The Falling Rate of Profit as a Research Program

By Thomas R. Michl*

This paper argues that the Marxian law of the tendency of the rate of profit to fall defines an important analytical framework for studying the role of capital-using, labor-saving (Marx-biased) technical change in the accumulation process. Using a tractable one-sector model of growth and distribution, the paper examines two viability conditions used in the study of Marx-biased technical change. In the Standard Interpretation, capitalists choose techniques if they increase their transitional rate of profit. As Duncan Foley and others have observed, if wages are rising, Marx's prediction of a declining rate of profit can go through conditionally. Anwar Shaikh has argued that under "real competition" capitalists will be forced by competitive forces to choose techniques that increase their profit margins, even if they lower the rate of profit. While empirical research on the viability condition under the Standard Interpretation has generally found it to be comfortably satisfied (which would be consistent with real competition as well), there is enough ambiguity in the evidence to warrant further study. Theoretical research has only begun to explore the possibility that a game-theoretic approach might bridge the gap between these accounts. Other issues raised include the origin of Marx-biased technical change and the role of wage growth in mediating technical choices.

JEL: B24, B51, O33
Keywords: Marx-biased technical change, falling rate of profit, fossil production function, Okishio theorem

My training in advanced political economy at the New School for Social Research came at the end of the long 1970s crisis of managerial capitalism during a renaissance of Marxian theory, in which Anwar Shaikh played a central role in reestablishing interest in core principles drawn from Marx's own writings.[1] Among these was the "law of the tendency for the profit rate to fall," which had fallen out of favor in the English-speaking world largely under the influence, I think, of Paul Sweezy's (1942) skeptical (but thoughtful) treatment. Students like me who were attracted to the New School because their political activism had acquainted them with the rudiments of Marxian economics found Shaikh's clear, compelling writing and spellbinding lectures to be a source of deep intellectual stimulation and inspiration. While his seminal essay (Shaikh 1978*b*) on the topic was the subject of considerable controversy among the faculty, student body, and a wider community of heterodox economists,[2] I found its alleged weak points to be the focal points of a research program rather than grounds for a summary dismissal of the law itself.

Eventually I became convinced (Michl 1988, 1991) by empirical evidence supporting that assessment and further contemplating the theoretical foundations of Marx's approach led me to a positive framework for attacking some problems in long-run growth theory that have traditionally been the province of the neoclassical Solow model. This work was facilitated by Duncan Foley's (1986*b*) influential treatment of Marx's *Capital*, which provided an alternative and less-controversial interpretation of the economics of falling profitability.[3] When Duncan and I teamed up to write our text, *Growth and Distribution*, I was delighted by his support for a full chapter based on this framework, centered on the prevalence of

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[1] Shaikh (1978*a*) was quite influential in this regard.

[2] Roemer (1979) is a particularly sharp appraisal.

[3] By virtue of the fact that a more recent text (Basu 2021) also utilizes the same approach, I will call it the Standard Interpretation of the law of the tendency for the rate of profit to fall.

"Marx-biased technical change" (labor-saving, capital-using) and its signature pattern in macroeconomic data, the "fossil production function." Without his encouragement and intellectual support, I am sure this work would not have progressed as it did; indeed, both these apposite terms came at Duncan's suggestion.[4]

The current paper revisits this terrain in the interest of clarifying two different approaches to the Marxian theory. Shaikh's approach was criticized for his insistence that in what he now (Shaikh 2016) calls "real competition" firms compete over profit margins and are willing to adopt a less profitable technique if it awards them a competitive advantage over their competitors. Foley (1986*b*) accepts the principle that capitalists seek to maximize their rate of profit and points out that in the presence of Marx-biased technical change (MBTC), this can lead to a falling rate of profit if workers are able to win sufficient increases in their real wages after the new techniques propagate across capitalist firms.[5] To clarify the relationship between these two viewpoints, the paper sets the problem up in the one-sector model of capital accumulation that performs workhorse duties in Foley, Michl and Tavani (2019). The fossil production function that characterizes MBTC has inspired an empirical literature that indirectly brings these alternative approaches to the data. My assessment is that the jury remains out on their relative merits both empirically and theoretically.

Before plunging into a thicket of algebraic theory, let us consider some empirical evidence establishing the plausibility of the long-run tendency implied by Marx's putative law.

I. Empirical evidence of secular decline in the profit rate

Recent work on macroeconomic history offers two kinds of evidence on long run trends in profitability, one involving interest rates and the other directly measuring the rate of profit from national income accounts.

The classical economists were more or less unanimous in thinking that declining profitability was an established stylized fact and they fashioned their theories and models to explain it. Yet until roughly the mid-twentieth century, the national income accounting data necessary to measure and study trends in profitability did not exist. The classical economists probably did have available financial data on the rate of interest, and they believed that there was a close connection between the rate of interest on loans, bonds, mortgages, etc. and the rate of profit earned by capitalists on their investments in capital goods, labor and materials. Foley (2006, p. 24) observes that Adam Smith regarded the interest rate as a "good approximation" to the profit rate prevailing at any given time and place, while Foley (1986*b*, p. 127) comments that Marx did not discover a tendency for the rate of profit to fall "but took it over as a stylized fact already well-established in the work of the political economists," mainly Smith and his successor David Ricardo.

Recent empirical research by economic historians (Schmelzing 2020*b*) supports the classical belief that interest rates had been falling from the early days of capitalism (say, the sixteenth or seventeenth century or even earlier). Moreover, as illustrated in Figure 1, it appears that interest rates have continued to decline with the further development of the global capitalist economy. The figure shows real (inflation-adjusted) global interest rates on "safe" assets, meaning high-quality sovereign debt, although broader measures including private debt instruments show a similar pattern, as do unadjusted data on nominal rates. Schmelzing (2020*a*) provides detailed descriptions and meticulous documentation of the data.

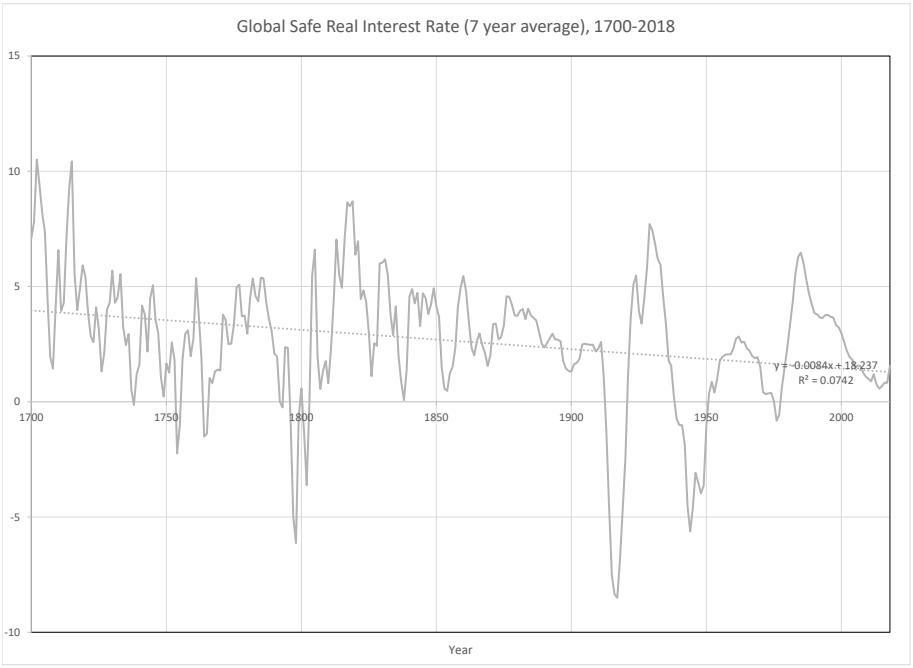
Our modern understanding of the relationship between the interest rate and the profit rate is not settled. There is probably no mechanical relationship between the two, and it is not hard to develop a modern growth model in which the interest rate declines independently of the profit rate.[6] Shaikh's theory (2016, Ch. 10) of the interest rate builds upon Marx's incomplete account in Volume 3 of *Capital*, and links it to the rate of profit through the principle that bank capital participates in equalization of

[4]Daniele Tavani joined us in writing the second edition (Foley, Michl and Tavani 2019) and mainly under his influence we included more material on the theory of induced technical change, which remains a candidate explanation for episodes of Marx-biased technical change driven by the pressure of labor costs.

[5]Here Foley is in the company of some so-called Analytical Marxists, including ironically the same John Roemer (1978) who took exception to Shaikh's formulation.

[6]Michl (2012) presents a neo-Kaleckian model with a long-run equilibrium at normal capital utilization that gives it classical-Marxian properties. The rate of interest that stabilizes the system is bounded from above by the rate of profit but structural changes in parameters such as capitalist propensities to save or invest can affect its long-run value.

Figure 1. Global safe real interest rate



Note: The trend line has been added. The negative coefficient is statistically significant (t=-5.04).
Source: Schmelzing (2020*a*).

the rate of profit.[7] Foley's (1986*b*, pp. 113-14) account suggests some role for a modern theory of the rate of interest but accepts Marx's argument that it must be bounded from above by the profit rate. The evidence in Fig 1 has to be regarded as suggestive and we can turn to the direct evidence offered by national income accounts.

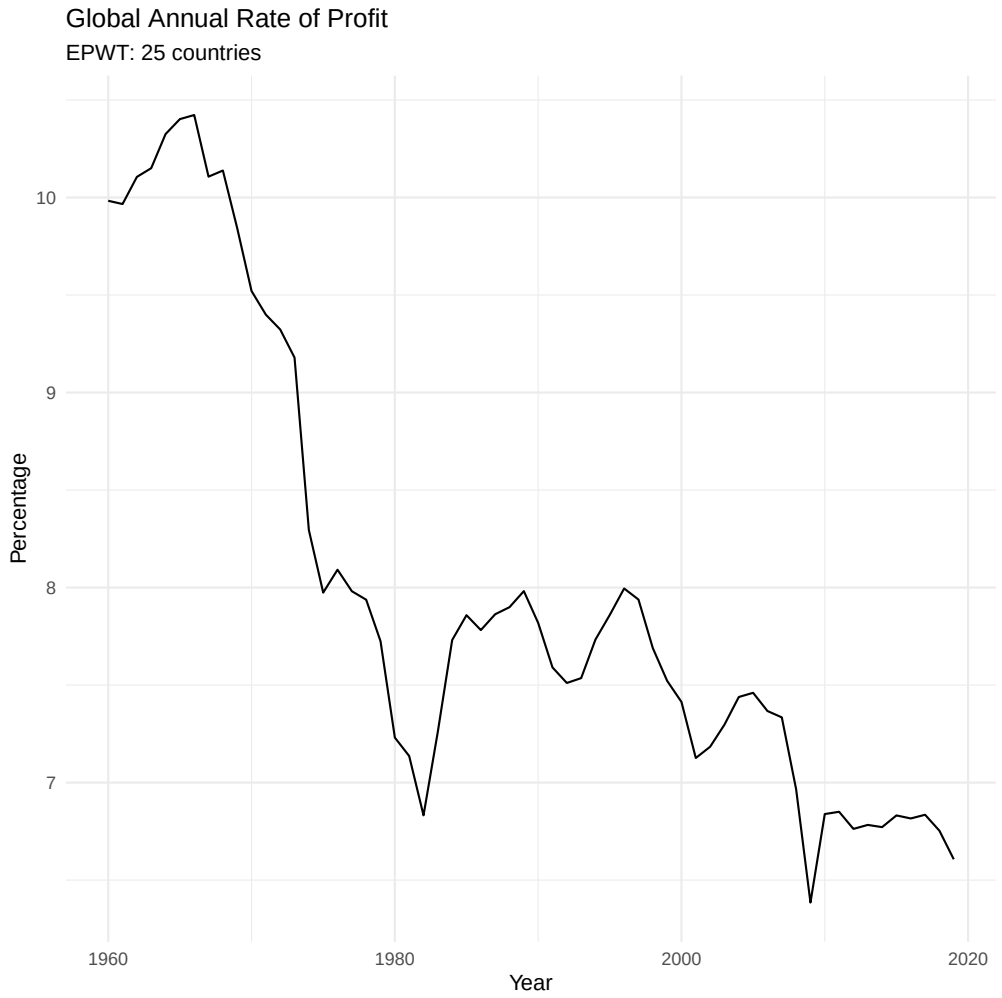
Figures 2 and 3 use national income accounting data from the Extended Penn World Tables (EPWT) compiled by Marquetti, Miebach and Morrone (2021). The primary data come from the Penn World Tables supplemented by various national and international sources. The figures were generated by the on-line World Profitability Dashboard (Basu et al. 2022) that allows users to quickly visualize trends in the profit rate and its underlying components.

The methodology employed by Adalmir Marquetti and his collaborators follows the theoretical framework in Foley, Michl and Tavani (2019) very closely, in its definition of capital for example. For that reason, we used the EPWT extensively in the text. The main message we chose to convey was that there is considerable evidence for MBTC, particularly in the early developmental stages of capitalist economies. For advanced capitalist economies, we present the view that the key component of MBTC—capital-using technical change—was episodic, motivated by evidence that there are substantial periods in many countries of capital-saving or Harrod-neutral technical change interspersed with periods of MBTC. Recent research on the profit rate in the U.S., the most studied country with perhaps the highest-quality data, seems to support our decision (Basu and Vasudevan 2012).

Rather than select one individual country or region, Figure 2 focuses on the global rate of profit, as measured by the aggregates carefully constructed for this purpose by the World Profitability Dashboard.

[7] An alternative attempt to build on Marx's writing that deserves mention is Park (2021) which identifies differential productivity as the source of inter-capitalist borrowing and lending.

Figure 2. Global annual rate of profit



Note: The global rate of profit based on Extended Penn World Tables database has declined secularly. The data are calculated in the World Profitability Dashboard using purchasing power parity adjusted world dollars. Similar results are obtained using actual exchange rates.
Source: Basu et al. (2022).

Taking a broader perspective makes sense given the increasing internationalization of production through global supply chains for example. The result is quite dramatic: there appears to be a secularly declining rate of profit at the global level, consistent with MBTC. In particular, note that in Figure 3 the data for capital productivity (the output-capital ratio) shows a rather clear declining trend. While there has at the same time been an attenuating increase in the profit share in more recent decades, it has not been sufficient to prevent the profit rate from falling. Since this is precisely the pattern predicted by Marx, it warrants a more detailed investigation of the economics of declining profitability.

II. Marx-biased technical change

Declining capital productivity is a signature feature of capital-using technical change. In conventional neoclassical economic theory, of course, it would normally be interpreted as evidence of "capital deepening" or movement along a pre-existing production function. That approach came under withering theoretical criticism in the Cambridge capital controversies and has been almost completely abandoned among a wide range of heterodox economists, including Keynesian, neo-Ricardian, and Marxian theo-

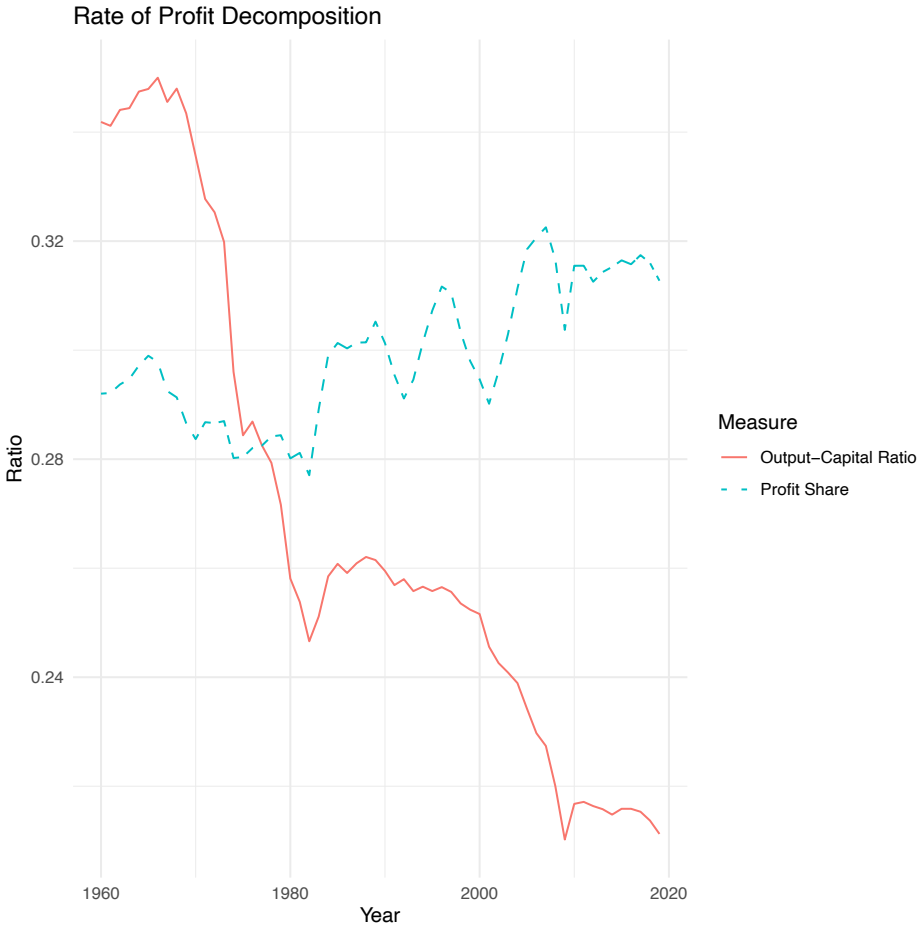


FIGURE 3. RATE OF PROFIT DECOMPOSITION

Note: The two major factors determining gross profitability are the output-capital ratio (capital productivity) and the profit share. The decline in the capital productivity is consistent with Marx-biased technical change.
Source: Basu et al. (2022).

rists.[8] Some of this criticism has also called into question the empirical methods used by neoclassical economists to estimate the parameters of the production function and the underlying rate of technical change (total factor productivity), much of it following the lead of Shaikh (1974).

Another line of attack inspired by the fossil production function and briefly reviewed below has focused on the lack of empirical correspondence between the *apparent* marginal product of capital and the profit rate. As elaborated in Foley, Michl and Tavani (2019, Ch. 8) MBTC gives rise to a functional relationship between observed output per worker and capital per worker that takes a Cobb-Douglas form. This invites a comparison between the power term (which appears as ω below) and the profit share since the neoclassical interpretation of the Cobb-Douglas function predicts equality between them while the classical interpretation generally does not. That raises the question of what accounts for MBTC in the first place. Here there are several possible answers, but let us focus on two prominent lines of attack.

The first is to hypothesize that capitalist relations of production impart a constitutional predisposition for the forces of production to evolve in ways that reinforce and deepen the control of capital over

[8]There are some examples of heterodox economists who use the aggregate production function, probably because they regard it as a reasonable first approximation or perhaps for want of something better (Rowthorn 1999; Basu and Budhiraja 2021). For that reason, theoretical and empirical work scrutinizing the production function does add value to the heterodox project even if it no longer seems be of concern to any but the most intellectually honest neoclassical economists.

the labor process. This viewpoint was part of the renaissance in Marxian economics inspired by Anwar Shaikh (1978*a*) who argued in his essay on the Cambridge Marxist Maurice Dobb that the

> ... tendency towards substitution of machinery for living labour, which Dobb sees as merely one of many equally likely outcomes, is according to Marx an absolutely necessary outcome of the capitalist-controlled labour-process. This is not to say that rising real wages or rising prices of some inputs may not induce technical changes which seek to offset these factors, nor that other forms of technical change will not occur. What it does say is that automation is both intrinsic to capitalism and is its dominant form of technical change. It is the technological expression of the social relations of production under capitalism.

Since this perspective argues for the relative independence of technical change from distribution or real wages, we can call it exogenous Marx-biased technical change.

The second approach is adumbrated in the quote above by the possibility that rising wages can induce technical changes. This approach, which arguably originates in Marx's trenchant observations about British industrial capitalism, has attracted a range of supporters including John Hicks, William Kennedy, Christian von Weiszäcker. Having been resurrected by Gérard Duménil and Dominique Lévy in a stochastic formulation (1995), it forms the foundation for Foley (2003).

The basic model assumes the existence of an invention possibility frontier of the form

$$\gamma = f(\chi) \qquad f_\chi < 0 \qquad f_{\chi\chi} < 0$$

where γ represents the rate of labor-saving and χ the rate of capital-saving technical change. (Obviously, capital-using change occurs when $\chi < 0$.) Under the assumption that capitalists will choose technical changes that minimize costs, it can be shown that the bias of technical change will be regulated by the profit share so that, for example,

$$\chi = h(\pi) \qquad h_\pi > 0$$

where π represents the gross profit share in value added. (A complete list of the notation used in this paper is provided in Table 1.)

The induced technical change approach explains historic episodes of capital-using technical change as the predictable response to a high wage share (low profit share) making it economically attractive to pursue labor-saving innovations even though they require more capital per unit of output.

Most attempts to integrate induced technical change into a growth model endogenize distribution, typically by including some sort of labor constraint on growth, so that this state of affairs represents a transitional phase. The ultimate steady state will then necessarily involve Harrod-neutral technical change, which is labor-saving change with an absence of any capital-saving or -using bias. Foley, Michl and Tavani (2019, Ch. 7) provides an overview of growth with induced technical change.

It is sometimes argued that this steady state or balanced growth destination is an argument in favor of the induced technical change approach since exogenous MBTC under reasonable assumptions about the behavior of real wages (discussed below) involves continuous declines in the rate of profit, an apparent impossibility. But that is not necessarily true. If the accumulation process is labor-constrained and governed by the Cambridge equation so that distribution adjusts to maintain a so-called "natural" rate of growth and the corresponding profit rate, an exogenous process of MBTC will require the profit share to rise continuously to preserve the profit rate.[9] As we discuss extensively below, the profit share must satisfy a viability condition in order to make biased technical changes economically attractive to capitalists. Under the standard assumption that capitalists choose new techniques that increase their rate of profit, eventually the profit share will reach a level high enough that technical progress comes to a halt.[10] Since technical knowledge continues to advance (new capital-using, labor-saving techniques are

[9]For more details, see Michl (2008, Chs. 10-11), which also argues that the historical record does not support the predictions of such a labor-constrained growth model. However, this model (or one like it) may become salient looking ahead to zero population growth and the depletion of global reserves of labor.

[10]This can also happen in a capital-constrained setting in which wages rise less than labor productivity, as in Michl (1999).

potentially available), this destination represents a theoretical expression of the relations of production forming a barrier to further development of the forces of production.

The preponderance of growth models that incorporate Marx-bias opt for some version of the induced technical change hypothesis.[11] Growth models with a steady state offer theorists the ability to achieve rigorous comparative equilibrium results, but that alone should not inhibit research into patterns of unbalanced growth. Indeed, some of the most influential twentieth-century theoretical contributions (Baumol 1967; Lewis 1954) are unbalanced growth models. It appears sensible to keep both approaches to MBTC in play.

III. Viability and Marx-biased technical change

The fossil production function generalizes the Okishio Theorem (1961), which examines Marx's theory of the falling rate of profit after a one-time labor-saving capital-using technical change, by envisioning an on-going process of such innovations over time.[12] The presentation of the fossil production function in Foley, Michl and Tavani (2019) assumes that capitalist firms evaluate each capital-using, labor-saving technical change based on the existing wage, and that as a result of the general adoption of the technique, real wages increase enough to maintain the original profit and wage shares at their conventional values; this is called the "conventional wage share" model. In effect, rising real wages are an externality of innovation from the point of view of an individual capitalist, and the falling rate of profit is a prime example of a social coordination problem.

We will begin by assuming the capitalist firms adopt a technique if it increases their profit rate before turning to Shaikh's treatment involving the profit margin in the next section of the paper.

A. A generalized viability condition

An alternative treatment of real wages following Basu (2010) and Michl (2002) assumes that they are growing independently of technical choices by firms, which then factor that growth into their decisions.[13] We can incorporate this form of wage growth by assuming that wages are expected to increase by a constant growth factor, $w' = (1 + \eta)w$, where we use the prime notation to indicate the value expected to prevail in the next period when a technical change has been adopted. In general, we will extend this convention of using primes to indicate the new technique under consideration and follow the nomenclature from Foley, Michl and Tavani (2019).

The other generalization worth considering involves changes in the depreciation rate. Although this direction has not been studied in connection with the fossil production function to the best of my knowledge, it forms the basis for an approach to the choice of technique pioneered by Anwar Shaikh in support of Marx's hypothesis that biased technical change would tend to reduce the rate of profit even if wages were maintained at a constant level. Shaikh's argument uses the distinction between circulating capital (capital that is used up in one production period and therefore has a depreciation rate of 100%) and fixed capital (capital which is used up over multiple periods). Foley, Michl and Tavani (2019) offers some problems and examples of these treatments of capital through its use of Ricardia (circulating capital) and Industria (fixed capital). We will assume that a technical change affects the depreciation rate by a constant growth factor: $\delta' = (1 + \epsilon)\delta$. Although the opposite pattern might prevail in other settings (consider, for example, the increased importance of short-lived computer software), we focus below on reductions in the depreciation rate ($\epsilon < 0$).

It is worth pointing out that the economics of depreciation are quite complex, and that the treatment we will use has well-known flaws (Kurz and Salvadori 1995, pp 62-64). We will assume that capital goods

[11] For example, Taylor, Foley and Rezai (2019) features a kind of reduced-form representation of induced technical change that could also be consistent with models of technical change that involve capitalist investments in research as a response to high labor costs. Michl and Tavani (2022) builds on that representation by also including capital-using technical change arising from labor market pressures.

[12] The basic insight that MBTC creates the impression of a Cobb-Douglas (fossil) production function in the statistical record originates from Michl (1994).

[13] In Michl (2002) biased technical change is embodied in machines so anticipated real wage growth is almost imperative by the virtue of the assumption that machines, like wines, are distinguished by their vintage or year of origin. In order to evaluate the profitability of a newly invented machine, it is necessary to forecast the future stream of profits it generates, which eventually dwindle as real wages rise, reaching zero when the machine is retired (scrapped).

Table 1—Definitions of Selected Variables and Parameters

Variable	Definition
χ	rate of capital-saving (-using) technical change
δ	depreciation rate
ϵ	rate of growth of depreciation rate
η	rate of growth of wage rate
γ	rate of labor-saving technical change
g_z	growth rate of variable z
K	capital stock
m	profit margin
N	employment
ω	viability threshold parameter (Standard criterion)
$\tilde{\omega}$	viability parameter with wage growth
ω_s	viability parameter (Shaikh criterion)
π	gross profit share
r	net profit rate
ρ	output-capital ratio (capital productivity)
v	gross rate of profit
w	real wage rate
X	gross output
x	gross output-worker ratio (labor productivity)
y	net output-worker ratio

(machines) depreciate at a constant geometric rate, sometimes called "depreciation by evaporation." Thus, in the absence of any gross investment, the capital stock obeys $K_{+1} = K - \delta K = K(1-\delta)$. This approach is widely used in national income accounts and growth theory by virtue of its convenience and plausibility.

Using the notation and approach of Foley, Michl and Tavani (2019), we consider a MBTC of the form $x' = (1+\gamma)x$ for labor productivity and $\rho' = (1+\chi)\rho$ for capital productivity where $\gamma > 0$ and $\chi < 0$. The general problem facing a capitalist firm is to choose to adopt a new technique when it raises the net rate of profit evaluated at the new expected wage, or when $r'(x', \rho', \delta', w') > r(x, \rho, \delta, w')$, where r represents the net rate of profit using the old technique, evaluated at the new wage. (The net rate of profit is defined as $r = \pi\rho - \delta$ where π represents the gross profit share, $1 - w/x$.) Writing this out in detail gives

$$(1 - \frac{w'}{x'})\rho' - \delta' > (1 - \frac{w'}{x})\rho - \delta.$$

Substituting into this expression, and solving yields the *generalized viability condition*,

$$\pi < \frac{\gamma(1+\chi)}{(\gamma-\chi)(1+\eta)} - \frac{\epsilon\delta(1+\gamma)}{\rho(1+\eta)(\gamma-\chi)} + \frac{\eta}{1+\eta}.$$

When this condition is satisfied, profit-rate maximizing firms will choose the new technique. The three terms on the right-hand side each have intuitive interpretations. The first represents the main effect of MBTC, which offers an increase in labor productivity at the expense of lower capital productivity. The second term registers the role of depreciation, which could in principle either relax or tighten the viability condition.[14] The shift away from circulating capital toward fixed capital we study below will lower the depreciation rate ($\epsilon < 0$) so this change will relax the viability condition given the negative

[14]To interpret the logic of the second term, it might be helpful to observe that δ/ρ represents the share of depreciation charges in gross product. Multiplied by ϵ then gives a measure of the increase in the *net* profit share due to a reduction in the depreciation rate.

sign on the second term. The third term reflects the role of expected wage increases, which relax the condition because higher wages increase the relative cost advantage from labor-saving technical changes.

B. Expected wage growth with constant depreciation

The special case with $\epsilon = \eta = 0$ is the textbook case in Foley, Michl and Tavani (2019). We will use the convention established there and identify this baseline viability threshold parameter as ω:

$$\omega = \frac{\gamma(1+\chi)}{\gamma - \chi}.$$

An interesting special case with constant depreciation is to consider what happens when wages are expected to grow at the same rate as labor productivity, or $\eta = \gamma$. In this case as Basu (2010) demonstrates (also, see below) the viability condition simplifies to

$$\pi < \frac{\gamma}{\gamma - \chi}.$$

Because it incorporates a more realistic assumption about wage growth, this version of the viability condition is used in empirical work by both Basu (2010) and Campbell and Tavani (2019).

In any other case, expected wage growth will affect the viability of new techniques by incentivizing more labor-saving innovations at the cost of greater capital use.[15] Let the viability threshold with expected wage growth and constant depreciation to be $\tilde{\omega}$.[16] It is possible that technical change could be nonviable in the absence of wage growth but become viable because of wage growth if the profit share lies between the relevant threshold parameters just so: $\omega < \pi < \tilde{\omega}$. This could be relevant to empirical studies reviewed below which generally omit wage growth in computing the viability parameter.

C. Discrete versus continuous time

It is interesting that as Sasaki (2008) shows the viability condition in continuous time does not depend on the expected growth of wages, presumably because time must be allowed to transpire before wage growth plays a role in the choice of technique. Working through a modified version of his proof and comparing it with the same problem in a discrete time environment provides a cautionary tale on the pitfalls of continuous time in economic models. We seek to explain why in continuous time wage growth drops out of the picture generally while in discrete time it only drops out when $\eta = \gamma$. Growth in continuous time is exponential, so that, e.g., $\gamma = \dot{x}/x$ where the dot notation indicates a time derivative.

In both cases, since we assume that depreciation remains constant it is convenient to work with the gross rate of profit, $v = r + \delta = \pi\rho$. We will use v_0 to identify the original rate of profit, v' to identify the rate of profit using the new technique and v to identify the rate of profit using the old technique. In both cases, wages are assumed to be increasing at the exponential rate, η. The capitalist decision rule will select the new technique when $v' > v$, and since $v' = v_0 + \dot{v}'dt$ and $v = v_0 + \dot{v}dt$, we need only concern ourselves with the differential terms to find the viability threshold.

Finding the relevant time derivatives and rearranging,[17] we arrive at these expressions:

$$\dot{v}' = \rho[(1-\pi)(-\eta)] + \rho[\pi\chi + (1-\pi)\gamma]$$
$$\dot{v} = \rho[(1-\pi)(-\eta)].$$

It is immediately clear why wage growth plays no role in the viability condition. The first term on the right-hand side of both equations captures the effects of wage growth. Since these effects are evaluated instantaneously in continuous time, they are identical in the two investment options. Solving for the viability threshold condition by setting $v' > v$ leaves only the second term on the right-hand side

[15] Michl (2002) discusses the differences between the neoclassical treatment of wage-driven substitutions and the classical account associated with the fossil production function. An important property of the fossil production function is that faster wage growth will not *generally* lead to more substitutions as it would in a neoclassical treatment.

[16] From the generalized viability condition, we have $\tilde{\omega} = (\omega + \eta)/(1 + \eta)$.

[17] Sasaki (2008) provides a clear explanation of the mathematical details.

of the first equation (for the new technique), which resolves to the viability condition $\pi < \gamma/(\gamma - \chi)$, the same expression we found in discrete time with wage growth equal to labor productivity growth.

Now let us retrace these steps in discrete time. In this case, using discrete calculus we can see that the analogous problem is to compare the changes in the profit rate implied by the competing investments, or

$$\Delta v' = \rho\Delta\pi + \pi\Delta\rho + \Delta\pi\Delta\rho$$
$$\Delta v = \rho\Delta\pi.$$

In general the rate of wage growth will play an important role in the selection process, as makes good intuitive sense. Proceeding with appropriate substitutions (e.g., $\Delta\rho = \chi\rho$) and writing out the discrete changes in comparable form to the time derivatives brings its role into sharp relief:

$$\Delta v' = \left[\frac{\rho(1-\pi)(-\eta)(1+\chi)}{(1+\gamma)}\right] + \rho\left[\pi\chi + \frac{(1-\pi)\gamma(1+\chi)}{(1+\gamma)}\right]$$
$$\Delta v = \rho(1-\pi)(-\eta).$$

By substituting $\eta = \gamma$ into these expressions, we verify the viability condition derived above, $\pi < \gamma/(\gamma - \chi)$. In this case, assuming exogenous technical change it is clear that wage growth drops out of the picture altogether.

However, in discrete time with $\eta \neq \gamma$ the first terms on the right-hand side do not cancel out as they did in continuous time when we derive the threshold condition because the wage increase operates through the new technology. The ratio $(1+\chi)/(1+\gamma)$ represents the (reciprocal) of the growth factor for the capital-labor ratio, which grows with MBTC creating a more favorable trade-off between wages and the profit rate. Thus, rising wages make the new technique more attractive and their rate of growth will generally affect the viability condition as a result.

This example illustrates an important point. Economic activity takes place in time. The discrete time solution to the decision problem encompasses the fact that time will elapse so that the expected profit rate will have an opportunity to enjoy the more favorable terms of trade between wages and profits afforded by using the new technique.

The classical tradition embraces the bedrock principle that the most basic economic activity, production, takes time. It is possible to incorporate this fact in continuous-time models by imposing some restrictions on the time pattern of inputs and outputs as Foley (1986*a*) shows using the mathematics of convolutions in a circuit of capital approach. But the discrete time framework solves the problem directly by simply assuming that all activity resolves itself in one period, effectively imposing a uniform lag structure on a range of economic processes.[18]

IV. Alternative viability conditions

Finally, we can consider the role that changes in the durability of capital play in technical choice. The most obvious place to start is the effects of reductions in the depreciation rate that occur in the transition from a circulating capital world like Ricardia to a fixed capital world like Industria. This scenario plays an important part in Anwar Shaikh's (1978*b*; 2016) interpretation of the Marxian theory of the tendency of the rate of profit to fall. Since Shaikh's main objective is to show that this theory does not depend on an increasing real wage to explain declining profitability, we will restrict the discussion to cases with a constant expected wage, $\eta = 0$ (which could still be consistent with the causal structure referred to above, with wages rising as a consequence of technical change).

Shaikh objects to the selection criterion used in Foley, Michl and Tavani (2019), which in turn has been taken from a large literature on the theory of technical choice that started with Okishio (1961). Okishio and most writers in the field assume that firms will evaluate a new technique at the existing

[18] When we were planning the second edition of Foley, Michl and Tavani (2019), I recall a long conversation with Duncan Foley about whether it would make sense to switch to the continuous time presentation of growth models found in almost all the heterodox literature. We elected to stick with discrete time despite the fact that continuous-time modelling is often more convenient. My recollection has influenced this paragraph and I'm pretty sure it does not do justice to the sophistication of Duncan's side of the conversation.

wage, and only choose to adopt if it increases their expected net rate of profit, compared with the rate they anticipate using the old technique. Okishio observes that if wages remain constant, MBTC will tend to *increase* the rate of profit, seemingly in contradiction to Marx's prediction. But as Duncan Foley and others (Roemer 1978) point out, if wages do rise after the technical change, the rate of profit can indeed decline. Under the causal structure adopted in Foley, Michl and Tavani (2019), in which wages rise as a consequence of the technical change, Marx's predictions can certainly hold, and if we assume wage growth that equals labor productivity growth, as in the conventional wage share model, the decline in profitability is assured. This might be called the Standard Interpretation of Marx's theory of the falling rate of profit as it appears in the leading texts on his economic theories (Foley 1986*b*; Basu 2021).

Shaikh's objection focusses on the theory of competition implicit in the selection criterion under the Standard Interpretation. He argues that the neoclassical conception of perfect competition motivates this criterion, in particular by conceiving of the rate of profit as the opportunity cost of a technical choice. Defenders of the Standard Interpretation disagree, and can point to the classical theory that competition tends to equalize the profit rate (implying that the profit rate is an investment criterion) as well as to Marx's own observation that

> . . . no capitalist ever voluntarily introduces a new method of production, no matter how much more productive it may be, and how much it may increase the rate of surplus value, so long as it reduces the rate of profit (Marx 1977, p. 264).

Shaikh, seizing on Marx's qualifying word "voluntarily" argues that under real competition capitalist firms engage in economic warfare through cost-cutting technical changes. The winners are the capitalists that are able to lower their unit costs most aggressively because they can then drive out their competitors by price-cutting.

One way of justifying the belief that inter-capitalist rivalry can force capitalists to involuntarily adopt Marx-biased technical changes, even if they are not viable under the Standard Interpretation, would be to invoke some sort of game-theoretic mechanism. Indeed Foley (1986*b*, p. 131) adumbrates this possibility when he points out that for Marx, "each capitalist is in fact forced to innovate because the capitalists are in a prisoner's dilemma situation with regard to each other." Baldani and Michl (2000) formalize this argument in a Cournot-Nash partial equilibrium model of oligopolistic firms in which technical change increases the fixed costs of production but reduces the variable average cost. Under a wide range of parameter values, profit-maximizing firms are in fact in a prisoner's dilemma and will choose a Nash equilibrium with a lower mass of profits for each firm. Another game-theoretic formalization (Kang and Rieu 2009) of the falling rate hypothesis argues that under some plausible assumptions about technical change and growth the capitalist decision problem undergoes a transition from an Invisible Hand game to a Prisoner's Dilemma at some stage in the accumulation process. While these models do not directly address the issue of alternative decision rules under MBTC, they invite further exploration of the question using a game-theoretic approach.[19]

In place of the selection criterion of the Standard Interpretation, Shaikh proposes that capitalist firms evaluate a new technique based on its profit *margin* (the difference between prices and unit costs, including labor, material, and capital charges) rather than its expected profit rate. Under his selection criterion, a new technique is viable if it raises the profit margin, or alternatively, lowers unit costs. It turns out his model can be represented easily in the basic Foley, Michl and Tavani (2019) one-sector model.[20]

The profit margin is expressed as the ratio between unit profits and unit costs, or

[19] In the former paper, fixed costs are somewhat loosely defined. A capital-using technical change could tend to increase depreciation charges, which is one source of fixed costs. In the latter paper, the transition to a Prisoner's Dilemma occurs when the rate of capital-using technical change exceeds the rate of growth of the rate of surplus value (roughly the profit share), which is consistent with the Standard Interpretation of viability with wages rising by less than labor productivity.

[20] Shaikh worked with a classical definition of capital as a sum of money advanced that includes wages in addition to capital goods so that the profit rate would be defined using advances for wages as well as capital goods. Foley, Michl and Tavani (2019) adopts the convention that the profit rate is calculated using the stock of capital goods only. The economic basis for this assumption is that capitalists pay workers at the end of the production period so they do not have to advance their wages.

$$m = \frac{X - wN - \delta K}{wN + \delta K} = \frac{1 - w/x - \delta/\rho}{w/x + \delta/\rho}$$

where X is gross output and N is employment.

This compares with the net profit rate, which is expressed as a ratio between unit profits and the capital stock, or

$$r = \frac{1 - w/x - \delta/\rho}{1/\rho}.$$

The wage rate-profit margin curve will in general lie to the northeast of the familiar wage rate-profit rate curve used in Foley, Michl and Tavani (2019). The wage rate-profit margin curve is

$$w = \frac{x - (1+m)\delta k}{1+m}.$$

For comparison, we can write out the wage-profit rate curve in terms of the net rate of profit as

$$w = (x - \delta k) - rk$$

which reveals that the two curves always share the same w-axis intercept, $y = x - \delta k$, where y is net output per worker. But the wage-profit margin curve has a (weakly) larger horizontal axis ($r-$ or $m-$axis) intercept since $(\rho - \delta)/\delta \geq \rho - \delta$; they are equal in Ricardia with $\delta = 1$. Note also that the wage-profit rate curve is linear while the wage-profit margin curve is convex to the origin.[21]

To bring the difference between the two viability criteria into the sharpest possible relief, we can follow Shaikh's classic paper (Shaikh 1978*b*) by focussing on the choice between a pure circulating capital technique ($\delta = 1$) and an alternative technique that combines fixed capital ($\delta' < 1$) and MBTC. Just to be clear, this set-up is intended to be illustrative. The examples below are highly stylized and are not intended for implementation in actual data.

In general, it is possible that the new capital-using fixed capital technique will dominate the old circulating capital technique under both viability criteria, meaning that it will be chosen no matter what the profit share happens to be. Since we know that a labor-saving technique will have a larger maximum wage equal to net output per worker, $y = x - \delta k$, which is the vertical intercept of both wage-profit curves, we can focus on the maximum profit rate and margin. If the new maximum profit rate exceeds the old maximum, or $\rho' - \delta' > \rho - 1$, we can be sure that the new maximum profit margin will also exceed its old maximum. The condition for this outcome is $\epsilon < \chi\rho$; both new wage-profit curves lie to the northeast of the old curves. This case offers little informational content about the selection criterion or the role of wage growth in the selection process.

On the other hand, if $\epsilon < \chi$, there will be a conflict between the two viability criteria. Under the Shaikh criterion, the new technique will dominate and it will be chosen no matter what the profit share or real wage. But under the Standard criterion, the new technique's maximum profit rate will be interior to its old maximum, implying that there will be an intersection of the adjacent wage-profit rate curves, known as a switchpoint. For real wages that lie below the switchpoint (which is another way of defining a nonviable technique), the new technique will not be selected under the Standard criterion. Thus, there will be some techniques chosen under the Shaikh criterion that would be rejected under the Standard criterion.

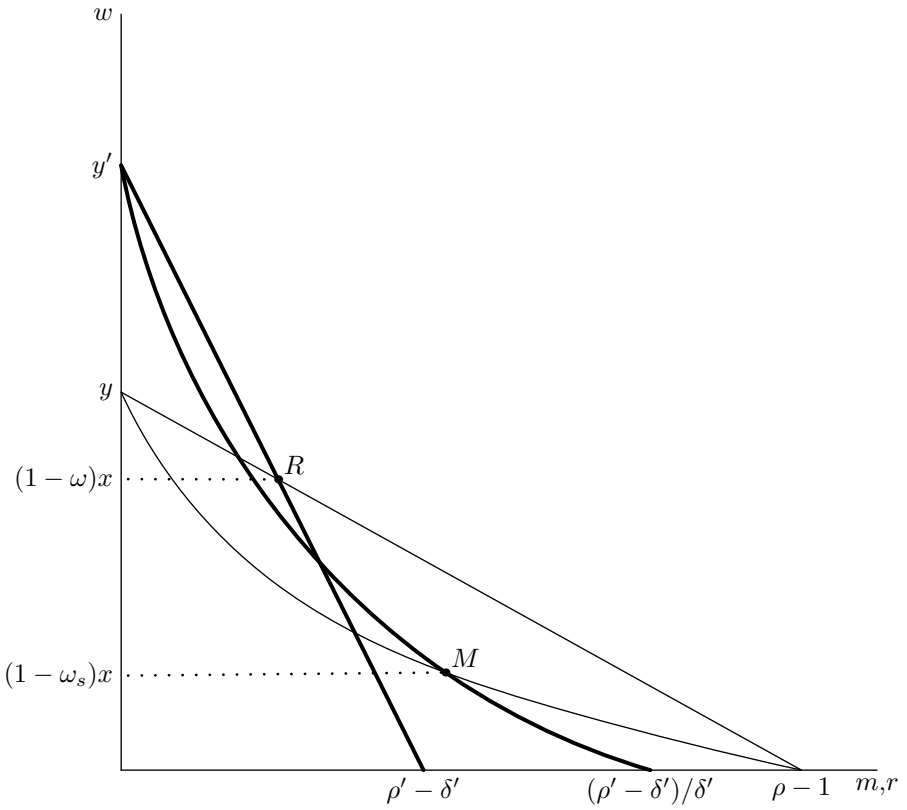
This conflict will also characterize the situation in which the new technique is not dominant under either criterion, which occurs when $\epsilon > \chi$. This is more or less the case that appears as Figure 1 in Shaikh (1978*a*) so let us elaborate on its properties. The viability condition under Shaikh's criterion (call it ω_s) can be derived using the methods rehearsed above:

$$\pi < \omega_s \left(= \frac{\rho(1+\chi)\gamma + (\chi - \epsilon)(1+\gamma)}{\rho(1+\chi)\gamma} \right).$$

[21] Under the convention Shaikh uses (see previous footnote) the wage-profit rate curve would also be convex to the origin. Our definition of the profit margin is the same as his.

With the parameter restrictions we have imposed the viability condition under Shaikh's criterion is clearly less constraining than the threshold condition for the Standard Interpretation (i.e., $\omega_s > \omega$). Figure 4 shows a case in which the fixed capital technique is nondominant under the Shaikh criterion. The contrast between the linear wage-profit rate curves and the convex wage-profit margin curves should make this figure easy to decipher. The critical switchpoint identifying the threshold condition under the Standard Interpretation has been labelled R (for profit-rate maximizing) and under Shaikh's criterion M (for profit-margin maximizing). For wages in the interval between R and M, Shaikh's criterion will lead firms to adopt techniques that lower the rate of profit at the existing wage. For wages above R, Shaikh's criterion will not conflict with that of the Standard Interpretation, the fixed capital technique will be selected under either, and firms will enjoy an increase in the profit rate as long as the wage rate remains constant.

Figure 4. The choice between a pure circulating capital technique (thin lines) and a non-dominant fixed capital technique (bold lines)



Note: The choice between a pure circulating capital technique (thin lines) and a non-dominant fixed capital technique (bold lines). The straight lines represent wage-profit *rate* curves and the convex lines represent wage-profit *margin* curves. Under the Standard Interpretation the fixed capital technique would be selected only at wage rates above point R because that increases the rate of profit. Under Shaikh's criterion the fixed capital technique would be selected at wage rates above point M because that raises the profit margin. The wage range between points R and M identifies technical choices that would lower the rate of profit at the existing wage following Shaikh's criterion.

While this discussion has taken us to a fairly high level of abstraction, it does offer some guidance for an interrogation of the statistical and historical record. In particular, it suggests that it might be possible to identify real-world examples of technical changes that lie in the zone of conflict between the two viability criterion. Indeed, there is an established literature examining the Standard viability condition to which we now turn.

V. Empirics of alternative selection criteria

The fossil production was initially motivated by some suggestive descriptive statistics presented in Michl (1999) and Foley and Michl (1999). Plotting the value of the (Standard) viability threshold parameter, ω, against the observed profit share for a sample of advanced (OECD) capitalist countries revealed that the observations almost all lie comfortably above the 45-degree line, indicating that the viability condition was satisfied by a wide margin.[22]

This fairly comfortable margin between the viability threshold parameter and the observed profit share calls into question the marginal productivity theory of distribution. Under MBTC with constant depreciation and wages the growth rates of output per worker and capital per worker obey $g_x = \omega g_k$. In an economy moving along the Cobb-Douglas production function $x = k^\alpha$, these growth rates satisfy $g_x = \alpha g_k$. It is clear then that the viability parameter corresponds to the power term in a Cobb-Douglas production function. In the neoclassical theory of production and distribution, it should be equal to the profit share under competitive conditions.[23] Thus, the inequality referred to above falsifies the neoclassical theory.

Our early and suggestive descriptive statistics stimulated an econometric literature seeking to show that this inequality could be verified more rigorously in a broader sample of countries including both developed and developing nations. One branch broadened the sample to include developing economies (Sasaki 2008; Michl 2008). Another branch, begun by Basu (2010) and elaborated by Campbell and Tavani (2019), similarly broadens the sample and also includes an auxiliary assumption that the threshold parameter is itself dependent on the profit share, invoking the theory of induced technical change. The consensus in this literature is that the viability threshold condition does not hold as an equality, thus verifying with some qualification the empirical failure of the neoclassical marginal productivity theory.[24]

However, for present purposes it is important to note that one motivation for the use of the auxiliary assumption is that there are many observations that do not fit the pattern we found originally. Basu (2010) points out that the raw data are not as unambiguous once the sample is broadened to include developing economies: there are a number of observations that lie below the 45-degee line of equality ($\omega = \pi$). Campbell and Tavani (2019) also find this pattern.[25]

These observations potentially bear on the question raised above about the selection criterion for technical choices. The viability condition thrown up by the Standard Interpretation is a falsifiable hypothesis.[26] While profit rate maximizing behavior has been central to political economy since at least the days of Adam Smith, there is nothing inherent in our understanding of the nature of inter-capitalist rivalry that excludes more aggressive forms of competition, for example because of the presence of prisoner's dilemmas. As the discussion above shows, observations of real economies selecting techniques that violate the Standard viability condition could provide evidence for these pathologies, and justify more research into the nature of real competition. But observations that conform to the Standard condition offer less informational content since they also satisfy the less restrictive condition for profit margin optimizing.

[22] Michl (2002) evaluated the viability condition for a vintage model, which compares the profit share on new machines to the viability threshold parameter. Since the profit share on new machines is unobservable, this requires data on the service life of machines so that it can be inferred. The viability condition was found to be satisfied in all but one country (Greece) in a sample of 14. In the vintage model, the viability condition is only a sufficient condition for profit-rate improvement so this exception remains ambiguous.

[23] For more details, see Foley, Michl and Tavani (2019, Ch. 8.3).

[24] Here the basic problem is that the neoclassical theory has an escape clause in the form of unobservable shifts in the entire spectrum of known techniques that they call total factor productivity. It is not without reason that this is sometimes dismissed as a "measure of our ignorance" by neoclassical growth theorists. We discuss this in Foley, Michl and Tavani (2019, Ch. 11).

[25] The other two studies (Sasaki 2008; Michl 2008) do not find many such observations. One major difference is that they use data for the profit share that have been corrected on the grounds that national accounts using the share of reported employee compensation in national income tend to overstate the profit share because much income of the self-employed is misclassified, as shown by Gollin (2002). Campbell and Tavani (2019) argue that more recent vintages of the Penn World Tables and the Extended Penn World Tables derived from it have addressed this shortcoming, but it would appear to me to be an important line of research for future work on the issues raised in this paper. Another possibility is that wage growth that deviates from productivity growth may be a confounding factor as discussed earlier.

[26] To anticipate objections, I am not a devotee of Popperian epistemology, and do not regard falsification as the Philosopher's Stone of science. But it surely has some value.

VI. Concluding remark

Duncan Foley once observed (2006, p. 25) that

> "... almost all schools of thought have adopted some version of the thesis that profit rates tend to fall with accumulation, and the investigation of this idea has been one of the most fruitful lines of thought in developing the ideas of political economy."

In this paper, we have offered some observations on possible lines of empirical and theoretical research that have been opened up by the contributions of two exceptional and prolific political economists. The sources and consequences of Marx-biased technical change, the contours of the selection process, and the role of fixed capital remain outstanding topics in a positive research program.

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