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biased and unbiased technological change

This article provides working definitions of biased and unbiased technological change based on the relative responses of the marginal products of capital and labour that occur in the face of shocks. These Hicksian definitions are then distinguished from others that focus on how technology augments the production function. The bias and augmentation of technical progress are then linked through the substitutability of labour and capital. Examples of 'labour-biased' and 'capital-biased' technological change from the 19th century to the present illustrate these ideas.

Among the central problems in growth economics is how to organize thinking about technological progress and its role in macroeconomic outcomes. In *The Theory of Wages* (1932), John Hicks offered a set of classifications for technical change that remains in common use. These classifications are based on the observation that inventions are unlikely to increase the marginal products of all factors of production in the same proportion, but rather will affect the marginal products of some factors more than others. Take, for example, that baseline two-factor neoclassical production function:

$$Y = F(K, L), \tag{1}$$

where Y is aggregate output, K is the capital stock, and L is labour. One way to introduce a technology parameter A is to place it at the front of the production function as

$$Y = AF(K, L). \tag{2}$$

Notice that A enters linearly, so that a doubling of the technology parameter also doubles output. Technological progress of this type is said to be 'unbiased' or 'Hicks neutral' in that the ratio of the marginal products of capital and labour used in the production process does not change. In this case, progress simply requires a renumbering of production isoquants.

Innovations are rarely neutral, however, and for this reason economists have naturally been more interested in cases where technological change alters the ratio of marginal products. When this occurs, technological change is said to be 'biased'. Hicks defines the bias as 'labour-saving' when the marginal product of capital increases more than that of labour for a given capital-labour ratio, thereby increasing the demand for capital. 'Capital-saving' technical progress occurs when the marginal product of labour rises more than that of capital for a given capital–labour ratio, thereby increasing the demand for labour. Nowadays economists simply refer to technological change that is labour-saving in the Hicksian sense as having a 'capital bias,' and change that is capital-saving in the Hicksian sense as having a 'labour bias.' This avoids confounding the bias of a given technological change with the way that it enters the production function.

An alternative concept of proposed by R.F. Harrod (1937; 1948) defines technological change as neutral if the marginal product of capital is unchanged at a given capital–output ratio. Another way of stating this is that, under a constant rate of interest and an infinite supply of capital at that rate, a technological change is 'Harrod-neutral' if it leaves the length of the production process unaltered. H. Uzawa (1961) shows that this implies a production function of the form

$$Y = F(K, AL), \tag{3}$$

where AL is a unit of 'effective' labour. Note that this formulation is *not* neutral in the Hicksian sense unless the production function is Cobb–Douglas. Economists commonly refer to (3) as a 'labour-augmenting' production function, but it does not follow that technological change is necessarily labour-biased in the Hicksian sense of relative marginal products.

The opposite symmetric case to Harrod-neutrality defines an invention as neutral if the wage rate remains unchanged at a constant labour-output ratio. This implies a production function of the form

$$Y = F(AK, L), \tag{4}$$

where AK is a unit of 'effective' capital. Economists often refer to this 'capital-augmenting' form of the production function as 'Solow-neutral,' but only because Robert Solow (1959) was first to use this form to model technological progress. Once again, this formulation is *not* neutral in the Hicksian sense unless the production function is Cobb–Douglas, and changes in A are not necessarily capital-biased in the Hicksian sense. R. Sato and M.J. Beckmann (1968) offer a useful taxonomy of these and other 'neutral' production functions.

Of the three output equations shown above, it turns out that only the second (that is, labour-augmenting) form is consistent with a settling down to constant growth under steady technological progress and assumptions of constant returns to scale and diminishing marginal rates of substitution in production. Thus, if we are interested in neoclassical models that move beyond Cobb–Douglas production and possess a steady state, it is useful for technology to multiply labour and make it more effective. Since US wages have risen over the past century while the rental rate has remained relatively steady, the labour-augmenting formulation is at least a priori consistent with the evidence from the United States.

To distinguish technological progress that is factor-augmenting from their underlying Hicksian factor-biases, it is necessary to consider the elasticity of substitution between the factors as technical change occurs. Daron Acemoglu (2002) illustrates this with a CES (that is, constant elasticity of substitution) production function of the form

$$Y = [w(A_L L)^{\frac{\sigma-1}{\sigma}} + (1-w)(A_K K)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}}, \tag{5}$$

where σ is the elasticity of substitution between capital and labour, A_L and A_K are factor-specific technology parameters, and w is a weight $(0 \leq w \leq 1)$ that measures the relative importance of each factor. The factors are gross substitutes when $\sigma > 1$, whereas they are gross complements when $\sigma < 1$. With$\sigma > 1$, substitutability between factors allows both the augmentation and bias of technological change to lean towards the same factor. In the case where $\sigma < 1$, however, a capital-augmenting technological change (or a rise in A_K) actually increases demand for the complementary input (that is, labour) more than it increases the demand for capital. The excess demand for labour raises its marginal product more than that of capital, leading to a labour bias in production. Similarly, a labour-augmenting technological change (or a rise in A_L) leads to a capital-bias when $\sigma < 1$. When $\sigma = 1$ the production function is Cobb–Douglas and an increase in A does not produce a bias towards either factor.

Hicks and A.C. Pigou (1920) have contended that most technological change is capital biased, and the American experience in the latter half of the 19th century would seem to support this view. Innovations such as Bessemer process of steelmaking, new distillation methods in petroleum refining, and the adoption of European reduction methods in flour milling, as noted by John James (1983), led to capital deepening and economies of scale in these industries that increased concentration. Such technological changes seem so important that the rise of big business around the turn of the 20th century is sometimes attributed to them. Though this view probably overstresses the role of technology in the evolution of industrial structure over this period, it is interesting that the capital bias observed in industries for which the story fits were a result of labour augmentation (that is, a rise in A_L) and inelastic factor substitution (that is, $\sigma < 1$).

Electrification offers another example. Prior to its arrival, manufacturing had been designed around the rigidities of steel shafts that ran through the length of a factory and were turned in unison by a single water or steam-powered generator. Afterwards, as Warren Devine (1983) describes, the organization of work gradually evolved to exploit the open factory structure that electric unit drive made possible. Unit drive meant less time spent maintaining complex systems of leather straps and pulleys that transferred power from the rotating steel shafts to the machines, and less down time caused by the need to stop all production to repair a single machine. Electrification and unit drive also made it economical for factories to stay open longer. These innovations made labour more productive (that is, raising A_L), but more focused machinery also reduced the amount of labour that was needed to operate a factory ($\sigma < 1$), raising the marginal product of capital more quickly than that of labour and producing a capital bias. The bias leaned even more towards capital as the diffusion of electricity began to mature, and labour-saving innovations such as vacuum cleaners, toasters, and electric blast furnaces became commonplace.

But is the apparent capital-bias in technological change largely 'induced' by changes in factor prices? Charles Kennedy (1964) points out that falling capital prices will motivate individuals to build more inventions that economize on labour than they would build at constant factor prices. Since the prices of capital goods have declined fairly consistently for more than a century and a half, it seems natural that the vast majority of induced inventions would have been capital biased. At the same time, it is important to distinguish biased technological progress (that is, an outward movement and shift along an isoquant) from movements along a fixed isoquant that arise from changes in factor prices, since such changes do not represent technological progress at all. Noting these potential biases, Hicks concludes that 'autonomous' inventions, meaning those not prompted by decline of a relative factor price, need not be predominantly capital biased. Indeed, information technology (IT) presents an example where the bias may have moved in the opposite direction.

Computers reduced expenditures on specialized and/or mechanical office machines, thereby making capital more productive (that is, raising A_K). At the same time, labour also became more productive as skilled individuals learned how to use computers to perform complex tasks and less-skilled individuals accomplished routine tasks much more quickly (that is, raising A_L). Thus, there seem to be complementarities between IT and skilled workers, raising the return to skill and producing a 'skill bias', while there has been some substitution of computers for less skilled individuals, pressing towards a capital bias. On the whole, however, the complementarity effects so far have outweighed substitution effects, leading to a labour bias. As an invention in the method of inventing, IT has also led to a wide range of induced innovations, both capital- and labour-saving. Design tools used by engineers, for example, have improved the quality of capital goods and allowed more new products to be created. The availability of a broad base of knowledge on the World Wide Web from all over the globe has also transmitted the information needed to make labour more productive.

Is IT typical of the type of technological change that is likely to continue, starting with a labour bias but spawning new innovations that are for the most part labour-saving? If so, parsing out the components of labour bias, and particularly understanding the role of skill bias in the post-war US economy, seems at the core of understanding the role that technology will play in 21st century economic growth.

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See also

<xref=xyyyyyy> Hicks, John Richard;
<xref=xyyyyyy> skill-biased technical change;
<xref=T000034> technical change.

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Index terms

biased and unbiased technological change
CES production function
Cobb–Douglas functions
elasticity of substitution
information technology
neutral production functions
skill-biased technical change
substitutes and complements
technical change

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Index terms not found:

skill-biased technical change
substitutes and complements