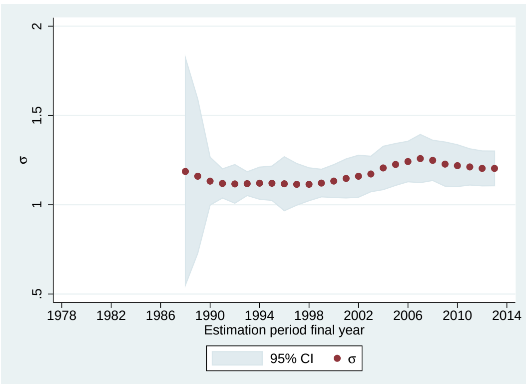
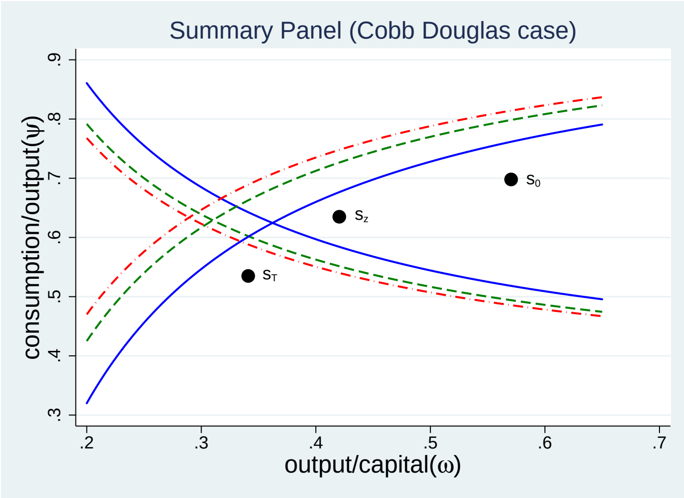


FIGURE F.3: TRANSITIONAL DYNAMICS OF CONSUMPTION AND CAPITAL




# G Graphical Treatment of the Positive Relationship between Growth and the Elasticity of Substitution

Recalling figure 8, we draw investment schedules conditional on three $\sigma$ cases: the Leontief, linear and $\hat{\sigma}$ cases. We see that everywhere except in the common normalization point $A_z$ the curve corresponding to $\sigma \to \infty$ exceeds that of $\sigma = 1.2$ which, in turn, lies above the schedule with $\sigma \approx 0$. Accordingly, on the left-hand-side of their respective intersection points with the ray, the distance of each investment schedule from the ray is increasing in $\sigma$.

In terms of (6) this implies the growth $(\frac{\dot{k}}{k}, \frac{\dot{y}}{y})$ corresponding to each value of $k$ value is also increasing in the substitution elasticity. In addition, as the rise in $\sigma$ shifts $k^*$ to the right, this implies a longer lasting transition period during which growth exceeds the BGP rate.

1. **Disequilibrium: Degenerative Growth** If $0 < \frac{\mathcal{S}}{\mathcal{R}} < \pi_z$, then $1 > \sigma^* > 0$. For $\sigma \leq \sigma^* < 1$ the economy converges to zero. For $\sigma > \sigma^*$ there is a finite $k^*$ towards which the economy converges.

   *(**Panel A**) allows this possibility since $\frac{\mathcal{S}}{\mathcal{R}} = 0.41 < \pi_z$. Using (12), this implies $\sigma^* = 0.24$ (green dotted line). There we also drew the investment schedule given $\sigma = \sigma^* = 0.24$; it is below $\mathcal{R} \times k$ and never intersects it.*

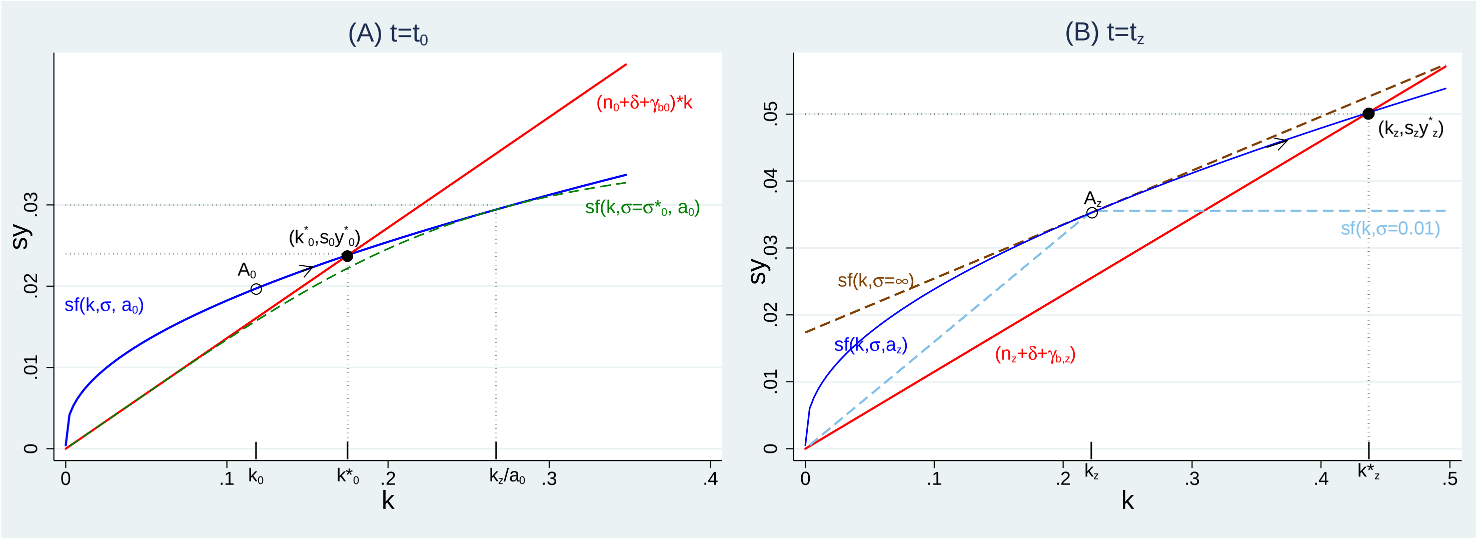
2. **Convergence** If $1 > \frac{\mathcal{S}}{\mathcal{R}} > \pi_z \Rightarrow \sigma^* < 0$. Now independently from the size of $\sigma \in [0, \infty)$ there is a finite $k^*$ towards which the economy converges.

   *(**Panel B**) represents this alternative since $\pi_z = 0.508 < \frac{\mathcal{S}}{\mathcal{R}} = 0.7 < 1 \Rightarrow \sigma^* = -0.91$ and, hence, for all feasible (i.e., positive) $\sigma$, the investment schedule intersects $\mathcal{R} \times k$ and there is an equilibrium. There we drew investment schedules corresponding to $\sigma \to \infty$ and $\sigma = 0.01$ (near Leontief) (brown and light blue dashed lines, respectively). Both schedules intersect implying an equilibrium for all feasible $\sigma$.*

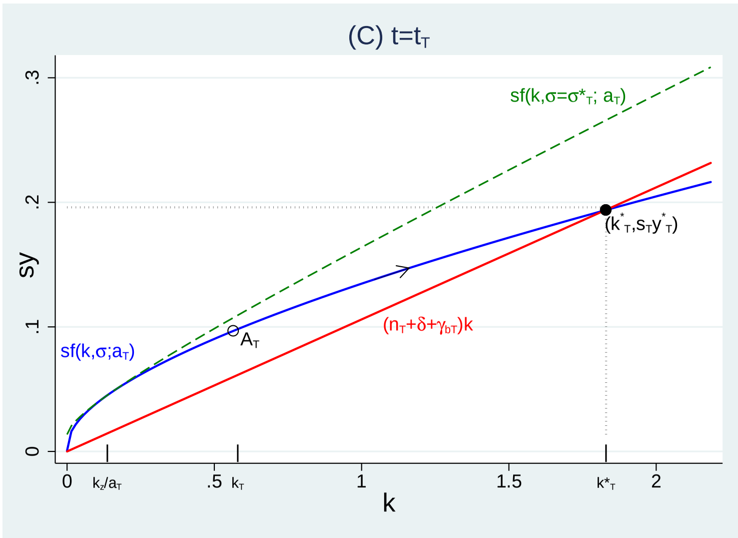
3. **Disequilibrium: Perpetual Growth** If $\frac{\mathcal{S}}{\mathcal{R}} > 1 \Rightarrow \sigma^* > 1$. Now with $\sigma \geq \sigma^* > 1$ the economy is in the disequilibrium regime of perpetual growth. With the values $\sigma \in [0, \sigma^*)$ there is a finite $k^*$ towards which the economy converges.

   *(**Panel C**) captures this alternative since $\frac{\mathcal{S}}{\mathcal{R}} = 1.59 > 1 \Rightarrow \sigma^* = 2.47$. There we drew also the investment schedule corresponding to this $\sigma^*$. We see that it becomes parallel to the ray when $k \to \infty$, and the two schedules never intersect.*

## FIGURE G.1: DYNAMIC GROWTH OUTCOMES CONT.




Note: In (**Panel A**) the horizontal line ($sy = 0.3$) intersecting the vertical line ($k = k_z/a_0$) denotes the point where functions $sf(k;a_0)$ for all $\forall\sigma \in [0,\infty)$ have a common tangent. In the panel where we have $sf(k,\sigma,a_{\{t\}})$, the $\sigma$ denotes the estimated value of $\widehat{\sigma} = 1.2$.



# H Aggregate Studies of China

The empirical literature dealing with the Chinese growth model did not reach a consensus neither on the functional form of the production function, nor on the magnitude of the elasticity of substitution sigma. A couple of studies aim to explain the high growth experienced by China using merely a Cobb-Douglas production function (CD PF) approach, assuming that the elasticity of substitution between factor inputs is 1. For example, in their attempt to understand how fast the Chinese economy can grow over the medium term, Bailliu et al. (2016) use a CD PF with a constant income share of 0.5 and decompose GDP trend growth by its drivers (the capital stock, labor, human capital and total factor productivity). This approach suggests that TFP has decelerated from around 4% during the 2001-2010 to around 1.5% in 2011-2015. By extrapolating the underlying trends of growth drivers, the authors also project that the Chinese trend output growth will decelerated from around 7% currently to about 5% by 2030, a view which is consistent with a gradual re-balancing of the Chinese economy amid declining investment rates.

Taking a longer term perspective, beginning with 1952, Chow (2007) estimates a CD PF in log levels, augmented with an exponential trend to account for China's growth model and to examine the extent of technical progress during the reform years since 1978. The coefficient estimates of capital and labor sum close to one suggesting that the data is supporting the constant return to scale assumption. The results also point to the importance of capital accumulation and increase in productivity in accounting for China's growth in the post-reform period of 1978 to 1998. Similarly, Zheng et al. (2008) employ a simple CD PF with 0.5 capital share and labour input adjusted for its quality. The authors confirms that the reform measures in China were associated with one-time level effect on TFP, and overall TFP growth declined from 3.7% in 1978-95 to 1.8% in 1995-2005, meaning that in the latter decade China's growth has been rather extensive. The authors also checked the sensitivity to different capital shares suggesting that since the early 1990s the productivity measures proved sensitive to the choice. Also, Zhanqi (2015) computes China's total factor productivity for the overall economy and manufacturing sector by using both the translog PF method and CD PF. The authors results validate that the reform policy, and the opening of the Chinese economy, has contributed to higher rate of productivity growth, but conclude that TFP has declined since 1993, and more strongly after the 2008 financial crisis.

Despite the abundance of CD PF estimates for the Chinese economy, several studies have proposed different approaches to account for China's growth. As early as 1990, Lau and Brada estimated the TFP growth in the state-owned sector of the Chinese economy (over 1953-1985) using a deterministic translog PF which allows for the technological progress to be neutral or capital/labor using. The authors found that the technological progress in the state-owned industry has averaged between 1.8% and 3.6% per year during 1953-1985. Their empirical exercise would also suggest that the implied elasticity of substitution between labour and capital is only a touch above 1 and that the Hicks-neutral technological progress has accelerated over the sample, which could be in line with long-run effects of learning by- doing and human capital formation in the industrial labor force. More importantly, their results suggest that technological progress in Chinese industry is labor-using and capital-saving, finding which they rationalize by the high reliance of Chinese industrial investment on domestic technology over that period. This also sustains the view that CD PF cannot be used to characterize the Chinese industry.

More recently, a more comprehensive research has been pursued by Shen and Whalley (2013), who estimate a multitude of CES PF with different nested structures of input factors:

capital, labor with or without human capital adjustment, and energy using data over the 1979-2006 period. They find positive and mostly below unity estimates for the substitution elasticities between capital and labor. Among the different alternative, the authors empirical evidence is in the favour of the (E,L)K structure. By contrast to this finding on the elasticity of substitution, Wang (2012) and Whalley and Chunbing (2012) research would suggest that the implied elasticity of substitution between capital and labor is higher than 1. More specifically, Wang (2012) estimate a long-linearized approximation of CES PF (in its intensive form) using panel data at province level for China and incorporate time and province fixed effects to control for heterogeneity and year specific shocks. The author finds that the distribution parameter is larger than 0.5 and that the implied elasticity of substitution is 1.11 and concludes that China would like to substitute physical capital for human capital because of relatively high marginal product of physical capital. Whalley and Chunbing (2012) choose to use relative factor share and the capital-labor ratio to infer the elasticity of substitution between capital and labour, and their results at the aggregate level of the Chinese economy show above unity elasticity of substitution. However, when looking at different sectors (primary, secondary and tertiary) their research point to above 1 elasticity of substitution only in the primary sector and significantly below 1 in the other two sectors.

# References


Bailliu, J., Kruger, M., Toktamyssov, A. and W. Welbourn (2016), How Fast Can China Grow? The Middle Kingdom's Prospects to 2030, Bank of Canada Staff Working Papers 16-15.

Chow, G. C and K.-W. Li (2002) China's Economic Growth: 1952-2010, *Economic Development and Cultural Change*, 51, 1, 247-256.

Lau, K.-T. and J. C. Brada (1990) Technological progress and technical efficiency in Chinese industrial growth: A frontier production function approach, *China Economic Review*, 1, 2, 113-124.

Shen, K. and J. Whalley, (2013) Capital-Labor-Energy Substitution in Nested CES Production Functions for China, NBER Working Papers, 19104.

Wang, Y. (2012) Estimating CES Aggregate Production Functions of China and India, Proceedings of the 4th WSEAS World Multiconference on Applied Economics, Business and Development, Recent Researches in Business and Economics.

Whalley, J. and X. Chunbing (2012) The Sustainability of Chinese Growth and the Aggregate Factor Substitution Elasticity, CESifo Working Paper Series 3736.

Zhanqi, Y. (2015) Productivity Growth and Industrial Structure Adjustment: An Analysis of China's Provincial Panel Data, *Chinese Economy*, 48, 4, 253-268.

Zheng, J., A. Bigsten and A. Hu (2006) Can China's Growth be Sustained? A Productivity Perspective, University of Göteborg, Department of Economics, Working Papers in Economics 236.

| Study | Sample | PF Assumption | Nesting structure | $\sigma$ | Productivity growth | L and K augmented TP | Output elasticity wrt K | Time coefficient | Capital Income Share |
|---|---|---|---|---|---|---|---|---|---|
| Bailliu et al. (2016) | 1980-2015 | CD PF | A(K, HL) | Assumed 1 | TFP annual avg.: 2.6% in 1997-2000; 4% in 2001-2005; 4.1% in 2006-2010; 1.5% in 2011-2015 | – | – | – | Assumed constant 0.5 |
| Chow (2017) | 1952-98 | CD PF + a trend , CRTS; | A(K,L) | Assumed 1 | TFP annual avg. growth: 0% in 1952-1978; 2.6% in 1978 to 1998. | - | 0.6 | 0.3 | 0.6353; data supports CRTS |
| Lau et al. (1990) | industries; 1953- 85 | Translog PF | (L,K) | Implied $\sigma$ 1.022 (1.016) LL=KK=-0.0218 (-0.0156) | TFP growth of 2.98% per year; no acceleration in TFP rate | $\lambda_L = 0.0036$; $\lambda_K = -0.0036$; TP is labor-using and capital-saving | – | – | – |
| Shen and Whalley (2013) | 1979-2006 | Two-level normalized CES | (K, HL)/(K,L) (K,HL)E (K,E)HL (E,HL)K; (K, L)E; (K, E)L; (K, E)L (E, L) | 0.5565/0.7418 ¡1 2.8637 | – | – | – | – | – |
| Wang (2012) | provinces; 1985-2006 | Intensive CES; Hicks-neutral TP, CRTS | (K,H) | Implied $\sigma$ 1.110371/1.181614 (estimated =0.0994/0.1537) | – | – | – | – | 0.5450/0.4298 |

## Table H.1: Production Studies of Aggregate Chinese Economy (Cont.)

| Study | Sample | PF Assumption | Nesting structure | $\sigma$ | Productivity growth | L and K augmented TP | Output elasticity wrt K | Time coefficient | Capital Income Share |
|---|---|---|---|---|---|---|---|---|---|
| Whalley and Chunbing (2012) | 1978-07 | Regresses log(L share/K share) on K/L | K and L augmenting TP | Imputed 1.44 | annual rate of 4% | biased TP; HK-λL=-0.033; labor TP grows faster than capital TP | – | 0.01 | Actual income shares ; changing over time |
| Zhanqi YAP (2010) | industries 1985-07 | CD PF | A(K,L) | Assumed 1 | the avg. marginal K productivity in manufacturing: 0.62 in 199807; two times higher than that in 198597 the avg. marginal L productivity 0.14% in 198597 ;-0.4% in 199807 | – | 0.51 after normalization | | - |
| Zheng et al. (2008) | 1978-05 | CD PF, fixed factor shares | A(K, HL) | Assumed 1 | TFP annual average: 3.7% in 1978-95; 1.8% in 1995-2005 | – | – | – | Assumed constant 0.5 |

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