What's Wrong with *Capital in the Twenty-First Century*'s Model?*

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1 Introduction

The lasting contribution of Thomas Piketty's *Capital in the Twenty-First Century* is to demonstrate the importance of better measurement in economics. Focusing on inequality, Piketty broadens the set of facts available in multiple dimensions. He develops new national accounts statistics to examine a much longer historical time period than economists typically study, and uses administrative micro data to create new measures of inequality such as the top one percent's share of national income. Piketty's facts bear on questions typically asked by macroeconomists – on capital's share of income – and by microeconomists – on inequality

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in labor income. For example, Piketty demonstrates that the capital share exhibits a long cycle over the past century, and that the income of top earners has increased much faster than the rest of society.

But the animating force behind the predictions in *Capital in the Twenty-First Century* – that inequality will explode and that owners of capital will take an increasingly large share of national income – is its economic model. This model harkens back to Marx's *Das Kapital*, and motivates the main policy prescription of a global wealth tax. Does it hold up to critical scrutiny?

In this chapter, I first present the economic model of *Capital in the Twenty-First Century*. Piketty's model predicts that a decline in economic growth will raise the capital share so long as the elasticity of substitution between capital and labor is greater than one. Therefore, I examine Piketty's estimation strategy for this elasticity in relation to the broader evidence on capital-labor substitution, and explain why most of the estimates of the elasticity are much lower than Piketty's estimate. I conclude by suggesting two other reasons for a rising capital share, labor saving technological progress and exposure to international trade, and discuss the empirical evidence supporting them.

2 Model

In *Capital in the Twenty-First Century*, Piketty uses the standard neo-classical growth model of Solow (1956) and Swan (1956) to examine the evolution of the capital-output ratio – his Second Law of Capitalism – and the capital share – his First Law of Capitalism. In particular, Piketty is interested in how a decline in economic growth, perhaps due to demographic change, would affect the capital share. Changes in the capital share affect the level of inequality in society, because, as Piketty documents, capital ownership is heavily concentrated in a few hands.

2.1 Second Law

Piketty's Second Law governs the steady-state value for the capital-output ratio, which Piketty denotes as β. In each period, savings S_t equals investment I_t. Piketty assumes that net savings is a constant s fraction of net output Y_t, so $S_t = sY_t$. In other parts of his book, Piketty examines the implications of savings rates and rates of return to capital that vary across capital owners. These are, however, not part of his explicit model, and I will not cover them in this chapter.

On a balanced growth path, capital K_t and output Y_t grow at a constant rate g over time, so the investment to capital ratio is constant and equal to the growth rate. After rearranging terms, these assumptions imply:

$$\frac{sY}{K} = g \tag{1}$$

$$\beta = \frac{K}{Y} = \frac{s}{g} \tag{2}$$

In other words, the capital-output ratio β is constant over time and equal to the savings rate s divided by the growth rate g over the balanced growth path. Piketty uses this relationship to predict that, if the growth rate falls, the capital-output ratio will rise. For example, with a savings rate of 12 percent, a fall in the growth rate from 3 percent to 1 percent would increase capital from 4 to 12 times net output.[1]

2.2 First Law

Piketty's First Law is simply an accounting identity; the capital share of income, which Piketty denotes as α, is the rental rate of capital r times the capital-output ratio β:

$$\alpha = \frac{rK}{Y} = r\beta \tag{3}$$

If factor markets are competitive, capital's rental price will be equal to its marginal product. To calculate the marginal product, I assume, for simplicity, a CES production function[2]:

$$Y_t \quad = \quad [a(A_t^K K_t)^{\frac{\sigma-1}{\sigma}} + (1-a)(A_t^L L_t)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}} \tag{4}$$

L_t is labor. Productivity can both augment capital – A_t^K – and labor – A_t^L. A larger A_t^K is thus akin to more capital, and a larger A_t^L to more labor.

The substitution elasticity σ is the elasticity of the aggregate capital-labor ratio K/L to a change in relative factor prices w/r:

$$\sigma = \frac{\mathrm{d}\ln K/L}{\mathrm{d}\ln w/r} \tag{5}$$

[1] Krusell and Smith (forthcoming) criticize Piketty's assumption of a constant net savings rate, and point out that both a constant gross savings rate, or an endogenous rate of savings, would reduce how much the capital-output ratio rises with a fall in the growth rate, and eliminate the explosion of the capital-output ratio when growth falls to zero. The qualitative implications of Piketty's model on a rise in the capital-output ratio with a fall in the growth rate would remain unchanged, however.

[2] The CES production function nests a number of special cases, including a Leontief fixed proportions production function when σ is 0, a linear production function when σ is infinite, and a Cobb-Douglas production with capital coefficient a when σ is one.

The marginal product of capital, and thus the rental price r, is:

$$r = \frac{\mathrm{d}Y}{\mathrm{d}K} = a((A^K)^{1-\sigma}\beta)^{-\frac{1}{\sigma}} \tag{6}$$

After substituting in how the rental price responds to changes in β and the Second Law, the First Law becomes:

$$\alpha = a(A^K\beta)^{\frac{\sigma-1}{\sigma}} = a(A^K\frac{s}{g})^{\frac{\sigma-1}{\sigma}} \tag{7}$$

Piketty envisions a scenario in which population growth slows but technology, including A^K, remains the same. In that case, β will rise and the rental price r will fall. Predictions about the capital share then depend upon the degree of capital-labor substitution. When capital is more substitutable with labor, more use can be made of the extra capital and so the fall in the rental price is smaller. If, as Piketty assumes, the elasticity of substitution σ is above one, the fall in g will also increase the capital share α.

3 Piketty's Estimation Strategy

Piketty's prediction that falling economic growth will raise the capital share depends upon how well capital can substitute with labor. To identify the capital-labor substitution elasticity, Piketty uses the relationship between the capital share α and capital-output ratio β encapsulated in equation (7). Over a long historical time period, Piketty documents that both α and β exhibit a U shape, declining from 1910 to 1950 and rising from 1980 to 2010. Piketty then identifies the elasticity through the co-movement of these series, assuming that the movement in β causes the movement in α. He states that:

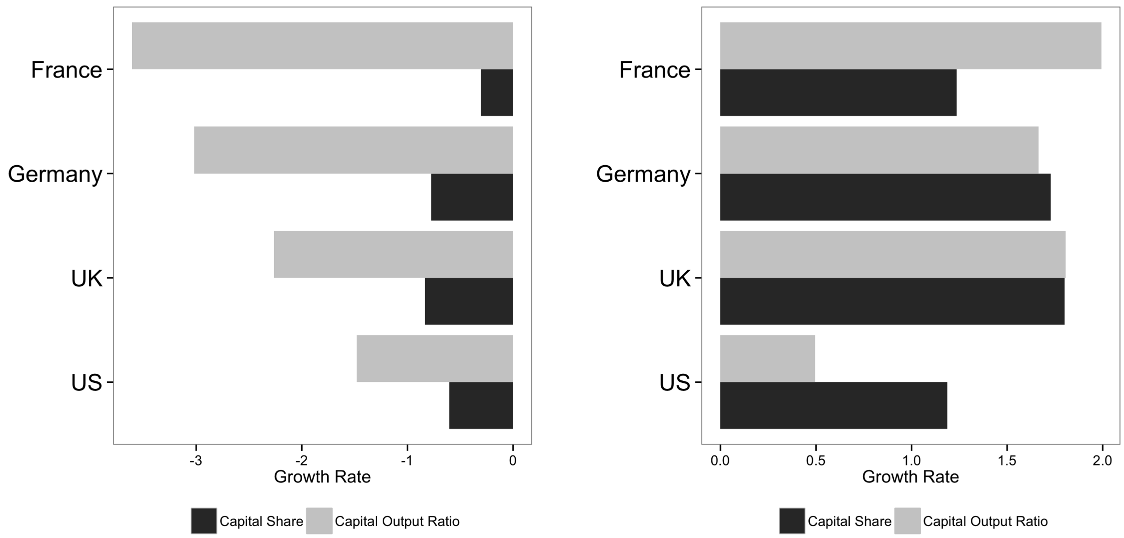
> Given the variations of the capital share observed during the 20th century, and the observed increase in rich countries during the period 1970–2010, we can conclude that this variation can be adequately explained with an elasticity of substitution slightly higher than 1 (1.3–1.6).

Figure 1 displays the growth rate in the capital-output ratio β and capital share α for the four countries for which Piketty develops a long time series of observations – France, Germany, the UK, and the US. The light grey bars indicate the capital-output ratio and the black bars the capital share; the growth rate of each variable is depicted for both 1910 to 1950 (1929 to 1950 for the US), and 1980 to 2010. For all four countries, both series decrease in the early period and increase in the later period. The decline in β is much greater than α in the early period, while for the later period α grows faster than β for the US, slower for France, and about the same for the UK and Germany.

A more formal approach to estimation using Piketty's identification strategy would be to regress α on β, as in equation (7). I do so using data from all four countries in Figure 1 over the same time period, using data points for 1910 (1929 for the US), 1950, 1980, and 2010. The estimated value of the elasticity is 1.34, within the range that Piketty reports.

3.1 Measurement of Capital

The estimation strategy above requires data on the capital-output ratio β. Piketty measures capital in β by using the total value of wealth. Thus, he measures capital at its market value, so changes in the valuation of capital will affect Piketty's measure of β, as Rowthorn (2014)



(a) 1910–1950

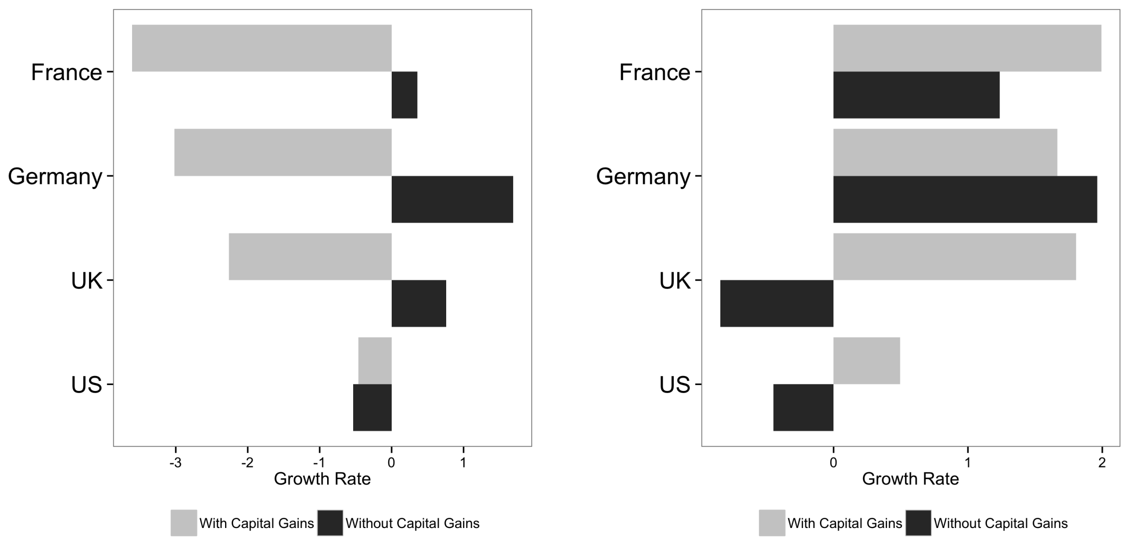
(b) 1980–2010

Figure 1 Growth Rate in the Capital-Output Ratio and Capital Share

Note: Estimates based upon data provided by Piketty and Zucman (2014), and are in percent change per year. The US changes in the early period are based upon the 1929 – 1950 period rather than the 1910 – 1950 period as capital share data is not available for 1910 for the US.

and Rognlie (2015) point out. But changes in the valuation of capital should only affect production if they reflect changes in the quantity of effective capital. Piketty's estimating equation, equation (7), contains the product of the capital used in production and capital augmenting technology A^K as the correct measure of effective capital.

Many of the economic shocks that Piketty describes would affect the market value of capital without necessarily changing the amount of capital used in production. Take, for example, an increase in the probability that a factory is nationalized in the future. Since the market value of the capital in the factory depends upon its future income stream, the market value of the capital would decline. But nothing has changed in production: the factory continues to have the same amount of capital in production and the same production process.



(a) 1910–1950

(b) 1980–2010

Figure 2 Growth Rate in the Capital-Output Ratio, With and Without Capital Gains

Note: Estimates based upon data provided by Piketty and Zucman (2014), and are in percent change per year.

The empirical analog to removing valuation effects is to remove capital gains from measures of β. In other words, the alternative is to measure capital at its book value. While measuring capital at book value removes valuation effects from β, it also removes intangible capital such as patents and brand value.

On a book value basis, β does not exhibit the U shape movement over time that the capital share does. Figure 2 displays the growth rate in β for the same four countries as above; the light grey bars include capital gains and the black bars exclude capital gains. Including capital gains, we see a clear U in all four countries; β decreases from 1910 to 1950 and increases from 1980 to 2010. Excluding capital gains, no country exhibits the U shape. β increases for all of the European countries from 1910 to 1950, and only decreases for the US. From 1980 to 2010, β falls for the Anglo-Saxon countries.

Both Rognlie (2015) and Bonnet et al. (2014) emphasize the role of housing capital, and rising housing prices, in the recent increases in β. Bonnet et al. (2014) argue that a rent measure more closely approximates the actual increase in housing capital. They find that, under a rent based measure, the capital-output ratio is stable or only slightly increasing for the France, the UK, and the US, unlike the price based measure that Piketty uses. The rent based measure does increase for Germany. Again, movements in β are very different after removing valuation effects. Policy changes that increase housing prices – for example, regulations that make it difficult to build new houses – may not improve housing services.

4 Capital-Labor Substitution

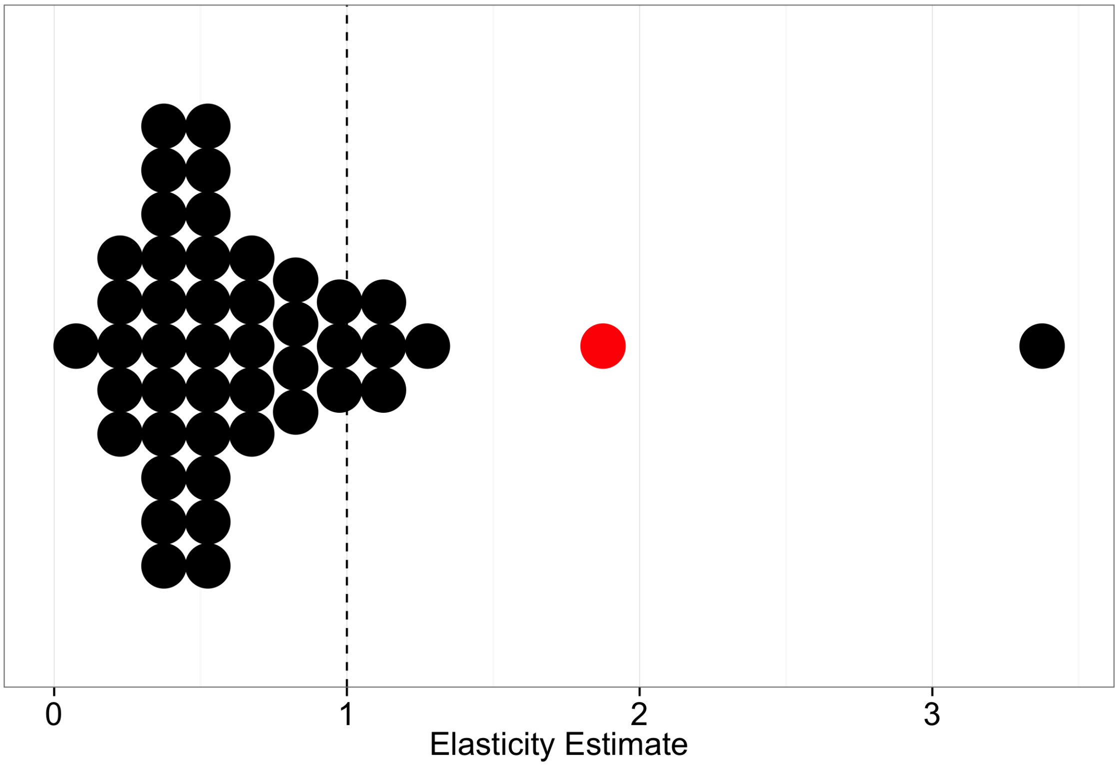
Piketty's estimates of σ are much higher than the typical estimate in the existing literature on capital-labor substitution. To compare to the literature, I convert Piketty's estimates to an elasticity based on a production function gross of depreciation. On a gross basis, Piketty's estimates range between 1.7 and 2.1.[3] Figure 3 depicts estimates found in the literature, based on 44 estimates compiled by literature surveys by Chirinko (2008) and Leon-Ledesma et al. (2010) as well as several papers written after these surveys. Piketty's estimate is in red. The median estimate in the literature is 0.54, only a few estimates are above one, and

[3] Rognlie (2015) derives the relation between the net and gross elasticity:

$$\frac{\sigma^N}{\sigma^G} = \frac{r^N K/Y^N}{r^G K/Y^G} = \frac{\alpha^N}{\alpha^G} \tag{8}$$

Here, N stands for the net value and G for the gross value. The ratio of the net to gross elasticity is equal to the ratio between the net capital share and the gross capital share. The net elasticity is always below the gross elasticity because the net capital share is always below the gross capital share. The intuition here is that any change in the gross return is a larger change in the net return, so, given the change in K/L is the same, the net elasticity must be smaller than the gross elasticity. Using data collected by Piketty and Zucman (2014), the gross capital share has been about 30 percent higher than the net capital share for the US on average over the 1970-2010 period. Also see Bridgman (2014) for the difference between the net and gross capital share.

Figure 3 Elasticity Estimates in the Literature



Note: This plot depicts elasticity estimates based on surveys in the literature by Chirinko (2008) and Leon-Ledesma et al. (2010), as well as a number of papers written after those surveys.[a] The red dot is the median of the estimates reported by Piketty. The vertical dashed line indicates an elasticity of one.

[a]These additional papers are Oberfield and Raval (2014), Raval (2014), Karabarbounis and Neiman (2014), Herrendorf et al. (2014), Alvarez-Cuadrado et al. (2014), **?**, **?**, and Lawrence (2015).

almost all are below Piketty's estimates.

Of course, the estimates in the literature vary across several factors, including the time period and country examined, the assumptions made on technical progress, the level of aggregation, and the econometric technique employed. Why does Piketty get such different estimates from the existing literature? And how should one go about estimating the capital-labor substitution elasticity? In other words, what conclusion should one draw about the validity of Piketty's estimate?

4.1 Identification

To answer these questions, we first turn to the topic of *identification*. An econometric parameter is identified if the data is only consistent with a single value for the parameter.

The identification strategy that Piketty uses – the historical co-movement of α and β – does not identify the elasticity without further assumptions on technology. Diamond et al. (1978) prove that, for any value of the elasticity, some path of movements in technology – productivities A^K and A^L – can rationalize the movements in α and β. Intuitively, change in the capital share can come from relative factor supplies or relative factor demands. Identification requires assumptions about which is moving, such as restrictions on how technology evolves or exogenous movements in factor prices or quantities.

The implicit assumption behind Piketty's identification strategy is that A^K, capital augmenting productivity, is either constant over time, or not correlated with changes in β. It is not obvious how to check whether these assumptions are true. A constant A^K is consistent with a long run balanced growth path, although as Acemoglu (2003) show, there may be considerable movements in A^K in the medium run. Econometric approaches that allow for movements in A^K typically find that A^K is not constant. For example, Antras (2004) estimates an average fall in A^K of 1.3 to 1.6 percentage points per year over the post-war period.[4] A correlation between A^K and β due to their medium or long run trends could lead to substantial bias in any estimate of the elasticity.

[4] Klump et al. (2007) estimate a *rise* of about 0.4 percentage points per year. However, the main difference between these estimates is that Antras (2004) uses a capital deflator series from Krusell et al. (2000), based on earlier work by Gordon (1990), that declines more steeply over time than the NIPA deflators used by Klump et al. (2007).

4.2 Macro Estimates

The key issue with any estimate of the elasticity is how to confront the identification problem highlighted by Diamond et al. (1978); that is, what to assume about movements in technology. Most estimates of the capital-labor elasticity are, like Piketty, based upon the aggregate time series, but examine how changes in factor prices affect factor costs. Take, for example, the equation for the capital cost to labor cost ratio $\frac{rK}{wL}$, derived from equation (5) after substituting in expressions for marginal products:

$$\ln \frac{rK}{wL} = \sigma \ln \frac{a}{1-a} + (\sigma - 1) \ln \frac{w}{r} + (\sigma - 1) \ln \frac{A^L}{A^K} \tag{9}$$

In this equation, one has to make assumptions on the change in $\frac{A^L}{A^K}$, which I will call the bias of technical change. Relative factor prices $\frac{w}{r}$ would identify the elasticity if they were not confounded with biased technical change. One possibility is to assume that $\frac{A^L}{A^K}$ is constant over time, so all technical change is neutral and there is no biased technical change; this is Piketty's implicit assumption. In that case, movements in relative factor prices $\frac{w}{r}$ identify the elasticity. Another assumption is that $\frac{A^L}{A^K}$ is exponentially growing over time. In that case, equation (9) above contains a time trend, and variation in relative factor prices *away from their long run trend* identifies the elasticity. A third possibility is that the rate of biased technical change itself varies over time.

Below, I show how estimates of the elasticity change by estimating equation (9) under three different assumptions on biased technical change: allowing only neutral technical change, allowing for a constant rate of biased technical change through a time trend, and allowing for the rate of biased technical change to vary over time through a Box–Cox transformation as in Klump et al. (2007).[5] I use data on US manufacturing from 1970 to 2010.

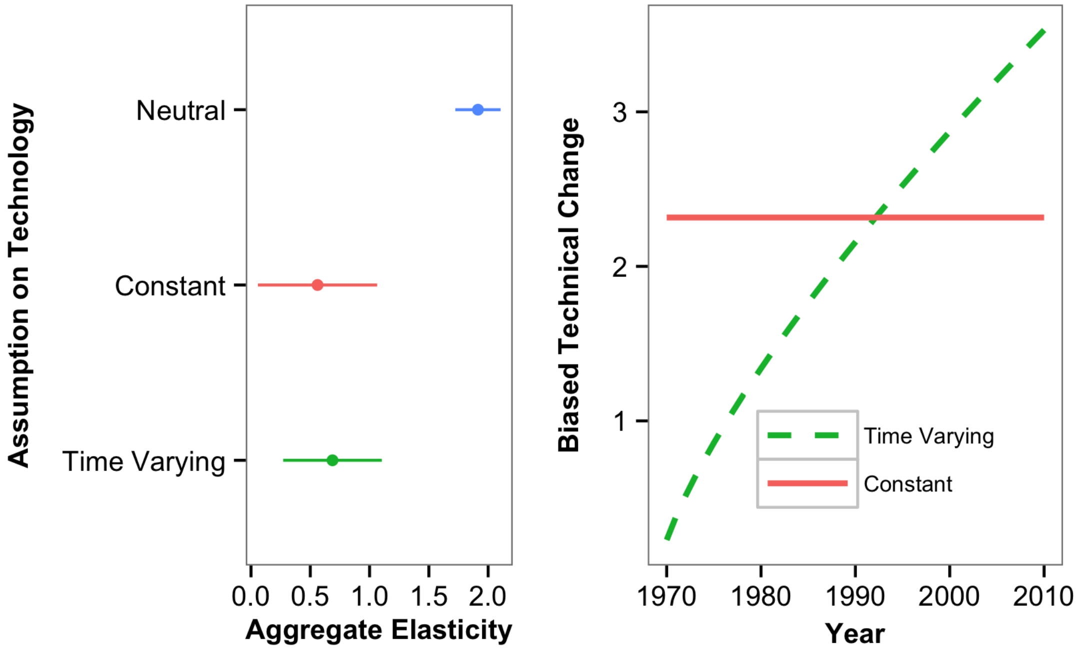
The left figure of Figure 4 contains these estimates and their 95 percent confidence intervals. With no control for biased technical change, the estimate of the elasticity is precisely estimated at 1.9 and within the range of Piketty's estimates. After allowing for biased technical change, however, the estimate of the elasticity falls to 0.56 for a constant rate of bias and 0.69 for a time-varying rate of bias. These estimates are much more imprecise than the case without biased technical change. The estimated confidence intervals in both the constant and time-varying bias cases include one; the confidence interval in the constant bias case ranges from 0.05 to 1.07. Intuitively, with biased technical change, there is less identifying variation in factor price changes.

The right figure of Figure 4 displays the rate of biased technical change, in percentage points per year, under each assumption. The regression model with a constant rate of biased technical change estimates a rate of biased technical change of 2.3 percent per year. Under the time-varying Box–Cox model, the rate of biased technical change increases from almost zero in 1970 to over 3.5 percent per year in 2010.

The above analysis on US manufacturing data showed that elasticity estimates fall below one once the econometric specification includes some controls for biased technical change. Similarly, the recent literature allowing for biased technical change has, in general, estimated elasticities below one. For example, Antras (2004) estimates an elasticity of one using the US aggregate time series assuming technological change is neutral, but significantly below

[5] The Box–Cox transformation implies that $d \log \phi = \gamma t^{\lambda}$; λ allows the rate of biased technical change to vary over time.

Figure 4 Elasticity and Bias Estimates from Aggregate Data



Note: The left plot displays the point estimate and 95 percent confidence interval for the aggregate elasticity of substitution from regressions based on equation (9). Specifications differ in assumptions on the bias of technical change. Technical change is respectively assumed to have no trend, follow a linear time trend, or follow a Box–Cox transformation of the time trend. The right plot displays the bias of technical change in percentage points, from either a linear or Box–Cox specification of the time trend.

one (between 0.6 and 0.9) after allowing exponential growth in A^K and A^L.[6]

Econometric approaches to estimating the aggregate elasticity still have to confront two major issues. First, there may not be enough identifying variation in the aggregate time series to estimate the elasticity after controlling for biased technical change. Leon-Ledesma et al. (2010) perform a Monte Carlo analysis to examine this issue. They find that, while it is difficult to obtain the true elasticity using aggregate time series data, a "systems" approach that simultaneously estimates equations for the production function and its marginal products (as in Klump et al. (2007)) performs better than just using information on factor

[6] In addition, see Klump et al. (2007), Herrendorf et al. (2014), Alvarez-Cuadrado et al. (2014), **?**, and Lawrence (2015).

marginal products as in equation (9).

Second, as we saw above, controlling for biased technical change may mean using more high frequency movements in factor prices. If changing factors entails adjustment costs, then these approaches may end up estimating a more short run elasticity. For the questions in *Capital in the 21st Century*, a long run elasticity is the appropriate elasticity. One solution is isolate long run variation in factor prices; for example, Chrinko and Mallick (2014) examine long run variation in rental prices of capital using panel data on US industries. Their estimate of the long run elasticity is much higher than the short run elasticity, but still ranges from 0.40 to 0.65.

The major exception in the recent literature to the finding of an elasticity of substitution below one is Karabarbounis and Neiman (2014). They estimate an aggregate elasticity of 1.25 using cross-country variation in the growth rate of capital prices. The main advantage of their approach is that cross-country variation may help get at the long run elasticity. However, their baseline strategy requires the change in A^K to be the same across countries or uncorrelated with rental price changes. Thus, they are subject to a similar identification problem with changing technology as the earlier literature assuming no biased technical change. In addition, as **?** shows, most countries import almost all of their capital goods, so much of the variation across countries over time may be due to differences in trade liberalization across countries. However, changes in trade patterns and trade barriers can affect the capital share for multiple reasons other than capital prices, as I will discuss in Section 5.1, which would bias any estimates of the elasticity.

4.3 Micro Estimates

As we have seen, it is difficult to separate movements in factor prices from technology in aggregate data without placing strong a priori restrictions on technical change. An alternative approach is to use micro data on firms or manufacturing plants, for which there is arguably more plausibly exogenous, and long run, variation in factor prices for identification.

A couple of recent studies have used micro data to estimate the long run micro elasticity. Chirinko et al. (2011) identify the elasticity using differences in the long run movements in the rental price of capital across US public firms. They control for non-neutral technical change at the industry level, so their identifying assumption is that firm level differences in rental prices have to be independent of firm level changes in A^K. They estimate the elasticity to be 0.40, as does Barnes et al. (2008) using UK firm level panel data with a similar approach.

Raval (2014) identifies the elasticity using differences in wages across US locations; for these estimates, local differences in wages have to be independent of firm A^L. Since differences in wages across locations are highly persistent, this type of variation should help uncover the long run elasticity. Using both OLS and instruments for wages from local demand shocks, I obtain estimates of the elasticity close to 0.5.[7]

To understand movements in the aggregate capital share, the macro elasticity of substitution is required, not the micro elasticity. These elasticities can be very different, as Houthakker (1955) famously demonstrated, because the macro elasticity will incorporate

[7] Doraszelski and Jaumendreu (2014) estimate a structural model in which the elasticity of substitution is equal between capital, labor, and materials. While the estimating variation in factor prices is due to differences between labor and materials prices, their elasticity estimates also range between 0.45 and 0.65, in line with the estimates discussed above.

substitution across producers as well as within them.[8] As Piketty and Zucman (2014) note, “the aggregate elasticity of substitution σ should really be interpreted as resulting from both supply forces (producers shift between technologies with different capital intensities) and demand forces (consumers shift between goods and services with different capital intensities).”

Oberfield and Raval (2014) develop an aggregation framework, based on earlier work by Sato (1975), that models these demand and supply forces in order to estimate the macro elasticity using micro data. For simplicity, take a baseline case of an economy with one industry in which firms maximize profits in a monopolistically competitive environment and face competitive factor markets.[9] In that case, Oberfield and Raval (2014) show that the macro elasticity of substitution between labor and capital, σ^{Macro}, is a convex combination of the micro elasticity of substitution between labor and capital, σ^{Micro}, and the micro elasticity of demand, ε.

$$\sigma^{Macro} = (1-\phi)\sigma^{Micro} + \phi\varepsilon \tag{10}$$

In response to a change in factor prices, the change in factor shares for the economy as a whole includes both substitution within individual plants and reallocation across them. The first term on the right hand side in equation (10) is a substitution effect that captures how plants change their input mixes, and so depends upon the micro elasticity σ^{Micro}. With a rise in the wage, plants will tend to use less labor. The second term is a reallocation effect that captures how the size of plants changes with the change in input prices. When wages rise,

[8] If A^K and A^L have independent Pareto distributions, Houthakker (1955) demonstrated that an economy of firms with an elasticity of zero has a Cobb-Douglas aggregate production function.

[9] Oberfield and Raval (2014) generalize this case to allow for many inputs and industries.

plants that use capital more intensively gain a relative cost advantage. Consumers respond to the subsequent changes in relative prices by shifting consumption toward the capital intensive goods. This reallocation effect is larger when demand is more elastic, because customers respond more to changing relative prices.

The weight between them, ϕ, is proportional to the cost-weighted variance of capital shares and lies between zero and one. When each plant produces at the same capital intensity, ϕ is zero and there is no reallocation across plants. Each plant's marginal cost responds to input price changes symmetrically, so relative output prices are unchanged. In contrast, if some plants produce using only capital while all others produce using only labor, all input substitution is across plants and ϕ is one. When there is little variation in capital intensities, within-plant substitution is more important than reallocation.

This aggregation approach allows one to use micro estimates of the elasticity of substitution to obtain the aggregate elasticity. Oberfield and Raval (2014) do so for the US manufacturing sector. They estimate the plant level elasticities of capital-labor substitution and demand from micro data, and compute the weight ϕ from the cross section of manufacturing plants. Because these elasticities are taken from the cross-section, they make no assumption on movements in technology over time. They estimate a macro elasticity of 0.7, modestly higher than a micro elasticity of about 0.5, but well below Piketty's range.

For the US, the differences in capital intensities across manufacturing plants are not large enough to mean a large difference between the micro and macro elasticities. The low micro elasticities estimated in the literature then imply macro elasticities below one. They do, however, find much larger differences in capital intensities for developing countries, where the prior literature documents major variation in capital intensity. Using the same demand

and supply elasticities as the US, the greater heterogeneity in capital intensities in India implies an elasticity of 1.1.

4.4 Capital-Labor Substitution in the 21st Century

The evidence in Section 4.2 and Section 4.3 points to an elasticity below one. One of the claims that Piketty makes, however, is that the elasticity of substitution has been rising over time. For example, as Piketty shows, most of capital was in land until the Industrial Revolution; Piketty argues that the elasticity between land and labor is less than the elasticity between modern capital and labor. What if new technologies – for example, robots – raise the elasticity of substitution to the levels estimated by Piketty?

Klump and De La Grandville (2000) examine this question within the Solow growth model. They prove that an economy with a higher capital-labor elasticity of substitution, with everything else initially equal, will have a higher capital share, per capita income, and per capita income growth. Thus, a higher elasticity of substitution means a richer, although more unequal, society.

With a high enough elasticity of substitution, an economy can have long run growth without technical progress. De La Grandville (1989) show that, provided σ is high enough (and above one), there is a threshold savings rate above which capital and output grow forever. The threshold savings rate increases in the population growth rate and decreases in the elasticity σ. The intuition here is that with a high enough elasticity, the marginal product of capital remains large even with a large capital stock, and so capital continues to grow faster than the rate of population growth so long as the economy saves enough of its output.

Even at the upper end of Piketty's estimates of the elasticity, the savings rate must be substantially higher, and population growth rate lower, in order for the perpetual growth scenario to hold. However, if Piketty's feared scenario comes to pass – a high elasticity of substitution and a low population growth rate – the Solow growth model implies that the economy would experience unbounded growth!

4.5 Capital Taxation

Piketty's main policy proposal to counteract increasing inequality from capital is a progressive capital tax. The desirability of this proposal, however, depends on the validity of Piketty's elasticity estimates. Given a elasticity below one, an increase in capital taxes would actually increase the capital share. In contrast, a reduction in the capital tax would work to reduce the capital share, and thus the level of inequality, through a rise in β.

The traditional argument in favor of capital taxation has been the opposite of Piketty's, arguing that the welfare cost to capital taxation is low because elasticities of substitution are low. Taxation has a welfare cost because people change their behavior in order to avoid the tax; for capital taxation, this is because people substitute away from capital. Chamley (1981) indeed finds that the welfare cost of capital taxation is increasing in the elasticity; the welfare cost is reduced by roughly two-thirds when the elasticity is 0.6 rather than 2. Thus, the welfare cost of capital taxation is much lower given the estimates in Section 4.2 and Section 4.3 than under Piketty's estimates.

5 Alternative Explanations for the Rise in the Capital Share

If Piketty's explanation is incorrect, then why has the capital share risen? Will the capital share continue to rise? In this section, I examine two potential explanations, globalization and labor saving technical change.

5.1 Globalization

The most prominent alternative explanation for the fall in the labor share is the increasing exposure of developed countries to global trade. I focus on the US as most of the literature has examined the US. US imports tripled as a share of GDP from 1970 to 2010, from about 5 percent of GDP in 1970 to about 16 percent in 2010. Trade with China has grown particularly rapidly, from about 1 percent of overall imports of goods to the US in 1985 to 19 percent in 2010.[10] This massive increase in trade from China was due to rapid economic growth in China, as well as China's accession to the World Trade Organization (WTO) in December 2001.

The labor share could fall with increased trade if labor intensive US production shifts to labor abundant countries. Elsby et al. (2013) indeed find that the payroll share falls in industries that are more exposed to imports. They find that industries with an extra percentage point increase in import exposure from 1993 to 2010 have, on average, a 0.87

[10] Data on US imports as share of GDP are from the World Bank Development Indicators, while data on the Chinese share of goods trade are from the US Census.

percentage point fall in the payroll share.[11] For example, for manufacturing as a whole, their estimates imply that increased import exposure from China over this period reduced the payroll share by about 8 percentage points. The realized increase in imports can explain about 85 percent of the 1993 – 2010 fall in the aggregate payroll share.

This fall in the labor share could be due to decreases in employment, decreases in wages, or falls in both employment and wages. Acemoglu et al. (forthcoming) find that exposure to Chinese trade led to US job losses of 2.0 to 2.4 million over the 2000s. Autor et al. (2013) examine how increasing exposure to Chinese imports affects different local labor markets across the US; some US labor markets are heavily exposed to manufacturing industries that experience a large rise in Chinese imports. In these markets, they find that the rise in Chinese imports affects both employment and wages.[12] For a \$1,000 rise in Chinese exports per worker in a ten year period, manufacturing employment in the local labor market falls by 0.60 percentage points (or 4.2 percent), and employment to population falls by 0.77 percentage points. Wages fall by three-quarters of a percent for a \$1,000 rise in Chinese exports per worker. For the local labor market with the 90th percentile increase in Chinese imports per worker, the increased import exposure from China from 2000 to 2007 would have reduced both employment and wages by about 3.25 percentage points.

The authors then examine these changes by manufacturing and non-manufacturing sectors; they find economically substantial and statistically significant falls in employment, but not wages, for the manufacturing sector, and the reverse pattern for the non-manufacturing

[11] They define import exposure as the percentage increase in value added if all output was to be produced domestically. Payroll is one component of labor income in addition to self-employment income.

[12] They define Chinese exports per worker by dividing Chinese imports across regions based on industry employment shares in the initial period. They examine changes between 1990 and 2000 and between 2000 and 2007.

sector. In addition, Chetverikov et al. (2015) find that low wage earners bear the brunt of the trade-induced fall in wages. Thus, increasing import competition likely affects the labor share both through changes in employment and wages, with different impacts for different types of workers.

Manufacturing employment could fall through a number of channels; labor intensive manufacturing producers could exit, could grow slower, or could produce products that require more capital intensive production. Bernard et al. (2006) finds evidence for all of these channels, examining industry level variation in the share of imports from low wage countries such as China. US manufacturing plants in industries with greater increases in the share of low wage country imports are more likely to exit and have lower employment growth – although these effects are smaller for the more capital intensive plants in the industry. They are also more likely to switch to producing products that are more capital intensive and thus face less import competition.

Increased import competition could also affect how firms operate by reducing the bargaining power of labor or by forcing firms to increase productivity in order to compete. Schmitz (2005) and Dunne et al. (2010) examine how incumbent producers in the iron ore mining and cement industries, respectively, responded to a sudden increase in import competition by changing their work practices. In both industries, union contracts specified that different types of repair work could only be performed by specific employees. In the cement industry, union contracts prohibited firing workers due to new equipment or new production methods, provided strict seniority rights, and prevented sub-contracting tasks to outside companies. These requirements, by restricting substitution away from labor or specific types of labor such as senior employees or repair workers, likely increased employment and the labor share.

After a massive surge in import competition, these requirements were mostly eliminated, and productivity and the capital to labor ratio rose.

Bloom et al. (forthcoming) find that Chinese import competition increased a number of measures of innovation – TFP, patents, and IT investment – for producers, and led to reallocation within the industry to producers that had high levels of innovation initially. This innovation could reduce the labor share if it resulted in labor saving technology; the authors do find that employment falls with exposure to Chinese import competition, although less so for the higher innovation firms. It is unclear, however, whether the improvements in innovation were linked to the decline in employment.

5.2 Labor Saving Technical Change

Economists studying technical progress have found that the adoption of "General Purpose Technologies" – for example, steam power or electricity – have had wide ranging impacts throughout the economy (Bresnahan and Trajtenberg (1995)).[13] The latest such General Purpose Technology has been the massive improvement in computing power and information technology in recent decades. Can the IT revolution lead to "technological unemployment" and explain the rise in the capital share?

Autor et al. (2003) provide a framework for understanding how new automation technologies affect production. They find that new automation technologies substitute with what they term "routine" labor – labor employed in explicit, codifiable tasks – and complement labor engaged in "abstract" tasks such as high level problem solving, creativity, and per-

[13] See, for example, Morin (2015) for the historical effect of electricity adoption on the labor share in the concrete industry.

suasion. Other "manual" tasks – for example, janitorial work or food preparation – are much less affected by the new technologies. Autor et al. (2003) show that new automation technologies lead to job polarization, as middle-skill routine tasks are automated away and high-skill abstract and low-skill manual tasks grow in demand.

While this type of job polarization clearly affects the wages and employment of different types of workers, it is far less clear how it affects the overall labor share. First, within an industry, a fall in the share of income going to routine task employees could be counterbalanced by a rise in the income share of abstract labor complementary with the new automation technologies. Second, the change in the overall labor share will depend upon how much demand for the industry rises as its price falls, how well workers can change their skills to match changing labor demand, and how well the economy reallocates such workers to other opportunities.

Take, for example, the introduction of the automated teller machine (ATM). As its name suggests, the ATM could perform the same functions as a bank teller. But, as Bessen (2015) document, employment actually increased, both because the number of bank branches rose as the cost of a branch fell, and because bank branches began to use tellers as "relationship managers" rather than merely clerks. Basker et al. (2015) examine the switch of gas stations from full service to self service. In this case, customers are substituting their own labor for the gas station attendant's labor. While Basker et al. (2015) find that employment and payroll fall at gas stations that adopt self service, with the cost savings passed on to consumers in the form of lower gas prices, employment in the gas station industry rises because of workers employed in new convenience stores attached to gasoline stations.

Autor et al. (forthcoming) explicitly compare the effect of automation and trade by examining the effects of both forces on local labor markets. They find that automation technologies increase the polarization of occupational employment, but do not reduce net employment; exposure to Chinese trade does lead to reduced employment.

Beaudry et al. (2013) examine the polarization hypothesis in the 2000s, the period with the largest decline in the labor share, and find that employment and wages decline for abstract labor. Their model has abstract task labor used to produce knowledge capital. An improvement in technology in the 1990s leads businesses to temporarily hire abstract labor to build knowledge capital, but then only need enough abstract labor in order to maintain the knowledge stock already built. Thus, employment and wages of abstract labor fall in the 2000s. The Great Recession makes it is difficult to disentangle business cycle effects from structural changes in labor market changes during the later half of the 2000s, but Beaudry et al. (2013) provide evidence that technological forces may be responsible for the falling labor share.

5.3 Future Changes in the Labor Share

Globalization seems unlikely to cause further large declines in the labor share. Barriers to trade are already fairly low. China was in a unique position over the previous three decades – large, growing rapidly, and transitioning from complete autarky. In addition, the US has already shed much of the labor intensive manufacturing employment that would be adversely affected by foreign competition.

If labor saving technical progress is to blame for the recent fall in the labor share, will the fall in the labor share continue forever? Answering this question requires a model of the production of technical innovations. The degree, and direction, of technical progress likely depends on the profit from that technical progress. In a world in which the labor share has declined considerably, and so labor is cheap, there is little incentive to develop labor saving inventions. This is what Acemoglu (2010) finds when σ is less than one and innovations are in A^L; the scarcity of labor encourages labor saving innovation. This type of model can help explain why the relatively labor-scarce US grew faster than England over the 19th century (known as the Habakkuk Hypothesis), or why Europe, not labor abundant China, experienced the Industrial Revolution.

Acemoglu (2003) develops a model that endogenizes technical progress in which factor shares remain stable in the long run. In his model, improvements in A^K and A^L are the result of efforts by a profit-maximizing R&D sector. While all technical progress is labor augmenting under the balanced growth path, both A^K and A^L can increase along the transition path. The returns to improving A^K and A^L depend upon the capital share; when the capital share is high compared to its long run equilibrium, there are large returns to developing A^K. The resulting improvements in A^K lower the capital share. In equilibrium, technical progress serves to stabilize factor shares, and so a Piketty type apocalyptic scenario for labor does not occur.

6 Conclusion

In *Capital in the Twenty-First Century*, Piketty employs a growth model to explain how a falling rate of economic growth would affect the capital share. Under his model, a lower growth rate would increase the capital-output ratio; this rise in the capital-output ratio would also increase the capital share if the capital-labor substitution elasticity is above one. Piketty then estimates this elasticity to be substantially above one by using the historical co-movement of the capital-output ratio and capital share.

Piketty's identification strategy requires a major assumption on technology – that capital augmenting technology A^K has been constant or uncorrelated with movements in the capital-output ratio over time. Estimates using the aggregate time series that relax this assumption, and so allow biased technical change, generally obtain estimates lower than one and much lower than those in Piketty. Estimates of the micro elasticity of substitution are also substantially below one; an aggregation framework that uses these estimates to estimate the macro elasticity also implies an elasticity less than one. Thus, Piketty's explanation for the declining labor share is unlikely to be correct.

Two alternative explanations for the decline in the labor share are globalization and labor saving technological progress. A substantial body of evidence, including differences across industries and local labor markets, indicates that the rise of trade with China lowered the US labor share. A number of mechanisms are likely at work. Labor intensive producers may exit, shrink, change the products they sell, or change their work practices.

The current evidence on technological progress indicates that the development of automation technologies has polarized labor by reducing demand for routine labor that is substitutable with new technologies and increasing demand for abstract labor that is complementary with the new technologies. However, there is limited evidence that automation reduced the overall labor share. With endogenous technical progress, a decline in the labor share may eventually reverse with shifts in technology. More research is needed in order to understand how technology can affect the labor share.

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