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

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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 granular¹, 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 enterprise 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., scarce 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,

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

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 8.3*pp*, the flow of funds data shows the decrease of only 4.5*pp* 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 surplus¹³ 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

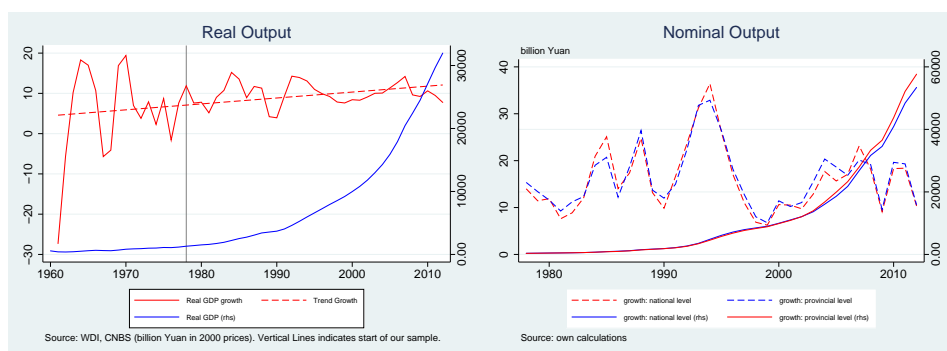


FIGURE 2: INVESTMENT, SAVINGS AND CAPITAL

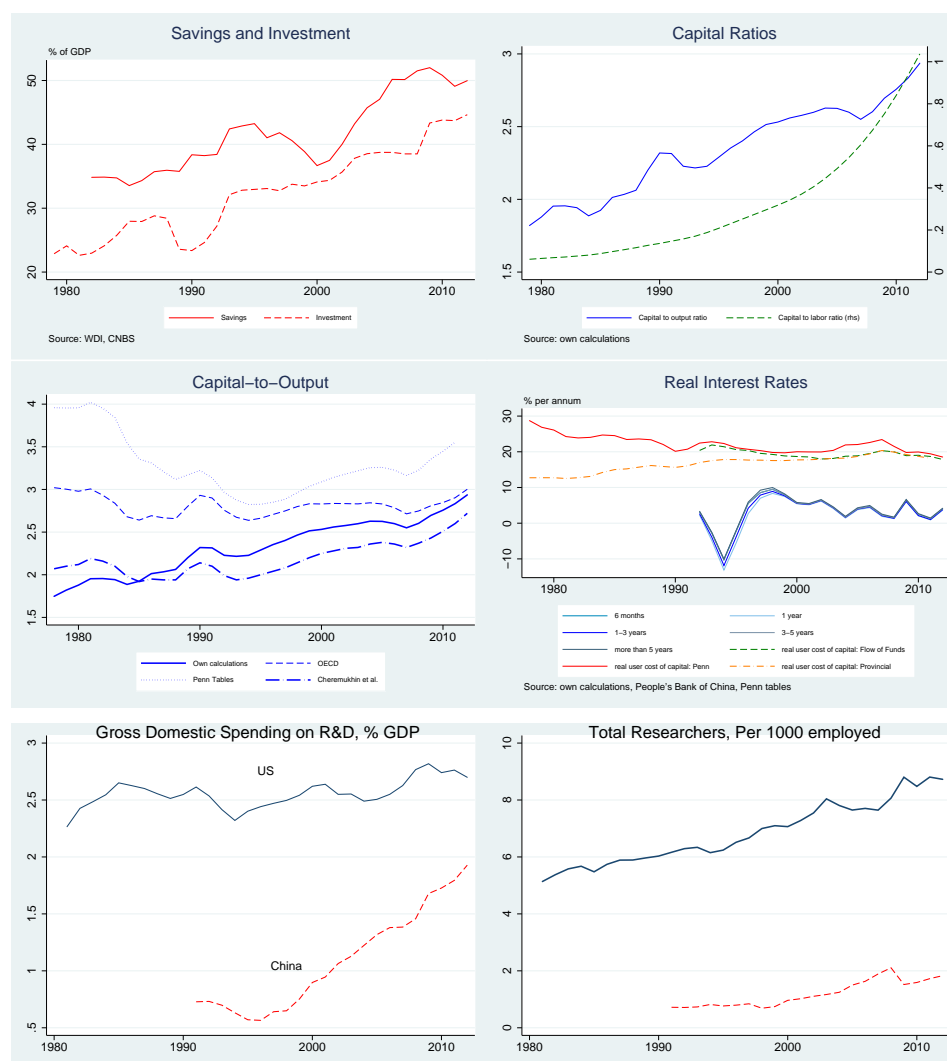
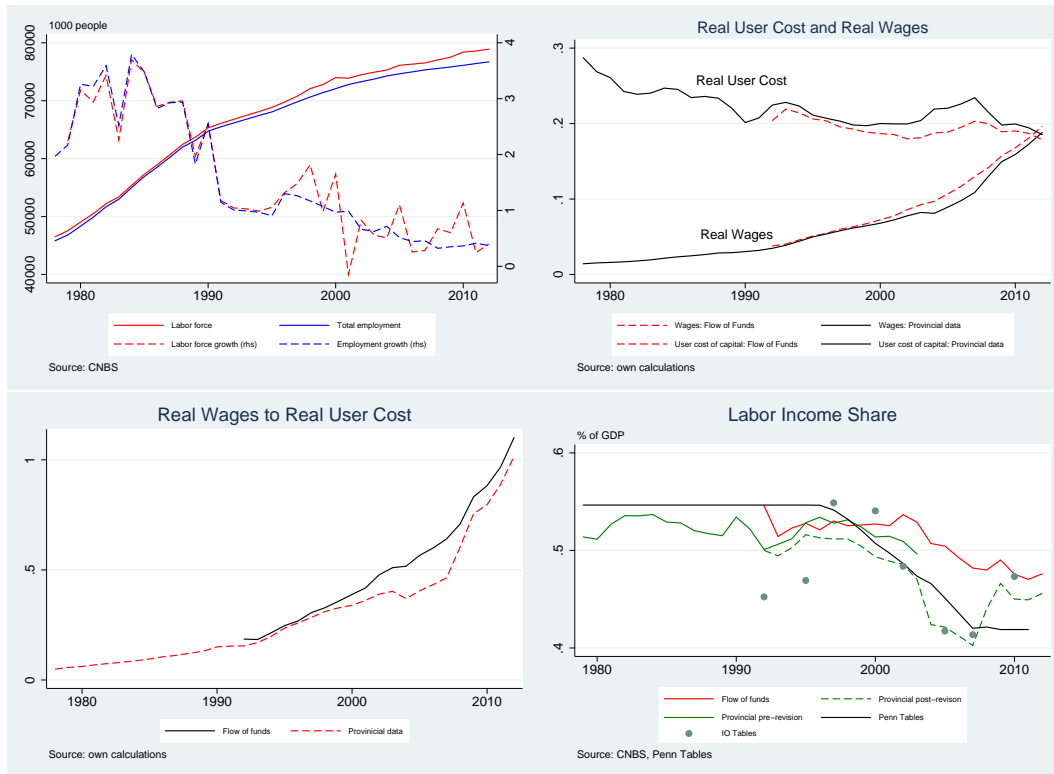


FIGURE 3: EMPLOYMENT AND FACTOR PRICES



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

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

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 $\sigma \rightarrow 0, 1, \infty$.^{15,16} For a given allocation, the higher is σ , 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,

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

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

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 σ 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 micro-foundations 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 σ 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 robustly 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,

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

The latter shows that income shares evolve with capital deepening and/or technical change.¹⁹ The direction of the effect, however, depends on $\text{sgn} \{\sigma - 1\}$, 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 λ_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.

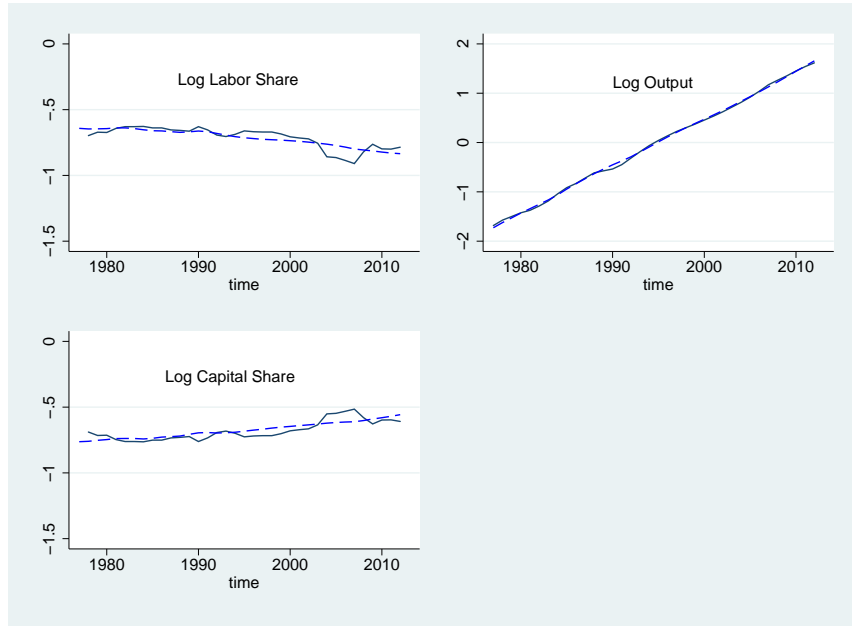
In the table below, we highlight the factor augmenting form since (across all metrics and estimation forms) it was the statistically-dominant form. **Figure 4** shows the fit of the equations and the clear mapping in the trends of factor shares and the close tracking of output. We estimate using the 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 F1.

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 F1 replicates the Figure 1 but additionally show that the σ 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

σ	γ_b	γ_a	λ_b	λ_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 $\hat{\sigma}$ 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.

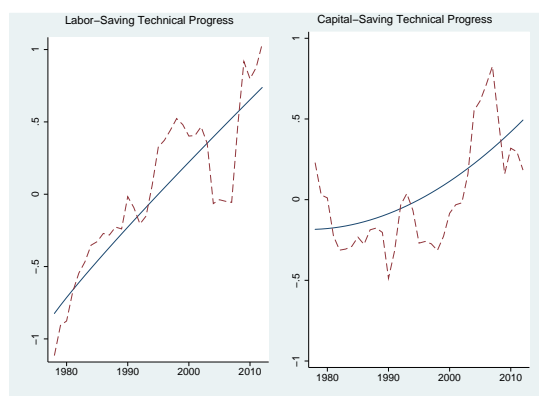
²⁷ Further $\bar{\sigma}' \approx 1.2$ from the statistically determined system. The parameter is extracted with limited time variation (See **Figure F.1**).

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.

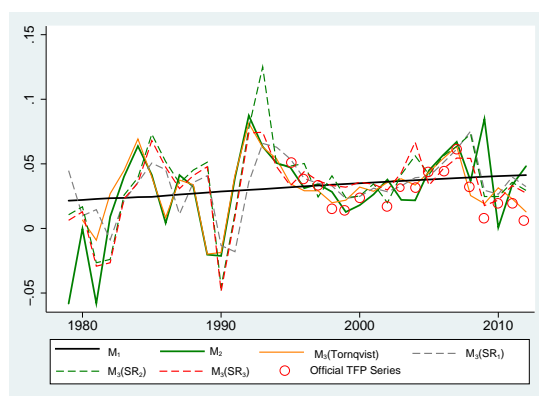
³⁰ See also Tian and Yu [2012].

FIGURE 5: TFP LEVELS COMPONENTS



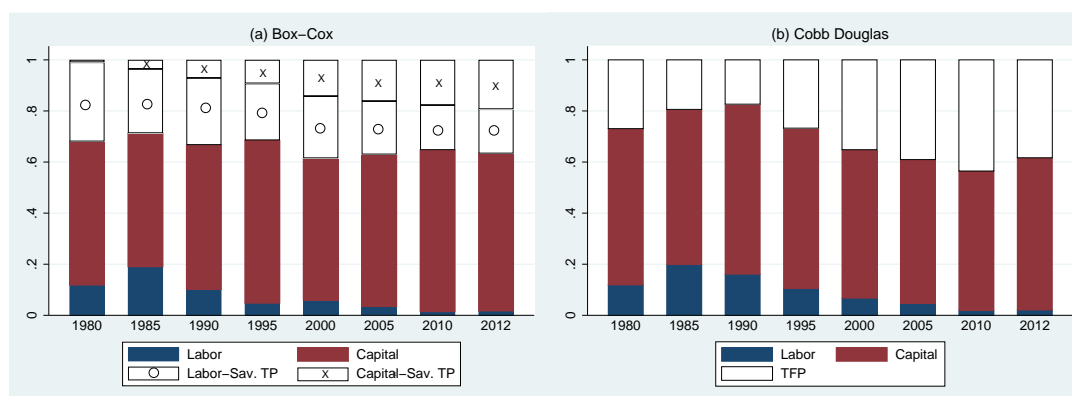
Note: Solid lines indicate the Box-Cox for of technical progress, M_1 , the dashed lines indicate the statically derived technical progress forms, M_2 .

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 to 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)		
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 $\hat{\sigma} > 1$ 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,

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

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,

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

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

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

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_τ^* , represent temporal equilibriums conditional on prevailing parameter values. Actual outcomes are denoted A_τ . 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 up-

wards 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
δ	0.060	Depreciation Rate
π_z	0.508	Capital Income Share
$\hat{\gamma}_{b,0}, \hat{\gamma}_{b,z}, \hat{\gamma}_{b,T}$	0.056, 0.045, 0.042	Labor Saving Technical Growth
$\hat{a}_0, \hat{a}_z, \hat{a}_T$	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
$\hat{\sigma}$	1.2	Elasticity of Substitution

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

From figure 8, we note the following:

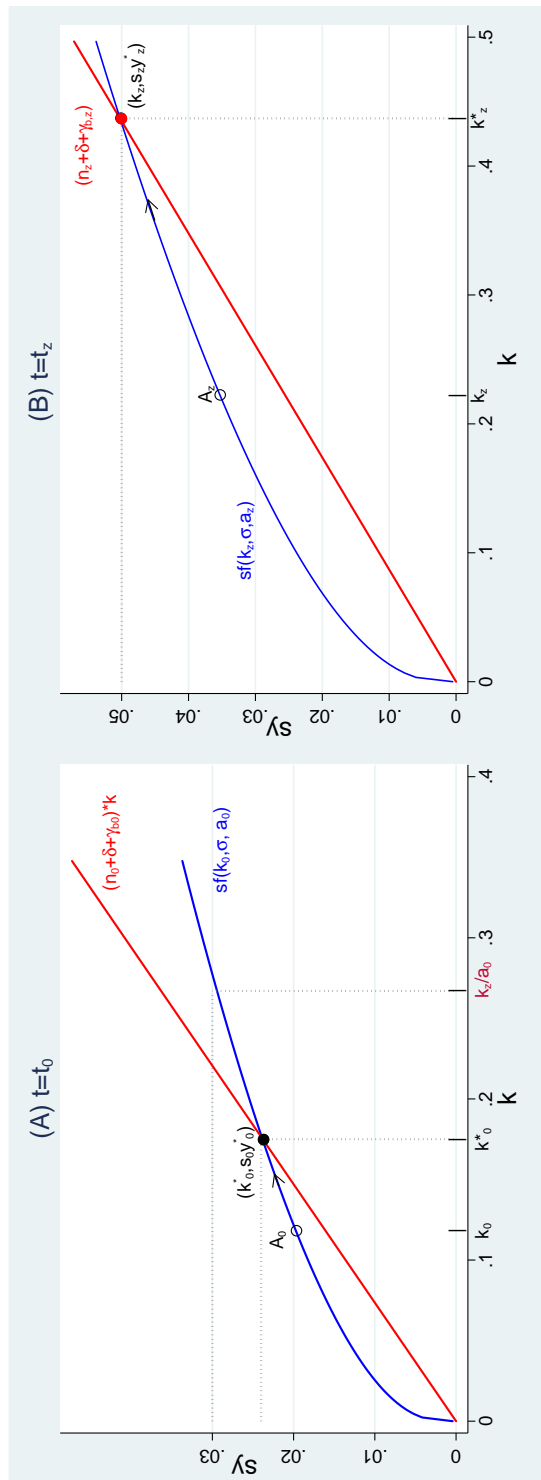
1. All points of $s_\tau f(k, a_\tau)$ moved upwards reflecting (mainly) the rise of capital saving technical change, as well as the rise in the saving rate.³⁴
2. Meanwhile, ray $(n_\tau + \delta + \gamma_{b,\tau}) k$ flattens. This reflects a deceleration in the labor force and in labor saving technical 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 A_0, A_z and A_T).

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

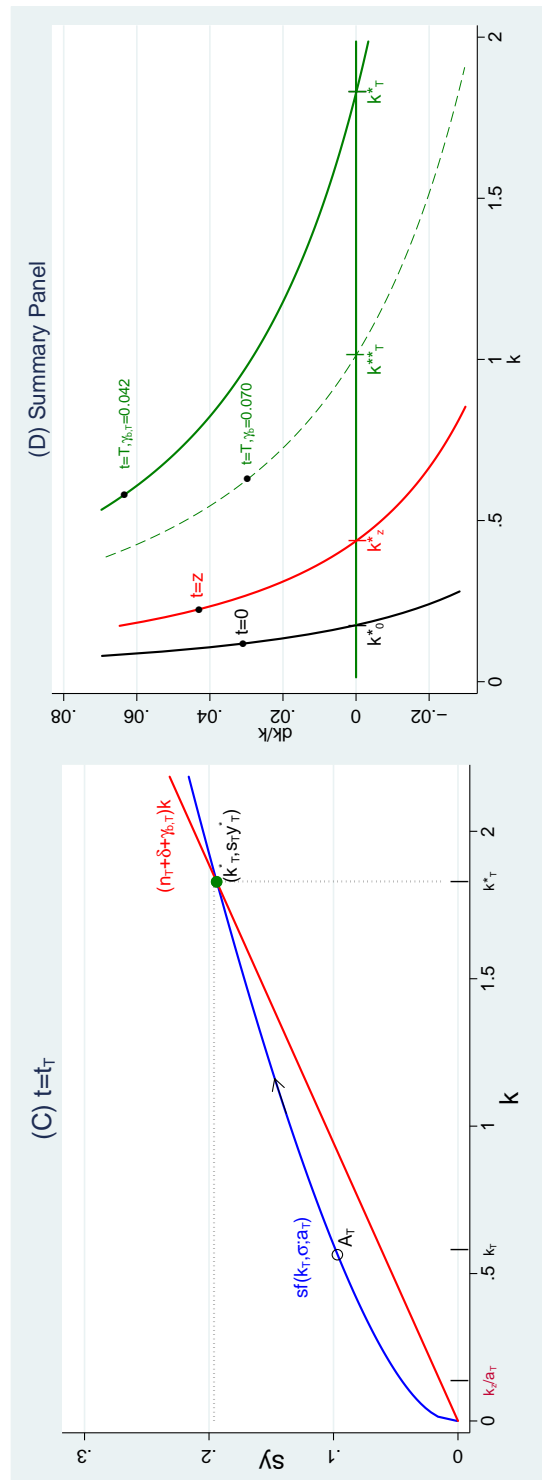
$$\lim_{k \rightarrow 0} \left(sy_0 \left[\pi_z \left(a \frac{k}{k_z} \right)^{\frac{\sigma-1}{\sigma}} + (1 - \pi_z) \right]^{\frac{\sigma}{\sigma-1}} \right) = sy_z (1 - \pi_z)^{\frac{\sigma}{\sigma-1}} > 0 \quad \perp \quad a.$$

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 ($k = k_z/a_0$) 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 $sf(k, \sigma, a_t), \sigma = \hat{\sigma} = 1.2$, 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 ≈ 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 γ_a in (8) alternatively equals 0.038 or 0.

mined recursively to (6) by,

$$\frac{\dot{y}}{y} = g(\sigma) \left(\frac{\dot{k}}{k} + \gamma_a \right) \quad (8)$$

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

$$\frac{\partial(\dot{y}/y)}{\partial\sigma} = g(\sigma) \frac{\partial(\dot{k}/k)}{\partial\sigma} + \left(\frac{\dot{k}}{k} + \gamma_a \right) \frac{\partial g(\sigma)}{\partial\sigma} > 0 \quad (9)$$

With $\dot{k}/k > 0$, $\gamma_a \geq 0$ 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 σ 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 $\hat{\sigma} \neq 1.2$ 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 $\sigma > \hat{\sigma}$ and marginal losses amplify as $\sigma < \hat{\sigma}$. 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) $\frac{\partial g(\sigma)}{\partial\sigma} = \frac{\pi_z(1-\pi_z) \left(a \frac{k}{k_z} \right)^{\frac{1-\sigma}{\sigma}} \ln \left(a \frac{k}{k_z} \right) \frac{1}{\sigma^2}}{\left(\pi_z + (1-\pi_z) \left(a \frac{k}{k_z} \right)^{\frac{1-\sigma}{\sigma}} \right)^2} > 0$, 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 σ 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 σ 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 $\{\sigma\} - \hat{\sigma}$ DEVIATIONS AS $k_z \rightarrow k_T$.

σ	$\frac{\Delta y}{y} _{k_z \rightarrow k_T}$	σ	$\frac{\Delta y}{y} _{k_z \rightarrow k_T}$
∞	-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:

$$\frac{\Delta y}{y} |_{k_z \rightarrow k_T} = 100 \left[\frac{f(a_T, k_T | \hat{\sigma}=1.2)}{f(a_T, k_T | \{\sigma\})} - 1 \right].$$

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 $\hat{\sigma} > 1$, 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, σ^* . 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,

$$\lim_{k \rightarrow \infty} sf'_{|\sigma > 1}(k) = \mathcal{S}\pi_z^{\frac{1}{\sigma-1}} \geq \mathcal{R} \quad (10)$$

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:

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

Note $\lim_{k \rightarrow \infty} f'_{|\sigma > 1} = \lim_{k \rightarrow 0} f'_{|\sigma < 1}$.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

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

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. $\forall \sigma \geq 0, k \rightarrow k^*$ 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

τ	σ_τ^*	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 $\sigma^* \rightarrow_+ \hat{\sigma}$?

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 σ^* is a function of time, the threshold elasticity may under some circumstances intersect our given estimate, $\hat{\sigma}$, implying that the Chinese economy (rather than structurally slowing down) enters a perpetual growth regime.

³⁸ Also \mathcal{S} has a clear interpretation; it is the slope of the linear investment function $sy_z[\pi_z a \frac{k}{k_z} + (1 - \pi_z)]$, implied by (5) when $\sigma \rightarrow \infty$. 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 σ^* 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 σ^* 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, γ_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 $\lim_{a \rightarrow \infty} \sigma^* \rightarrow 1$. 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,

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

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 $\hat{\sigma} = 1.2$. Using $\tau = T$ parameters set (13) yields $a^* = 30.5 \gg a_T = 1.64$. 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 σ^* . 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 intensifies 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 inter-temporal 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's actual realized savings).

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

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

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

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

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:

$$\frac{\dot{c}}{c} = \frac{1}{\theta} (f'(k) - \delta - \rho - \theta\gamma_b) \quad (15)$$

where $\frac{\dot{c}}{c} + \gamma_b$ 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 inter-temporal 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 ψ and the output-capital ratio ω ⁴⁴:

$$\dot{\psi} = \pi(\omega) \left[\omega \left(-\frac{\theta-1}{\theta} \right) + (n + \delta + \gamma_b - \gamma_a) \right] - \frac{\rho + \delta + \theta\gamma_b}{\theta} \quad (16)$$

$$\frac{\dot{\omega}}{\omega} = [\pi(\omega) - 1] [\omega(1 - \psi) - (n + \delta + \gamma_b)] + \pi(\omega)\gamma_a \quad (17)$$

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”,

$$\dot{\psi} = 0 \Rightarrow \quad = \frac{\theta-1}{\theta} + \frac{\rho + \delta + \theta\gamma_b}{\theta\pi_z(\omega_z a)^{\frac{\sigma-1}{\sigma}}} \omega^{-\frac{1}{\sigma}} - \frac{n + \delta + \gamma_b - \gamma_a}{\omega} \quad (18)$$

$$\frac{\dot{\omega}}{\omega} = 0 \Rightarrow \psi = 1 - \frac{n + \delta + \gamma_b}{\omega} + \gamma_a \frac{\pi_z(\omega_z a) \omega^{\frac{1-\sigma}{\sigma}}}{\pi_z(\omega_z a) \omega^{\frac{1-\sigma}{\sigma}} - 1} \quad (19)$$

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 ω and ψ iff $\gamma_{a,\tau} = 0, \forall t \geq \tau$.

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 ($\gamma_a = 0$) 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 γ_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 ω^* , ψ^* and circles labelled s_0 , s_z , s_T (reflecting the realized savings rates). It is striking to note that the ω , ψ 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).

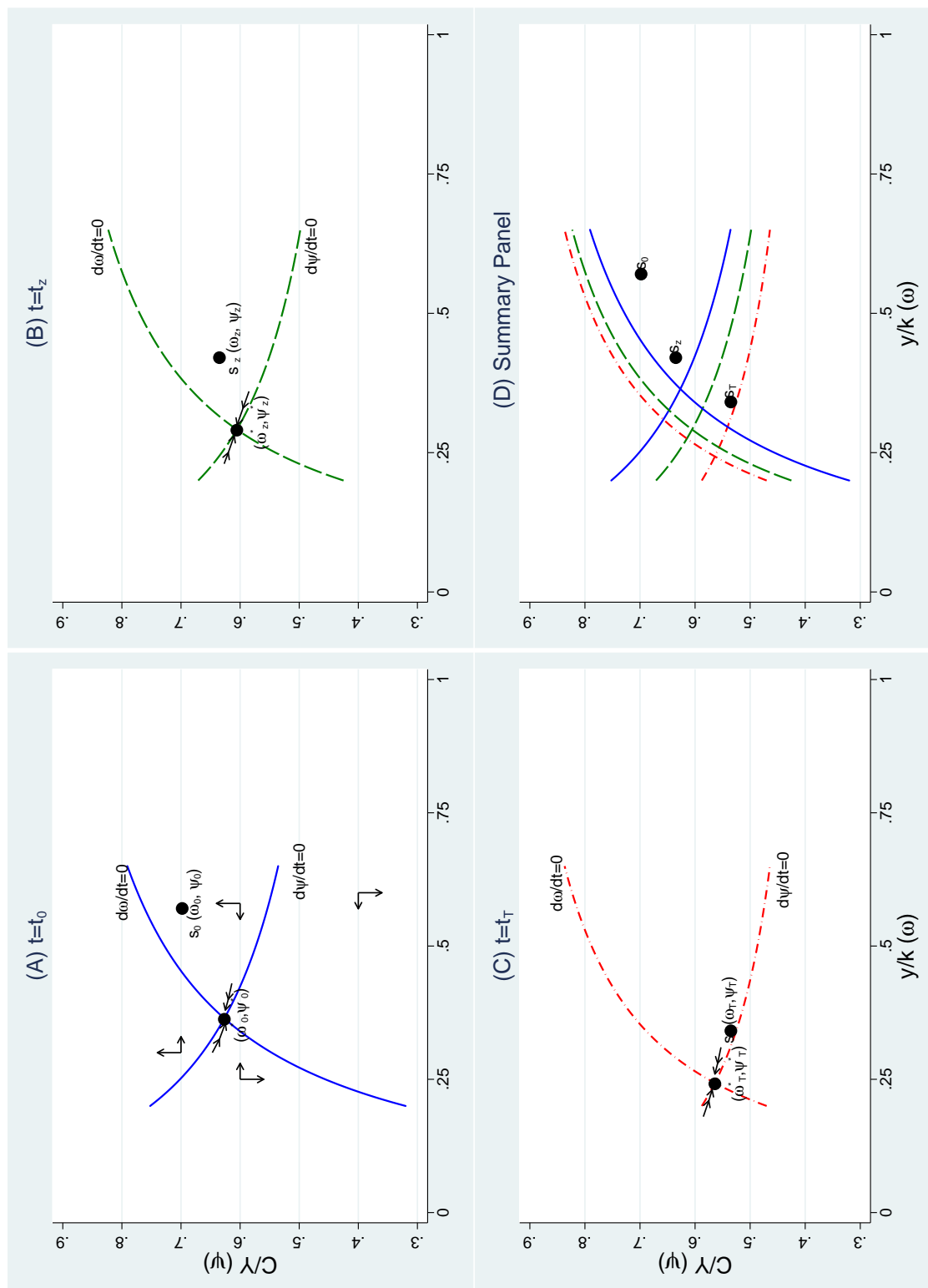
This, though, is *not* what happens. As summary (**Panel D**) shows the consumption rate fell through these two snapshot periods, resulting in a continuously increasing savings rate and a higher capital-output ratio. This happens to such an extent that, by 2012 (**Panel C**), the combinations are located 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.

⁴⁵Figure E3 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.

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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/Rural 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.

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

where $\tilde{t} = t/t_z$ and curvature parameter $\lambda_J \in \mathbb{R}$ determines the shape of the technical progress function. Note, the re-scaling of γ_J and t by the fixed point value t_z in (B.1) allows us to interpret γ_a and γ_b directly as the rates of labor- and capital saving technical change at the fixed-point period, when $\tilde{t} = 1$, independently from the same of parameter λ_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:

$$\begin{aligned} \lim_{t \rightarrow \infty} j &\rightarrow \infty & \lambda_J &\geq 0 \\ \lim_{t \rightarrow \infty} j &= -\frac{\gamma_J}{\lambda_J} t_z & \lambda_J &< 0 \end{aligned} \quad (\text{B.2})$$

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

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 γ_J and t by the fixed point value t_z in (B.1). This allows us to interpret γ_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)
σ	1.204*** {1.145:1.263}	1.099*** {1.056:1.142}	1.174*** {1.158:1.191}	1.308*** {1.276:1.340}
γ_b	0.045*** {0.036:0.054}	0.013 {-0.057:0.084}	0.034*** {0.026:0.042}	0.055*** {0.053:0.058}
γ_a	0.020*** {0.010:0.030}	0.043 {-0.016:0.102}	0.050*** {0.033:0.067}	0.014*** {0.007:0.020}
λ_b	0.910*** {0.734:1.086}	1.285 {-14.041:16.612}	0.622*** {0.413:0.831}	1.007*** {0.919:1.094}
λ_a	1.959*** {1.210:2.708}	1.706 {-2.109:5.521}	1.802*** {1.041:2.562}	2.312*** {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, π_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
σ	1.647*** {1.330;1.964}	1.622*** {1.520;1.724}	1.563*** {1.470;1.656}	1.080*** {1.058;1.103}	1.073*** {1.053;1.093}	1.071*** {1.052;1.090}	1.144*** {1.101;1.187}	1.128*** {1.094;1.162}	1.127*** {1.097;1.157}	1.153*** {0.877;1.428}	1.146*** {1.088;1.204}	1.204*** {1.145;1.263}
γ_b	0.068*** {0.066;0.070}	0.068*** {0.066;0.070}	0.068*** {0.065;0.070}							0.034 {-0.045;0.114}	0.034*** {0.018;0.049}	0.045*** {0.036;0.054}
γ_a				0.065*** {0.063;0.067}	0.065*** {0.063;0.067}	0.065*** {0.063;0.067}				0.031 {-0.046;0.108}	0.031*** {0.015;0.047}	0.020*** {0.010;0.030}
γ							0.033*** {0.033;0.034}	0.033*** {0.032;0.034}	0.033*** {0.032;0.034}			
λ_b	1.198*** {1.118;1.279}	1.131*** {1.056;1.206}	1.138*** {1.061;1.216}							0.924* {0.171;1.677}	0.835*** {0.584;1.086}	0.910*** {0.734;1.086}
λ_a				1.144*** {1.026;1.261}	1.097*** {0.982;1.212}	1.012*** {0.897;1.127}				1.611 {-0.030;3.252}	1.680*** {1.108;2.251}	1.959*** {1.210;2.708}
λ							1.217*** {1.117;1.317}	1.141*** {1.046;1.236}	1.013*** {0.914;1.112}			
ξ	0.975*** {0.960;0.991}	0.984*** {0.968;1.000}	0.984*** {0.968;1.001}	0.981*** {0.973;0.989}	0.986*** {0.979;0.993}	0.994*** {0.988;1.000}	0.982*** {0.974;0.989}	0.989*** {0.983;0.995}	1.000*** {0.994;1.005}	0.963*** {0.948;0.978}	0.967*** {0.951;0.983}	0.972*** {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
σ	2.224*** {1.183:3.266}	2.132*** {1.914:2.351}	1.490*** {1.405:1.574}	1.096*** {1.058:1.133}	1.084*** {1.050:1.118}	1.019*** {1.009:1.028}	1.169*** {1.100:1.238}	1.145*** {1.088:1.203}	1.150*** {1.107:1.193}	1.105*** {0.739:1.471}	1.144*** {1.084:1.204}	1.099*** {1.056:1.142}
γ_b	0.061*** {0.051:0.072}	0.058*** {0.049:0.067}	0.058*** {0.050:0.066}							0.004 {-0.177:0.184}	0.035* {0.000:0.071}	0.013 {-0.057:0.084}
γ_a				0.062*** {0.052:0.072}	0.057*** {0.046:0.068}	0.059*** {0.051:0.067}				0.058 {-0.122:0.239}	0.025 {-0.001:0.050}	0.043 {-0.016:0.102}
γ							0.031*** {0.026:0.036}	0.028*** {0.022:0.035}	0.024*** {0.017:0.031}			
λ_b	1.557*** {1.122:1.992}	1.733*** {1.318:2.148}	1.768*** {1.369:2.168}							2.851 {-35.383:41.085}	0.566 {-2.886:4.018}	1.285 {-14.041:16.612}
λ_a				1.152*** {0.680:1.624}	1.376*** {0.833:1.919}	1.620*** {1.237:2.003}				1.017 {-2.064:4.098}	2.273 {-0.403:4.949}	1.706 {-2.109:5.521}
λ							1.326*** {0.867:1.785}	1.532*** {0.957:2.107}	1.848*** {1.039:2.658}			
ξ	0.977*** {0.961:0.992}	0.971*** {0.958:0.984}	0.965*** {0.953:0.978}	0.987*** {0.980:0.995}	0.991*** {0.982:1.000}	0.980*** {0.973:0.987}	0.987*** {0.980:0.995}	0.993*** {0.984:1.002}	1.006*** {0.997:1.015}	0.975*** {0.960:0.990}	0.972*** {0.958:0.985}	0.961*** {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
σ	1.037*** {0.964;1.111}	1.042*** {1.010;1.074}	1.180*** {1.171;1.189}	1.060*** {1.039;1.080}	1.044*** {1.032;1.056}	1.010*** {1.007;1.012}	1.121*** {1.092;1.151}	1.091*** {1.067;1.114}	1.010*** {1.007;1.012}	1.165*** {1.128;1.201}	1.164*** {1.148;1.180}	1.174*** {1.158;1.191}
γ_b	0.085*** {0.077;0.093}	0.080*** {0.074;0.086}	0.062*** {0.058;0.065}							0.030*** {0.021;0.040}	0.031*** {0.024;0.038}	0.034*** {0.026;0.042}
γ_a				0.086*** {0.078;0.094}	0.079*** {0.074;0.084}	0.062*** {0.058;0.066}				0.059*** {0.037;0.082}	0.054*** {0.040;0.069}	0.050*** {0.033;0.067}
γ							0.041*** {0.038;0.045}	0.038*** {0.036;0.040}	0.030*** {0.028;0.032}			
λ_b	1.200*** {1.026;1.373}	1.156*** {1.016;1.297}	0.886*** {0.812;0.960}							0.533*** {0.289;0.777}	0.554*** {0.383;0.725}	0.622*** {0.413;0.831}
λ_a				1.087*** {0.910;1.264}	1.013*** {0.901;1.126}	0.890*** {0.810;0.971}				2.070*** {1.060;3.080}	1.930*** {1.282;2.579}	1.802*** {1.041;2.562}
λ							1.121*** {0.953;1.289}	1.023*** {0.926;1.119}	0.901*** {0.822;0.981}			
ξ	1.315*** {1.295;1.335}	1.305*** {1.287;1.323}	1.304*** {1.289;1.319}	1.146*** {1.136;1.155}	1.138*** {1.131;1.145}	1.117*** {1.111;1.123}	1.144*** {1.135;1.153}	1.138*** {1.131;1.144}	1.117*** {1.112;1.123}	1.303*** {1.277;1.328}	1.297*** {1.279;1.315}	1.303*** {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
$rmsc(\zeta_N)$	0.043	0.042	0.038	0.025	0.028	0.041	0.026	0.027	0.042	0.017	0.017	0.017
$rmsc(\zeta_K)$	0.045	0.045	0.057	0.035	0.034	0.042	0.029	0.031	0.044	0.023	0.023	0.024
$rmsc(Y)$	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
σ	1.716*** {1.420;2.011}	1.697*** {1.615;1.778}	1.994*** {1.954;2.035}	1.078*** {1.065;1.092}	1.083*** {1.072;1.095}	1.091*** {1.082;1.099}	1.155*** {1.125;1.184}	1.151*** {1.125;1.177}	1.179*** {1.168;1.190}	1.309*** {1.110;1.509}	1.248*** {1.219;1.277}	1.308*** {1.276;1.340}
γ_b	0.068*** {0.066;0.070}	0.068*** {0.067;0.069}	0.067*** {0.065;0.069}							0.056*** {0.043;0.068}	0.051*** {0.047;0.054}	0.055*** {0.053;0.058}
γ_a				0.078*** {0.076;0.080}	0.079*** {0.077;0.080}	0.080*** {0.078;0.082}				0.013 {-0.003;0.029}	0.019*** {0.012;0.026}	0.014*** {0.007;0.020}
γ							0.037*** {0.036;0.038}	0.037*** {0.036;0.038}	0.037*** {0.036;0.038}			
λ_b	1.111*** {1.053;1.170}	1.087*** {1.027;1.147}	0.864*** {0.804;0.924}							1.032*** {0.892;1.171}	0.978*** {0.871;1.084}	1.007*** {0.919;1.094}
λ_a				1.122*** {0.997;1.247}	0.986*** {0.904;1.068}	0.845*** {0.779;0.910}				2.393*** {0.654;4.133}	2.022*** {1.152;2.892}	2.312*** {1.179;3.445}
λ							1.204*** {1.109;1.299}	1.089*** {1.023;1.156}	0.815*** {0.769;0.861}			
ξ	0.943*** {0.928;0.959}	0.942*** {0.926;0.957}	0.971*** {0.949;0.992}	0.962*** {0.954;0.970}	0.970*** {0.964;0.976}	0.982*** {0.978;0.986}	0.963*** {0.955;0.971}	0.972*** {0.966;0.977}	0.995*** {0.992;0.997}	0.930*** {0.917;0.944}	0.933*** {0.921;0.944}	0.933*** {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
$rmse(s_N)$	0.026	0.024	0.031	0.026	0.026	0.027	0.026	0.025	0.023	0.021	0.021	0.021
$rmse(s_K)$	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*** (0.004)	-0.047*** (0.011)	0.025*** (0.005)	0.135*** (0.017)
Open ²	0.001*** (0.000)		-0.002*** (0.000)	
Import Content of Exports		7.105*** (0.736)	-1.745 (1.500)	
ICT Goods Exports*		0.057*** (0.012)	-0.019 (0.039)	
ICT Goods Imports**		0.069* (0.027)	-0.134*** (0.023)	
Tariff Rate [†]		-0.023* (0.010)	-0.016* (0.007)	
Tariff Rate (Manufacturing)		-0.019* (0.009)	-0.015 (0.009)	
Tariff Rate (Primary)		-0.037*** (0.006)	-0.004 (0.010)	
High-Tech. Exports [‡]		0.032*** (0.006)	0.012 (0.013)	
Adj. R ²	0.555	0.845	0.851	0.567
	0.262	0.352	0.267	0.642
	0.400	0.546	0.715	0.408
	0.139	0.656	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*** (0.002)		0.022*** (0.004)	
Patent Applications, Nonresidents (Number)	7.206e-6*** (1.220e-6)		6.292e-6*** (1.624e-6)	
Patent Applications, Residents (Number)	1.34e-6 (8.36e-7)		2.053e-6*** (6.360e-7)	
RnD Expenditure (% GDP)		0.559*** (0.132)		0.298 (0.186)
RnD Workers (per million people)			0.0012*** (0.0002)	1.004e-4 (3.26e-4)
Adj. R ²	0.715	0.642	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*** (0.004)	-0.040 (0.044)		0.044*** (0.006)	0.130*** (0.043)	
Urban Population Share ²		0.0001 (0.0001)		-0.0013** (0.0007)		
Air Transport Freight		4.44e-5*** (8.91e-6)		7.33e-5*** (9.98e-6)		
Railways Goods Trans		4.172e-7*** (7.66e-8)		5.876e-7*** (8.4e-8)		
Railways, Passengers Carried*		1.253e-6*** (2.44e-7)		1.763e-6*** (2.270e-7)		
Share of Electricity From Coal		0.017** (0.006)		0.047*** (0.006)		
CO ₂ emissions		9.16e-8*** (2.27e-8)		1.638e-7*** (2.06e-8)		
Adj. R ²	0.418	0.495	0.456	0.189	0.439	0.698
			0.575		0.576	0.581
			0.490		0.581	0.603
			0.754		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 θ we have a final realized estimated value, $\hat{\theta}$, conditional on the range of initial conditions tried: i.e., $\hat{\theta} | \theta_0 \in [\underline{\theta}, \bar{\theta}]$.

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 γ_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, σ and γ_a . In **E.2** is the γ_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 σ and γ_a are being varied between $0.5 - 2$, and $0 - 0.3$, and then for a fixed initial condition for γ_b , we plot the regions for $\hat{\gamma}_a$. As we can see when σ is initially set below 1 we derive negative γ_a values irrespective of the initial condition given to γ_a . In **(Panel b)** we do the same but plot the regions where the estimated value of σ ends up. In **(Panels c-e)**, we again hold the initial value of γ_b fixed and vary the initial conditions of σ and γ_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 $\hat{\sigma}$ 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 σ is just above unity and γ_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 γ_b initial condition where the estimated values of γ_a and σ reside. The most plausible region is the upper right quadrant in the small light blue box where γ_b estimated is around 0.05 and γ_a is around 0.01 and $\hat{\sigma}$ is around $1.4 - 1.8$.

FIGURE E.1: TRUST REGIONS I

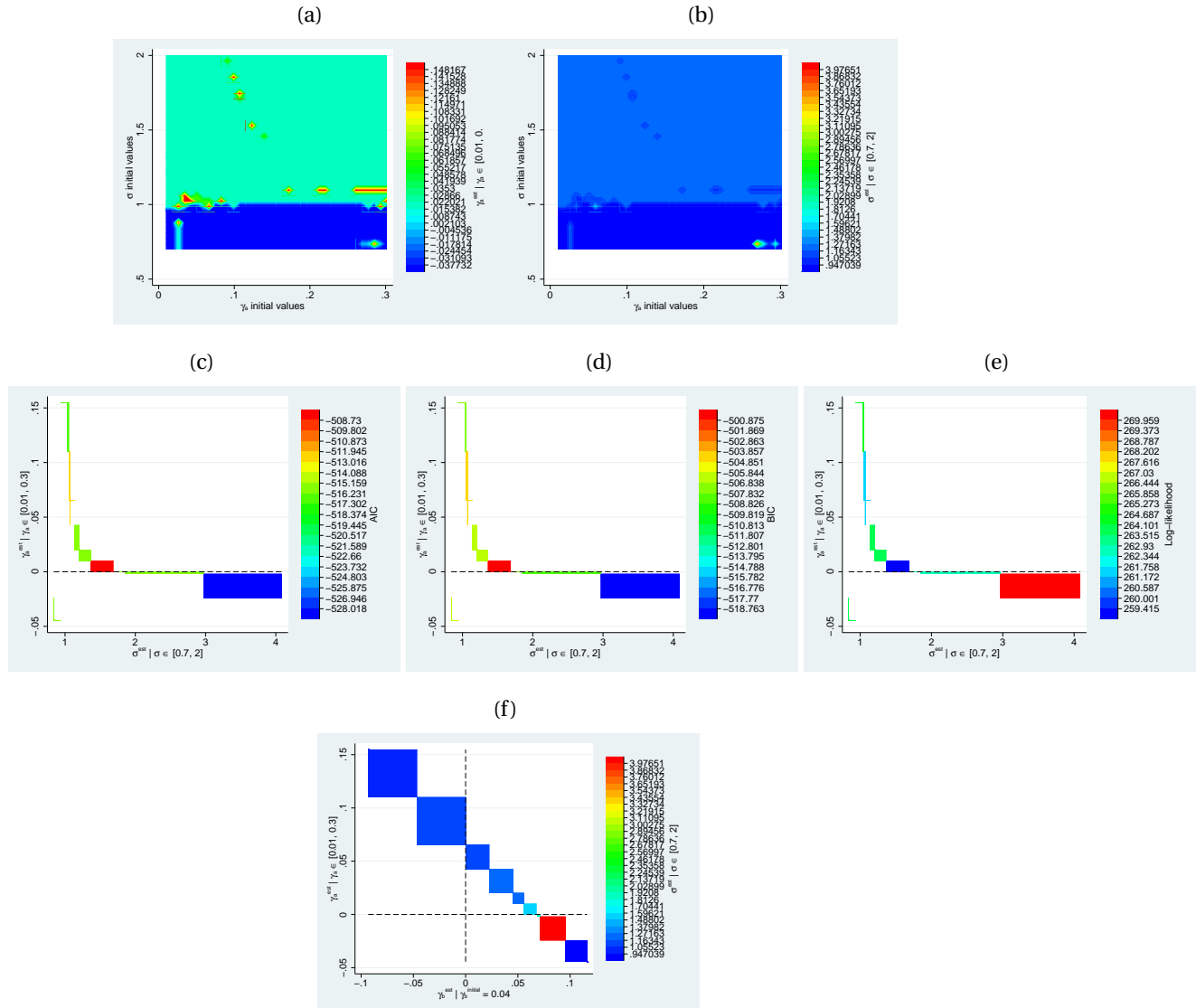
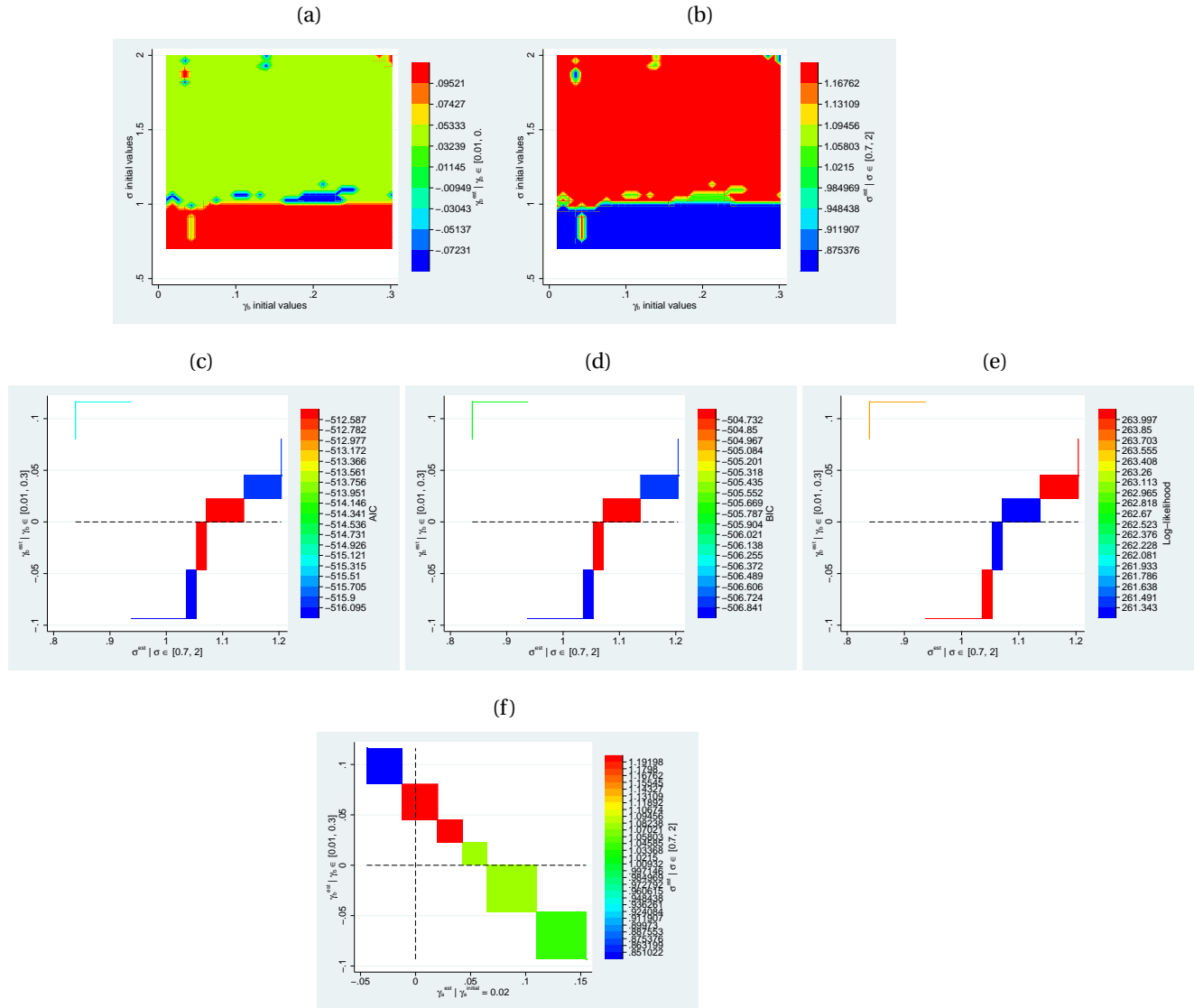


FIGURE E.2: TRUST REGIONS II



F Additional Figures

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

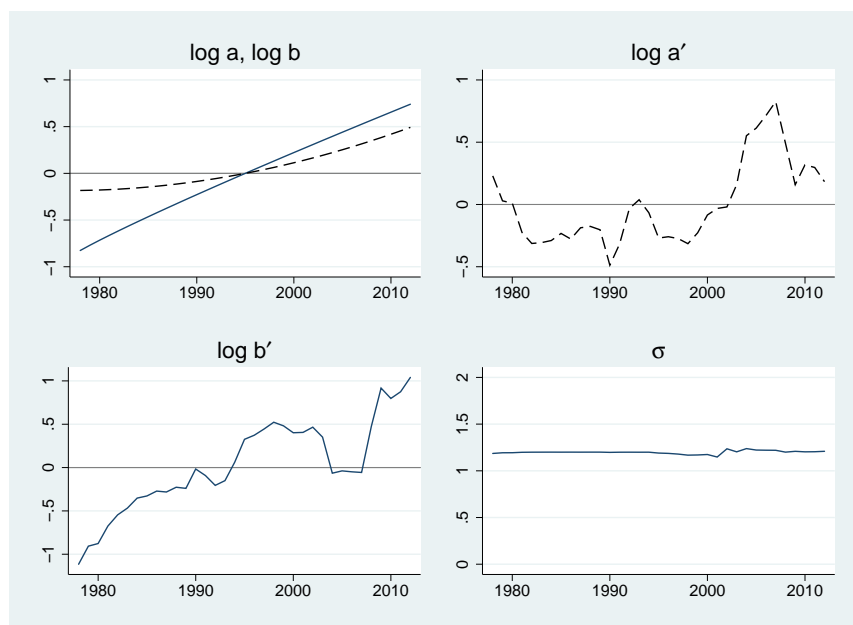


FIGURE F.2: RECURSIVE ESTIMATION OF AUGMENTING CASE OF TABLE 1

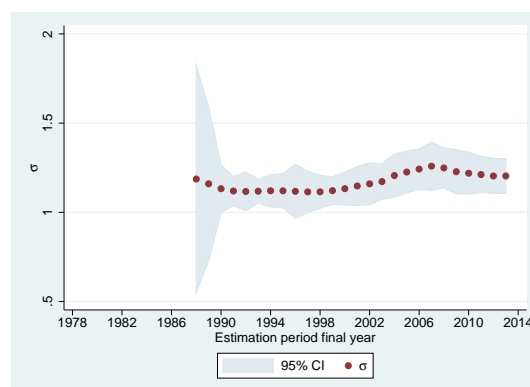
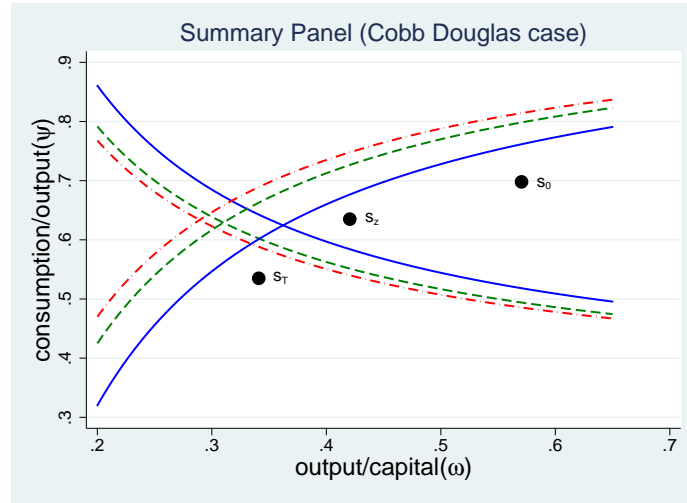


FIGURE F.3: TRANSITIONAL DYNAMICS OF CONSUMPTION AND CAPITAL



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

Recalling figure 8, we draw investment schedules conditional on three σ cases: the Leontief, linear and $\hat{\sigma}$ cases. We see that everywhere except in the common normalization point A_z the curve corresponding to $\sigma \rightarrow \infty$ 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 σ .

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 σ shifts k^* to the right, this implies a longer lasting transition period during which growth exceeds the BGP rate.

1. **Disequilibrium: Degenerative Growth** If $0 < \frac{S}{R} < \pi_z$, 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 $\frac{S}{R} = 0.41 < \pi_z$. 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 $R \times k$ and never intersects it.

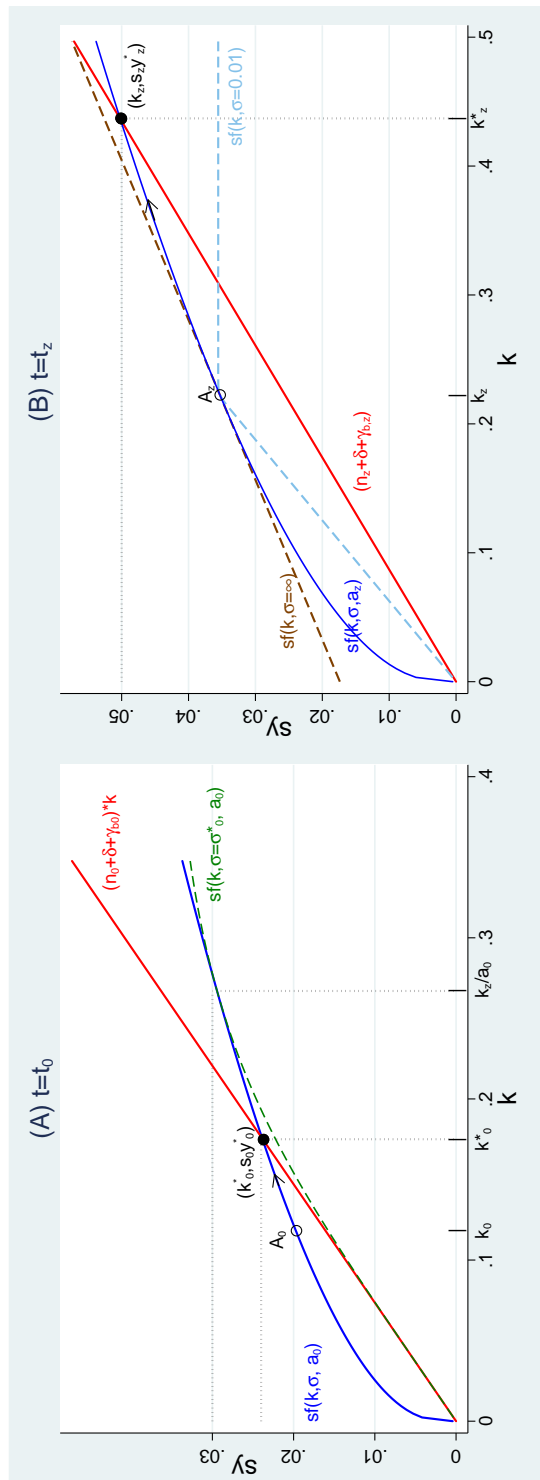
2. **Convergence** If $1 > \frac{S}{R} > \pi_z \Rightarrow \sigma^* < 0$. Now independently from the size of $\sigma \in [0, \infty)$ there is a finite k^* towards which the economy converges.

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

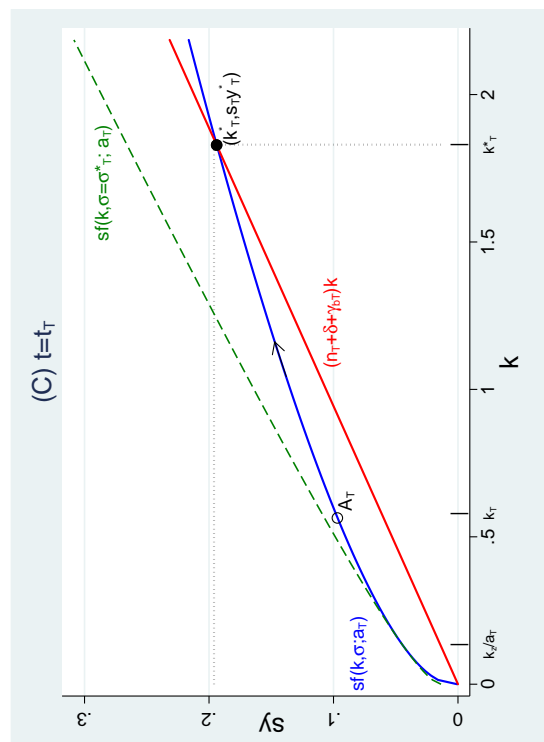
3. **Disequilibrium: Perpetual Growth** If $\frac{S}{R} > 1 \Rightarrow \sigma^* > 1$. Now with $\sigma \geq \sigma^* > 1$ the economy is in the disequilibrium regime of perpetual growth. With the values $\sigma \in [0, \sigma^*)$ there is a finite k^* towards which the economy converges.

(Panel C) captures this alternative since $\frac{S}{R} = 1.59 > 1 \Rightarrow \sigma^* = 2.47$. There we drew also the investment schedule corresponding to this σ^* . We see that it becomes parallel to the ray when $k \rightarrow \infty$, 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 σ denotes the estimated value of $\hat{\sigma} = 1.2$.



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 σ . 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 decelerate 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 confirm 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.

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Study	Sample	PF Assumption	Nesting structure	σ	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 1.022 LL=KK=-0.0218 (-0.0156)	σ TFP growth of 2.98% $\lambda_L = 0.0036$; $\lambda_K = 0.0036$; TP is labor-using and capital-saving	-	-	-	-
Shen and Whalley (2013)	1979-2006	Two-level CES	normalized (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; neutral TP, CRTS	Hicks- (K, H)	Implied σ 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 sumption	As- Nesting struc- ture	σ	Productivity growth	L and K augmented TP	Output elastic- ity wrt K	Time coeffi- cient	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- λ L=-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 fixed factor shares	PF, 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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