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Abstract

This paper presents a theory of biased technological change in which firms pursue a random, local, search for productivity-enhancing innovations. They implement profitable innovations at fixed prices, subsequently adjusting prices and wages. Factor productivity growth rates are shown to respond positively to factor cost shares. Combined with price-setting behavior, an equilibrium is characterized by constant cost shares and productivity growth rates. Under target-return pricing, capital productivity growth is zero at equilibrium, yielding Kaldor's "stylized facts" of constant capital productivity and rate of profit. Equilibrium can be disturbed by changes in the pricing regime or technological potential for productivity improvement.

Keywords: post-Keynesian; biased technological change; induced technological change

JEL: E12, E14, O33

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1 Introduction

In a well-known paper, Kaldor (1961, pp. 178–179) introduced six “stylized facts”, of which the first four are: rising labor productivity and output; rising capital per worker; a steady rate of profit; and steady capital-output ratios. Two of Kaldor’s “facts” are not strictly true: the rate of profit and capital-output ratios have not been steady. By compiling long historical data series, Maddison (1994, p. 10) demonstrated that capital productivity, although it does not exhibit a long-run trend, wanders over a wide range, while Piketty (2014) documents variations in both rate of profit and capital-output ratios and describes their social impact. Nevertheless, Kaldor’s stylized facts hold in a looser form: in high-income countries, labor productivity and output have risen substantially, while capital productivity and profit rates vary widely, but show no overall trend.

We explain these stylized facts using a theory of biased technological change. In such theories, the relative pace of labor-saving or capital-saving innovation depends on the shares of labor and capital costs in production. The inspiration comes originally from Hicks (Hicks, 1932, p. 124 ff.), with further contributions from neoclassical (Kennedy, 1964; Roemer, 1977), Sraffian (Okishio, 1961, 2001), Marxian and evolutionary (Duménil & Lévy, 1995), and classical (Foley, 2003, p. 42 ff.) perspectives. We follow the evolutionary approach of Duménil and Lévy (1995), but ground our assumptions in post-Keynesian theory. In our model, technological change and the functional income distribution are jointly determined through two mechanisms. First, firms seek innovations that increase returns under prevailing prices, inducing a bias toward saving on the input with the highest cost share. Second, as innovations diffuse throughout the economy, firms adjust their prices and the wages they pay in response to the new cost structure. Firms may use a variety of discovery processes, including learning by doing, funded R&D, or adaptation of competitors’ innovations. The resulting productivity change is random, and bounded by technological potential.

The theory of biased technological change can be contrasted with neoclassical theories of induced technological change. Neoclassical theory assumes that firms maximize profits given either a production function (e.g., Berndt & Wood, 1975) or a production possibilities frontier. Recent theories are dynamic, with endogenous expansion of the production possibilities frontier (Acemoglu, Aghion, Bursztyn, & Hemous, 2012; Kumar & Managi, 2009) or knowledge accumulation (Goulder & Schneider, 1999; Gritsevskyi & Nakićenović, 2000). In contrast, the evolutionary theory of biased technological change we present in this paper makes no sharp distinction between exogenous and endogenous technological change, and firms need not know the production possibilities frontier. Rather, firms make a local search relative to their current technology, and implement discoveries that increase their return on capital in the short run.

We start from Duménil and Lévy’s (1995) model, but go significantly beyond it. We relax their restrictive assumptions about technological discovery. We then show that if firms adopt target-return pricing, the stylized fact of trendless capital productivity emerges through an endogenous process. The combination of technological innovation and pricing generates an equilibrating dynamic, but in this post-Keynesian model, prices do not clear markets. Rather, the equilibrium is characterized by stable cost shares and productivity growth rates.

2 The model of Duménil and Lévy

We begin by presenting a version of Duménil and Lévy's (1995) evolutionary model, which has one sector and two factors of production – labor and capital. Firms are continually searching for technological discoveries; those discoveries may or may not be biased towards saving on one input or another, but a bias will arise in any case because, as argued by Okishio (1961), firms only adopt those discoveries that increase their return on capital.

Firms have a capital productivity κ and labor productivity λ. In this post-Keynesian model, firms operate in an oligopolistic environment in which they have considerable flexibility to set both wages and prices (Coutts & Norman, 2013). They employ labor at a wage w and set their price P. The profit rate r is then

$$r = \kappa\pi = \kappa\left(1 - \frac{w}{P\lambda}\right), \tag{1}$$

where π is the profit share. If a firm makes a discovery that would, if implemented, change productivities by amounts $\Delta\kappa$, $\Delta\lambda$, the firm then asks whether implementing it will raise profitability in the short run while keeping prices fixed. Using a hat to denote a growth rate, $\hat{x} = \Delta x/x$, we have

$$\hat{r} = \hat{\kappa} + \frac{\omega}{\pi}\hat{\lambda}, \tag{2}$$

where $\omega = 1 - \pi$ is the wage share. Firms adopt a discovery if it raises the profit rate at constant costs, giving the viability condition

$$\pi\hat{\kappa} + \omega\hat{\lambda} > 0. \tag{3}$$

When the expression on the left side of this inequality is equal to zero, it is an orthogonality relationship – that is, the vector with elements $(\hat{\kappa}, \hat{\lambda})$ is perpendicular to a vector with elements (π, ω). The inequality in (3) then says that viable technologies sit at points in $(\hat{\kappa}, \hat{\lambda})$-space that lie in a positive direction perpendicular to a line that passes through the origin and (π, ω). We illustrate this condition for the average viable technology in Figure 1. In the figure we suppose, with Duménil and Lévy (1995), that discovery is entirely neutral. Discoveries, if implemented, move productivities in a random direction, with a probability distribution that is circularly symmetric and also symmetric around the $\hat{\kappa} = \hat{\lambda}$ line. With these assumptions, the firm is just as likely to make a labor-saving or a capital-saving discovery. However, viable technologies must lie on the positive side of the line perpendicular to (π, ω), which introduces a bias.

Two such lines are shown, one with $\pi = 0.3$ (so $\omega = 0.7$) and one with $\pi = 0.4$ (so $\omega = 0.6$). The average viable technology lies along a vector perpendicular to the lines, and in a positive direction away from them, shown in the figure by the vectors labeled $(\hat{\kappa}_1, \hat{\lambda}_1)$ and $(\hat{\kappa}_2, \hat{\lambda}_2)$. As shown, in both cases capital productivity is falling, because both $\hat{\kappa}_1$ and $\hat{\kappa}_2$ are negative. As the profit share rises, the vector rotates clockwise, so when $\pi = 0.4$, capital productivity is falling more slowly, and labor productivity rising more slowly, than when $\pi = 0.3$.

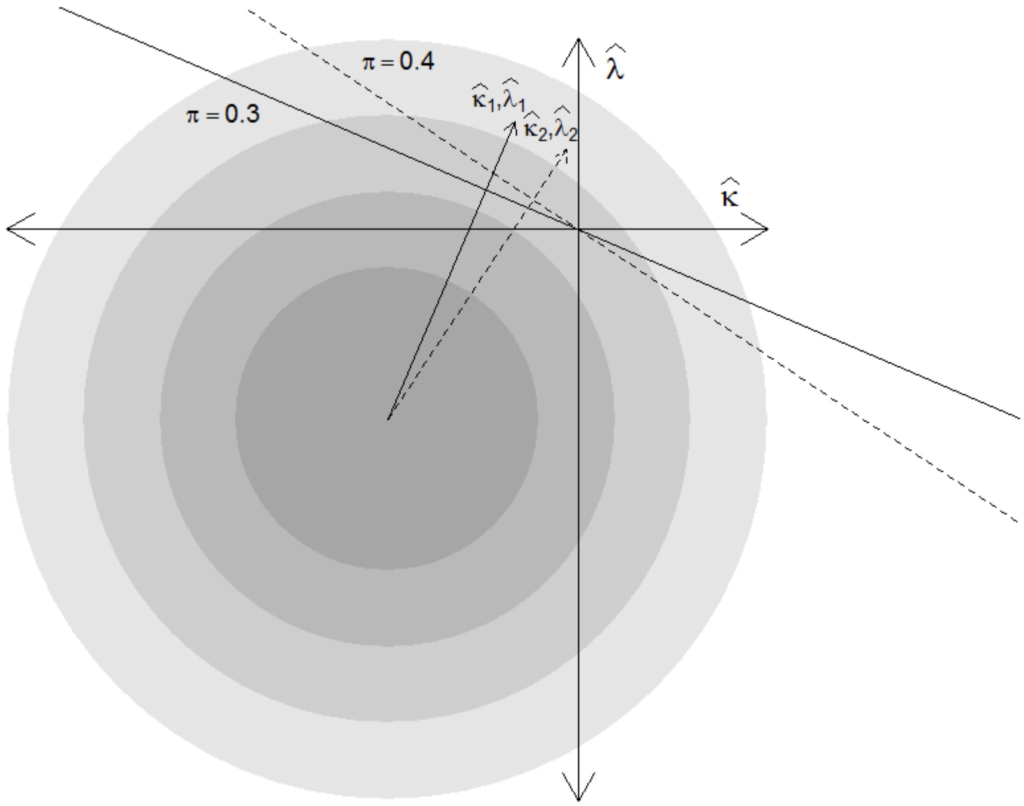

Figure 1: Source of bias toward labor-saving invention

As successful discoveries are implemented through innovation and emulation, firms subsequently adjust their prices. They engage in explicit or implicit bargaining over wages and may reduce prices to expand their market or discourage entry by rival firms. Duménil and Lévy (1995, p. 237) argued that labor productivity growth depends on the wage share such that the system approaches an equilibrium with constant labor productivity growth and a fixed wage share. In the example shown in Figure 1, this drives a steady improvement in capital productivity and a steadily falling rate of profit. However, the result depends on the probability distribution of technological discovery. As the origin of the probability distribution shifts, and as its boundary expands and contracts, it is reasonable to suppose that labor productivity growth continues to be biased in a positive direction, but capital productivity can either rise or fall, as the average rate of capital productivity growth becomes positive or negative. In this way Duménil and Lévy (1995) explained Kaldor's (1961) stylized facts.

3 A general model of biased technological change

Duménil and Lévy's model neatly explains Kaldor's stylized facts, but has some limitations. It requires a specific form for the probability distribution of technological discoveries, and exogenous changes in the distribution drive capital productivity growth. In this section we generalize their model and show how the capital productivity growth rate can emerge endogenously.

3.1 A multi-factor viability condition

We continue to denote capital productivity by κ and the price level by P, but we now allow for an arbitrary number of factors, N, indexed by $i = 1,\ldots N$, with costs per unit input q_i. Those factors, including labor, are used in production with productivity ν_i, so the profit rate is

$$r = \kappa\left(1 - \frac{1}{P}\sum_{i=1}^{N}\frac{q_i}{\nu_i}\right). \tag{4}$$

Suppose that a firm makes a discovery that would, if implemented, change productivities at rates $\hat{\nu}_i$. The change in the profit rate at constant prices is then

$$\hat{r} = \hat{\kappa} + \left(1 - \frac{1}{P}\sum_{i=1}^{N}\frac{q_i}{\nu_i}\right)^{-1}\frac{1}{P}\sum_{i=1}^{N}\frac{q_i}{\nu_i}\hat{\nu}_i. \tag{5}$$

The expression in parentheses is the profit share,

$$\pi = \left(1 - \frac{1}{P}\sum_{i=1}^{N}\frac{q_i}{\nu_i}\right), \tag{6}$$

while the cost share for each factor is

$$\sigma_i = \frac{1}{P}\frac{q_i}{\nu_i}. \tag{7}$$

Using this notation, we can write equation (5) as

$$\hat{r} = \hat{\kappa} + \frac{1}{\pi}\sum_{i=1}^{N}\sigma_i\hat{\nu}_i. \tag{8}$$

A discovery is viable if it increases the profit rate. Imposing the condition that $\hat{r} > 0$, we have

$$\pi\hat{\kappa} + \sum_{i=1}^{N}\sigma_i\hat{\nu}_i > 0. \tag{9}$$

To simplify the notation, we extend the set of factors to include capital, defining shares and productivity for index $i = 0$,

$$\sigma_0 \equiv \pi, \quad \nu_0 \equiv \kappa. \tag{10}$$

We can then write equation (9) compactly as

$$\boldsymbol{\sigma}\cdot\hat{\boldsymbol{\nu}} > 0. \tag{11}$$

This is the viability condition for new discoveries – when it holds, discoveries tend to be accepted, and when it fails, discoveries are certainly rejected.

3.2 Induced bias in a random discovery process

We follow Hicks (1932, p. 125) and Duménil and Lévy (1995) in supposing that discovery is a random process. Specifically, we label discoveries by their effect on productivities, and assume that any individual discovery is drawn from a probability distribution $f(\hat{\mathbf{v}})$. The average productivity improvement, $\langle \hat{\mathbf{v}} \rangle$, is then given by integrating over all possible values of $\langle \hat{\mathbf{v}} \rangle$ that satisfy the viability condition (11). We enforce the viability condition using the Heaviside function $h(x)$, which is equal to one when its argument is positive and zero when its argument is negative,

$$\langle \hat{\mathbf{v}} \rangle = \int d\hat{\mathbf{v}}\; h(\boldsymbol{\sigma} \cdot \hat{\mathbf{v}}) \hat{\mathbf{v}} f(\hat{\mathbf{v}}). \tag{12}$$

The Heaviside function has zero slope everywhere except when its argument is zero, where it has an infinite slope. This behavior is captured through a standard relationship,

$$\frac{d}{dx} h(x) = \delta(x). \tag{13}$$

In this expression, $\delta(x)$ is the Dirac delta function,[2] equal to zero except at $x = 0$. The cost share $\boldsymbol{\sigma}$ only appears within the Heaviside function in equation (12), so we can take the derivative of the ith element of $\langle \hat{\mathbf{v}} \rangle$, $\langle \hat{v}_i \rangle$, with respect to σ_j to find

$$\frac{\partial \langle \hat{v}_i \rangle}{\partial \sigma_j} = \int d\hat{\mathbf{v}}\; \delta(\boldsymbol{\sigma} \cdot \hat{\mathbf{v}}) \hat{v}_j \hat{v}_i f(\hat{\mathbf{v}}). \tag{14}$$

This is an essential result. Because of the Dirac delta function, the integral is taken over a reduced space (a hyperplane) in which $\boldsymbol{\sigma} \cdot \hat{\mathbf{v}} = 0$. Also, it holds for any probability distribution $f(\hat{\mathbf{v}})$. This is a more general and flexible expression than that found by Duménil and Lévy (1995), who assumed a specific form for the probability distribution and who went to some pains to evaluate the integral in equation (12) over the domain $\boldsymbol{\sigma} \cdot \hat{\mathbf{v}} > 0$, rather than just the hyperplane that bounds it.

We can express the right-hand side of equation (14) as the entries M_{ij} in a matrix $\mathbf{M}$,

$$M_{ij} = \frac{\partial \langle \hat{v}_i \rangle}{\partial \sigma_j} = \int d\hat{\mathbf{v}}\; \delta(\boldsymbol{\sigma} \cdot \hat{\mathbf{v}}) \hat{v}_j \hat{v}_i f(\hat{\mathbf{v}}). \tag{15}$$

The off-diagonal elements of $\mathbf{M}$ are symmetric, $M_{ij} = M_{ji}$, while its diagonal elements are positive,

$$M_{ii} = \int d\hat{\mathbf{v}}\; \delta(\boldsymbol{\sigma} \cdot \hat{\mathbf{v}}) \hat{v}_i^2 f(\hat{\mathbf{v}}) > 0. \tag{16}$$

For an arbitrary vector $\mathbf{x}$, a quadratic form constructed with $\mathbf{M}$ is non-negative,

$$\mathbf{x}^T \cdot \mathbf{M} \cdot \mathbf{x} = \int d\hat{\mathbf{v}}\; \delta(\boldsymbol{\sigma} \cdot \hat{\mathbf{v}}) \left(\sum_{i=0}^{N} x_i \hat{v}_i \right)^2 f(\hat{\mathbf{v}}) \geq 0. \tag{17}$$

This expression is zero only for vectors $\mathbf{x}$ that are proportional to $\boldsymbol{\sigma}$, because

$$\mathbf{M} \cdot \boldsymbol{\sigma} = \int d\hat{\mathbf{v}}\; \delta(\boldsymbol{\sigma} \cdot \hat{\mathbf{v}}) \hat{v}_i \left(\boldsymbol{\sigma} \cdot \hat{\mathbf{v}} \right) f(\hat{\mathbf{v}}) = 0, \tag{18}$$

[2] Strictly speaking, $\delta(x)$ is not a function, but a distribution, which means that it is only well-defined within an integral. Aside from this formal expression, we keep it within integrals.

where we have used the property of the Dirac delta function that $x\delta(x) = 0$. These properties mean that **M** is an $(N+1)\times(N+1)$ dimensional positive semi-definite matrix of rank N.

From the properties of **M**, we get the immediate result that the own-response of the productivity growth rate to a change in the cost share is positive,

$$\frac{\partial\langle\hat{v}_i\rangle}{\partial\sigma_i} = M_{ii} > 0. \tag{19}$$

If the probability distribution $f(\hat{\mathbf{v}})$ does not change, the total change in $\langle\hat{v}_i\rangle$ is given by

$$\Delta\langle\hat{v}_i\rangle = \sum_{j=0}^{N}\Delta\sigma_j \frac{\partial\langle\hat{v}_i\rangle}{\partial\sigma_j} = \sum_{j=0}^{N} M_{ij}\Delta\sigma_j. \tag{20}$$

Because $\boldsymbol{\sigma}$ is a vector of shares that must sum to one, the change $\Delta\boldsymbol{\sigma}$ has to sum to zero, so it cannot be proportional to $\boldsymbol{\sigma}$. From this fact, and the positive semi-definiteness of **M**, we find

$$\Delta\boldsymbol{\sigma}^T \cdot \Delta\langle\hat{\mathbf{v}}\rangle = \Delta\boldsymbol{\sigma}^T \cdot \mathbf{M}\cdot\Delta\boldsymbol{\sigma} > 0. \tag{21}$$

That is, given a change in the cost share, the response is, on balance, an increase in the productivity growth rates of those factors that saw their cost share rise.

3.3 Complementary factors as a special case

Both the positivity of the own-response in (19) and the general positivity condition in (21) suggest that the total response of the productivity growth rate of a particular factor to a rise in the cost share will generally be positive, but they do not guarantee it. A possible exception can arise when two factors are complementary.

We say that two factors i and j are complements if M_{ij} is positive, and substitutes if negative. If the only two factors are capital, with index $i = 0$, and labor, with index $j = 1$, then they must be substitutes, and all coefficients are determined up to an overall parameter. With two factors, equation (18) becomes

$$\begin{pmatrix} M_{00} & M_{01} \\ M_{10} & M_{11} \end{pmatrix}\begin{pmatrix} \pi \\ \omega \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}. \tag{22}$$

Because $M_{01} = M_{10}$, this implies

$$M_{01} = M_{10} = -\frac{\pi}{\omega}M_{00} = -\frac{\omega}{\pi}M_{11}. \tag{23}$$

All entries can then be expressed in terms of a single entry, for example M_{00}. When there are more than two factors, it is possible for some factors to be complements.

The distinction between complements and substitutes is important when determining the total change in productivity growth rates. Cost shares must sum to one, so any increase in the cost share of one factor must be compensated by a net decrease in the cost shares of other factors. Suppose that an increase z in the cost share for factor i is compensated entirely by a fall in the cost share for factor j,

$$\Delta\sigma_i = z, \quad \Delta\sigma_j = -z, \quad \Delta\sigma_k = 0 \text{ for } k \neq i, j. \tag{24}$$

Then the total change in $\langle\hat{v}_i\rangle$ is equal to

$$\Delta\langle\hat{v}_i\rangle = z\left(\frac{\partial\langle\hat{v}_i\rangle}{\partial\sigma_i} - \frac{\partial\langle\hat{v}_i\rangle}{\partial\sigma_j}\right) = z\left(M_{ii} - M_{ij}\right). \tag{25}$$

If factors i and j are substitutes, this is certainly positive, because M_{ij} is negative. However, if they are complements then this expression could, in principle, be negative. To constrain the possibilities, we use a property of positive semi-definite matrices, that the absolute value of the off-diagonal elements is bounded by the average of the corresponding diagonal entries,[3]

$$\left|M_{ij}\right| \leq \frac{1}{2}\left(M_{ii} + M_{jj}\right). \tag{26}$$

If i and j are complements, then $|M_{ij}| = M_{ij}$, and we have

$$\Delta\langle\hat{v}_i\rangle \geq \frac{z}{2}\left(M_{ii} - M_{ij}\right) = \frac{z}{2}\left(\frac{\partial\langle\hat{v}_i\rangle}{\partial\sigma_i} - \frac{\partial\langle\hat{v}_j\rangle}{\partial\sigma_j}\right). \tag{27}$$

As we have assumed z to be positive, the total change in $\langle\hat{v}_i\rangle$ is certainly positive when factor i's own-response exceeds that for factor j. However, using the same argument, a rise in the cost share of the other factor, j, could be negative, which can introduce a positive feedback. Under the assumed conditions, when the jth factor's cost share rises and the ith factor's cost share falls by the same amount, processes that use more of factor i become profitable even if they drive unit inputs of the jth factor upward. If they are adopted, we expect the cost share σ_j to increase, driving a further decline in v_j.

This positive feedback, which drives the cost share of factor j steadily upward and that of factor i downward, clearly cannot continue indefinitely; at some point, factor j figures so heavily in costs that firms can no longer accept increases in its use even if accompanied by declines in the cost of factor i. We therefore argue, on economic grounds, that pairs of factors should normally satisfy

$$\frac{\partial\langle\hat{v}_j\rangle}{\partial\sigma_i} = \frac{\partial\langle\hat{v}_i\rangle}{\partial\sigma_j} \leq \min\left(\frac{\partial\langle\hat{v}_i\rangle}{\partial\sigma_i}, \frac{\partial\langle\hat{v}_j\rangle}{\partial\sigma_j}\right). \tag{28}$$

For complementary factors, this inequality may be temporarily violated, accompanied by an unstable dynamic that halts when cost shares have shifted sufficiently that the inequality is re-established.

3.4 An equilibrating dynamic

From the above, aside from a transient condition for some complementary factors, we expect the following to hold:

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[3] This can be shown by defining $\mathbf{x}^{\pm}$ such that $x_i^{\pm} = 1$, $x_j^{\pm} = \pm 1$, $x_k = 0$ for $k \neq i, j$, and applying the inequality (17).

$$\Delta\sigma_i > 0 \quad \Rightarrow \quad \Delta\langle\hat{v}_i\rangle > 0. \tag{29}$$

This is the essential assumption in models of biased technological change: a rise in the cost share of a factor stimulates faster productivity growth in that factor. We have provided a justification for the assumption using a general probabilistic model of discovery and innovation.

For as long as the probability distribution $f(\hat{\mathbf{v}})$ does not change, changes in factor productivity depend on changes in cost shares, mediated by the $\boldsymbol{\sigma}$-dependent matrix $\mathbf{M}$,

$$\Delta\hat{\mathbf{v}} = \mathbf{M}\cdot\Delta\boldsymbol{\sigma}. \tag{30}$$

After innovation, firms respond to productivity changes by setting prices (following their pricing policies) and wages (through tacit or explicit negotiation with their employees). From the expression for the cost shares in equation (7), the subsequent growth in cost shares is

$$\hat{\boldsymbol{\sigma}} = \left(\hat{\mathbf{q}} - \hat{P}\right) - \hat{\mathbf{v}}. \tag{31}$$

The term in parentheses is a vector of growth rates of real costs. These, in turn, can be expected to respond to changes in productivity. Equations (30) and (31) form a dynamic system with an equilibrium solution $\Delta\hat{\mathbf{v}} = \Delta\boldsymbol{\sigma} = 0$. That is, equilibrium is characterized by fixed cost shares and productivity growth rates.

Equation (12), which relates $\boldsymbol{\sigma}$ to $\hat{\mathbf{v}}$, holds both in and out of equilibrium. An equilibrium, once established, can be disturbed by changes in pricing strategy or by changes in technological potential as captured in the probability distribution $f(\hat{\mathbf{v}})$. These results generalize those of Duménil and Lévy (1995).

4 Biased technological change with target-return pricing

Under target-return pricing, firms adjust their profit margins to maintain a fixed value for the profit rate, r, through a combination of changing price and changing wages, so after price adjustment,

$$\Delta r = \Delta\left(\pi\kappa\right) = \pi\Delta\kappa + \kappa\Delta\pi = 0. \tag{32}$$

The change in the profit share is then equal to

$$\Delta\pi = -\hat{\kappa}\pi. \tag{33}$$

Assuming biased technological change, and assuming the economy-wide productivity change to equal the average, we apply (29) to the specific case of the profit share and capital productivity,

$$\Delta\pi > 0 \quad \Rightarrow \quad \Delta\hat{\kappa} > 0. \tag{34}$$

Between (33) and (34) we have an equilibrating mechanism. If $\hat{\kappa}$ is positive then, from equation (33), target-return pricing pushes π downward. The process of biased technological change, as expressed in (34), subsequently pushes $\hat{\kappa}$ downward. Conversely, if $\hat{\kappa}$ is negative, the combination of target-return pricing and biased technological change pushes it upward. Equilibrium is reached when $\hat{\kappa} = 0$, at which point capital productivity κ, the profit share π, and the profit rate (which is the product of the two) are all constant. As in Duménil and Lévy (1995), the wage share, and the labor productivity growth rate, also approach constant values, while the real wage tracks labor productivity.

Through a combination of biased technological change and target-return pricing we therefore recover Kaldor's stylized facts. By assuming target-return pricing we impose one of those facts, a steady rate of profit, which drives capital productivity towards its equilibrium value. The result is a generally rising labor productivity; stable capital productivity; and stable functional income shares. As noted in the Introduction, in actual economies neither capital productivity nor the profit rate are steady (e.g., see Maddison, 1994, p. 10), and departures from them can have serious economic consequences (as noted by Piketty, 2014). However, while we have identified an equilibrating dynamic, the equilibrium itself is contingent on firm pricing strategies and technological potential; changes in these factors can disrupt an equilibrium, and it can take time to establish a new one.

5 Conclusion

We have expanded on past developments in the theory of biased technological change, particularly the work of Duménil and Lévy (1995). Our treatment is more general than previous contributions and yields stronger results. We find a dynamic with an equilibrium characterized by fixed cost shares and productivity growth rates. Under target-return pricing, a combination of discovery, innovation, and pricing creates a dynamic that drives the economy to a state in which Kaldor's (1961) "stylized facts" hold, but economies may depart from that pattern when equilibrium is disturbed by changes in the pricing regime or the technical potential for increasing productivity.

6 References

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *American Economic Review*, *102*(1), 131–166. https://doi.org/10.1257/aer.102.1.131

Berndt, E. R., & Wood, D. O. (1975). Technology, prices, and the derived demand for energy. *The Review of Economics and Statistics*, *57*(3), 259–268. https://doi.org/10.2307/1923910

Coutts, K., & Norman, N. (2013). Post-Keynesian approaches to industrial pricing. In G. C. Harcourt & P. Kriesler (Eds.), *The Oxford Handbook of Post-Keynesian Economics, Volume 1: Theory and Origins*. Retrieved from http://www.oxfordhandbooks.com.ezp.sub.su.se/view/10.1093/oxfordhb/9780195390766.001.0001/oxfordhb-9780195390766-e-019

Duménil, G., & Lévy, D. (1995). A stochastic model of technical change: An application to the US economy (1869–1989). *Metroeconomica*, *46*(3), 213–245. https://doi.org/10.1111/j.1467-999X.1995.tb00380.x

Foley, D. K. (2003). Unholy Trinity: Labor, Capital, and Land in the New Economy. London; New York: Routledge.

Goulder, L. H., & Schneider, S. H. (1999). Induced technological change and the attractiveness of CO2 abatement policies. *Resource and Energy Economics*, *21*(3–4), 211–253. https://doi.org/10.1016/S0928-7655(99)00004-4

Gritsevskyi, A., & Nakićenović, N. (2000). Modeling uncertainty of induced technological change. *Energy Policy*, *28*(13), 907–921. https://doi.org/10.1016/S0301-4215(00)00082-3

Hicks, J. R. (1932). *The Theory of Wages*. London: MacMillan and Company Limited.

Kaldor, N. (1961). Capital accumulation and economic growth. In F. A. Lutz & D. Hague (Eds.), *The Theory of Capital* (pp. 177–222). Macmillan and Co. Ltd.

Kennedy, C. (1964). Induced bias in innovation and the theory of distribution. *The Economic Journal*, *74*(295), 541–547. https://doi.org/10.2307/2228295

Kumar, S., & Managi, S. (2009). Energy price-induced and exogenous technological change: Assessing the economic and environmental outcomes. *Resource and Energy Economics*, *31*(4), 334–353. https://doi.org/10.1016/j.reseneeco.2009.05.001

Maddison, A. (1994). *Standardised Estimates of Fixed Capital Stock: A Six Country Comparison* (GGDC Research Memorandum No. GGDC Research Memorandum 199409). Groningen, Netherlands: Groningen Growth and Development Centre, University of Groningen. Retrieved from http://ideas.repec.org/p/dgr/rugggd/199409.html

Okishio, N. (1961). Technical changes and the rate of profit. *Kobe University Economic Review*, *7*, 86–99.

Okishio, N. (2001). Competition and production prices. *Cambridge Journal of Economics*, *25*(4), 493–501. https://doi.org/10.1093/cje/25.4.493

Piketty, T. (2014). *Capital in the Twenty-first Century*. (A. Goldhammer, Trans.). Cambridge, MA: Belknap Press.

Roemer, J. E. (1977). Technical change and the "tendency of the rate of profit to fall." *Journal of Economic Theory*, *16*(2), 403–424. https://doi.org/10.1016/0022-0531(77)90016-3