The neoclassical and Marxian theories of technology: a comparison and critical assessment

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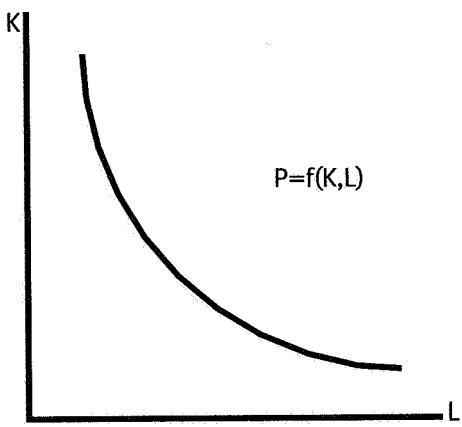
Neoclassical economics remains the leading theoretical alternative to Marxian economics. In this article I shall contrast the accounts of technical change in capitalism proposed by both theories. I shall introduce five criteria relevant to a comparison of competing social theories, and argue that the Marxian perspective on technical change in capitalism[1] is superior on all five counts.

A. Technology and neoclassical economics

The first task of the neoclassical theory of technology is to explain the selection of a specific technique from among the variety of techniques available on a given level of technology. The production function provides the basic framework for this explanation.[1]

In the simplest neoclassical model a firm produces a single homogeneous output. To produce this output it makes use of two sorts of inputs, two 'factors of production': capital ('K') and labour ('L'). A given quantity of output ('Q') can be produced with a variety of different techniques. In some techniques relatively more capital is employed and less labour, while in others the reverse holds. This state of affairs can be formulated mathematically by the production function Q=f(K,L), depicted graphically by an isoquant curve:

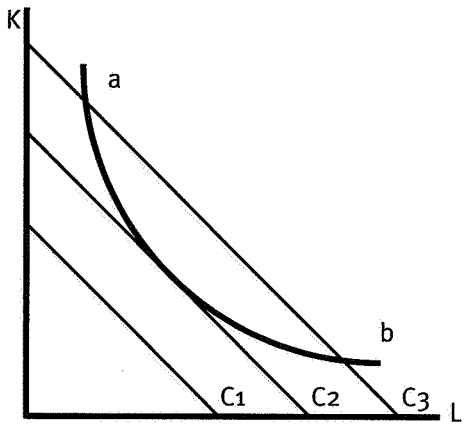


Graph 1

A technology can be defined as the set of all the techniques represented by points on this curve.

Why, then, is one technique selected over all the others in a given pro-

duction function? To answer this question neoclassical economists introduce the concept of the isocost line, derived as follows. The costs a firm must pay (C) equals the amount of labour used (L) multiplied by the price of labour (pl), plus the amount of capital used (K) multiplied by the price of capital (pk): C =Lpl+Kpk. This equation can be rewritten as K=(-pl/pk)L+C/pk, a straight line. With the price of labour and capital given, we can vary the total cost to the firm by varying the quantity of labour and capital purchased. This is depicted graphically by a family of parallel lines, for example:



Graph 2

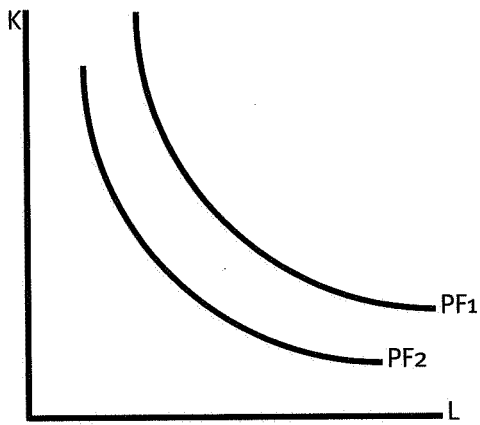
Let us assume that a firm wishes to produce Q units of some product, estimating that this is the amount the particular market can absorb. It obviously will not purchase inputs at the levels depicted in C1, for then it will not be able to produce the desired output. This output can be produced if capital and labour are purchased in the amounts depicted by points a and b on line C3, representing a capital-intensive technique and a labour-intensive technique, respectively. But it would not be rational for the firm to purchase the amount of capital and labour required by these techniques. The firm will be able to produce the same level of output at lower cost if it selects the technique depicted by the point of tangency between the isoquant and isocost line C2. In the given situation this technique is superior to all other possible choices as well.

The slope of the production function expresses the amount of one factor of production that must be added to compensate for the loss of a unit of the other input, keeping the quantity of output fixed. More precisely, it is defined as the negative of the ratio of the marginal productivity of labour to the marginal productivity of capital, -Mpl/Mpk. At the point of tangency this ratio will be equal to the slope of the isocost line, -pl/pk. Transforming the equation Mpl/Mpk=pl/pk to Mpl/pl=Mpk/pk provides further insight into why the technique represented by this point of tangency will be selected by the rational firm. Mpl/pl can be interpreted as the increase in quantity of output resulting from the purchase of an additional unit of labour at price pl. Suppose this is less than the increase

in output resulting from the purchase of an additional unit of capital at price pk. In this case it would be rational for the firm to adopt a more capital-intensive technique, for it would then be able to produce the same output at a lower cost. By symmetrical reasoning, it would be rational for the firm to shift to a more labour-intensive technique if Mpl/pl exceeded Mpk/pk. The eventual result of these shifts will be the selection of the technique represented by the point where the two ratios are equal, and this is the point of tangency.

Of course, if the ratio of factor prices changes, the point of tangency will shift as well. When this occurs a rational agent will select a new technique, represented by the new point of tangency. This new technique will either be more labour-intensive or more capital-intensive than its predecessor, reflecting the phenomenon referred to in neoclassical theory as 'factor substitution'.

If the first task of the neoclassical theory of technology is to explain the selection of a particular technique, the second is to account for technical change, that is, the shift from one level of technology to another, depicted by a new production function:



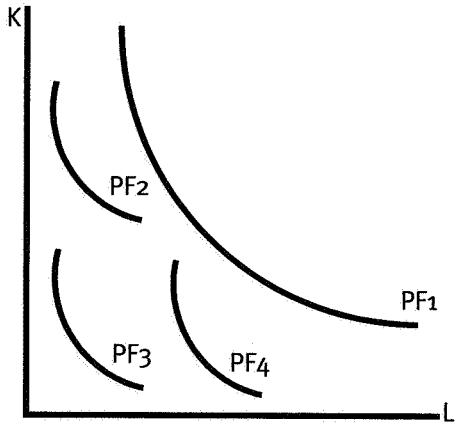
Graph 3

Rational agents will choose to move to a new technology only if it allows more efficient production. In other words, the techniques represented by the new production function must produce the same quantity of output as the techniques of the initial production function while employing fewer inputs. This is captured graphically by drawing PF2 closer to the origin than the original production function, PF1.

At this point the concept of a 'bias' in technological change must be introduced. Starting from a given production function, technological advances can take a number of different directions, as illustrated in graph 4 oveerleaf.

If we move from the initial production function to PF3, capital and labour are used more efficiently, but in the same proportions. This is called neutral technological change. If we move to PF2 or PF4 the pro-

portions shift. We have a more capital-intensive technology and a more labour-intensive technology, respectively.



Graph 4

What determines whether technological change is neutral, biased in a capital-saving direction, or biased in a labour-saving direction? The standard answer to this question was provided by John Hicks: if the state of scientific-technical knowledge advances to the point where neutral, labour-saving, or capital-saving technological change are all possible, the firm's choice will depend on existing trends in factor prices. If the prices of both inputs are fairly stable, or if these prices are both falling or rising in sync, then neutral technological change will occur. If the cost of capital is rising significantly relatively to the cost of labour, then the firm will select a capital-saving technology. If the opposite holds, a labour-saving technology will be chosen. In Hicks's view this last case has been the dominant tendency:

> The real reason for the predominance of labour-saving inventions is surely that which was hinted at in our discussion of substitution. A change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind – directed to economising the use of a factor which has become relatively more expensive. The general tendency to a more rapid increase of capital than labour which has marked European history during the last few centuries has naturally provided a stimulus to labour-saving invention.[2]

In other words, the direction of technological change is explained by a change in the ratio of factor prices, the same phenomenon that explains factor substitution on a given level of technology.

There are good reasons to believe that this standard account of technological change is incompatible with the logic of neoclassical economics. It is true that within this framework an increase in factor costs may induce a search for a new technology that will lower costs. But rational neoclassical agents will be concerned only with the sum total of costs. *Any* new technology that significantly lowers total costs will be welcome, even one that

employs relatively more of the factor whose price is increasing:

> If [Hick's] theory implies that dearer labour stimulates the search for new knowledge aimed specifically at saving labour, then it is open to serious objections. The entrepreneur is interested in reducing costs in total, not particular costs such as labour costs or capitals costs. When labour costs rise any advance that reduces total cost is welcome, and whether this is achieved by saving labour or capital is irrelevant. There is no reason to assume that attention should be concentrated on labour-saving techniques, unless, because of some inherent characteristic of technology, labour-saving knowledge is easier to acquire than capital-saving knowledge.[3]

The neoclassical approach can be elaborated much further, resulting in vast edifices of mathematical sophistication. The above account, however, is sufficient for our purposes.

B. Technology and Marxian economics

Marx's theory in *Capital* has a quite different logical structure from neoclassical economics. Neoclassical economists use the precepts of formal logic to deduce conclusions from given axioms. Marx, in contrast, attempted to reconstruct the capitalist mode of production in thought by moving step-by-step from simple and abstract economic categories to ever more complex and concrete categories. This is not the place to explore the methodology of this unique type of theory, termed 'systematic dialectics'.[4] A brief sketch of certain parts of the theory of importance to the question of technical change must suffice.

In the beginning of volume I, Marx examined the 'cell form' of the system of generalised commodity production and exchange. He distinguished 'concrete labour', privately undertaken labour that may or may not prove to be socially necessary, from 'abstract labour', defined as privately undertaken labour that proves its social necessity through producing commodities that are successfully exchanged for money. Marx then noted that commodity production and exchange is generalised only when labour-power has itself become a commodity that can be purchased by capital. The purchase of labour-power, and the setting of it to work producing commodities with economic value, thus occur within the context of the capital circuit. This circuit begins with the initial money capital (M) invested in commodity inputs (C), these inputs falling into the two categories of means of production and labour-power (purchased with constant capital and variable capital, respectively). The result of the production process (P) is then a set of commodity outputs (C′), which the owners and controllers of capital hope can be sold for a profit, that is, a sum of money (M′) exceeding the initial M invested. When this occurs the valorisation process is complete, and capital may be accumulated.

The central question of volume I can be posed as follows: if all commodities exchange at their value, that is, if there are no 'rip-offs' in the process of exchange – or if 'rip-offs' cancel each other out, the gain of one party being matched by the loss of another – how can we explain the existence of net profits in the capitalist system? Marx's answer is that the ultimate source of profits is the exploitation of wage-labour; while

labourers may receive wages that correspond to the value of their labour-power, they produce more economic value ('surplus-value') than they receive back in the form of wages.

This theory is to be applied on the level of the total social capital. It does not necessarily hold for any given unit of capital. A given unit of capital may go bankrupt and not receive any profits, no matter how much labour has been undertaken by its workers. Also, as we discover in volume III, next to no profitable units enjoy profits directly proportional to the surplus-value produced by their own workers. But in the system as a whole the profits distributed among the various factions of the capitalist class are produced by the surplus labour of the working class. The most basic social relation in capitalism is the capital/wage-labour relation, and this relation is necessarily antagonistic, being based on exploitation.

This is the very heart of Marx's theory. From the standpoint of capital, capital is the only 'subject' of the valorisation process; wage-labourers are simply one specific form capital takes in that process, the form of variable capital. According to Marx's theory of exploitation, however, it is the working class that is the true subject of economic life. 'Capital' is nothing but a form taken by the surplus-value produced by the collective working class, a form which has insanely become an alien power subsuming real human subjects under its imperatives so that '[t]he productive forces of social labour appear as inherent characteristics of capital.'[5]

Marx derived a necessary tendency to technical change in capitalism from this theory of exploitation. The owners and controllers of capital necessarily tend to introduce innovations that decrease the amount of time workers engage in necessary labour (the labour necessary to produce an amount of economic value equivalent to the wages they receive), while increasing the amount of time they spend in surplus labour, which produces the surplus-value appropriated in the form of profits. There is thus an inherent tendency in capitalism to introduce machinery with the potential to increase labour productivity. There is also a tendency to introduce technologies that allow a less skilled – and thus a less expensive – workforce to be employed. Further, there is a necessary tendency to seek innovations that restructure the labour process so as to lessen the 'pores' in the working day. This increases the intensity of labour, so that more surplus-value can be produced in a given period of time even if there have been no advances in labour productivity. Finally, there is a tendency to seek technologies that enhance capital's control over the production process in order to reduce waste, lessen the opportunities for sabotage, and so on.

How these various tendencies interact in given socio-historical contexts is a complex and contingent matter. Technologies that raise the level of labour productivity may sometimes require a higher overall level of skill in the workforce for an extended period in certain regions and sectors. If so, the drive for productivity advances may dominate the tendency to seek deskilling technologies in some circumstances; in others, it may be dominated by that other tendency. To take another example, in certain contexts innovations decreasing the pores in the working day might overlap with innovations that increase the control over the labour process enjoyed by the representatives of capital. In other contexts, how-

ever, the pores might best be reduced if these representatives relinquished a certain degree of control.[6] Whatever permutations may occur, however, one thing remains constant: in all these cases technology is employed as a powerful weapon in capital's class struggle against labour.

Labour, however, is hardly passive in the process of technical change. Technological change demands more than technical blueprints; the blueprints must actually be implemented in the concrete material conditions of the shopfloor or office. This inevitably requires the active participation of the labour force,[7] thereby creating a space within which it is possible to renegotiate the terms of technical change. Depending upon the strength of labour organisations and the external economic and political environment, such renegotiations may shift the social dynamic of technical change in favour of the interests of workers to a greater or lesser degree. In the limit case workers may constitute themselves as revolutionary subjects within this space, radically challenging the workings of society as a whole, and not just this or that workplace practice.[8]

However central class struggle at the point of production may be to Marxian theory, it remains just one moment in the circuit of capital.[9] A main thesis of the second volume of *Capital* is that while the production of surplus-value is the ultimate source of capital, it is not the only factor affecting capital accumulation. The more time capital is tied up in the various stages of the capital circuit, the less capital can be accumulated in a given period of time, everything else remaining equal.[10] It follows directly that there necessarily is a tendency in capitalism for technical innovations to be introduced that compress the turnover time of capital.

In the first two volumes of his masterwork Marx abstracted from features that distinguish one sector of industrial capital from another. In the beginning of volume III Marx moved from this level of 'capital in general' to the more concrete and complex level of 'many capitals'. In his account of the first category on this level, 'cost prices', Marx noted that different sectors have different technical compositions; some sectors require more means of production for a given number of workers than others. These differences are generally correlated with differences in the organic composition of capital, that is, in the ratio of constant capital invested in the purchase of means of production to variable capital used to purchase labour-power. Marx noted further that profits are not just a function of the variable capital invested and the surplus-value produced in a given sector. Profits are also a function of constant capital expenditures. It follows that there is, in the capitalist mode of production, a necessary tendency to seek technical innovations that reduce the costs of constant capital. This conclusion is reinforced later in volume III in the discussion of counter-tendencies to the falling rate of profit, where innovations lowering constant capital costs are considered alongside innovations increasing surplus-value.

With respect to industrial capital, the transition from 'capital in general' to 'many capitals' is completed with the discussion of stratification within sectors in chapter 10 of volume III. Here Marx discussed how the most productive individual units of capital within a sector are able to win surplus profits. Surplus profits can also result from product innovations that meet a new want or need, or that satisfy an old want or need in a new way. In Marx's view, surplus profits involve a redistribution of sur-

plus-value from firms with relatively low levels of productivity and outmoded products to more efficient firms with 'state of the art' products. Intercapital competition, which necessarily tends to generate a drive to appropriate surplus profits, thus necessarily tends to result in technical change as well.

In the remainder of volume III Marx introduced the categories of merchant capital, financial capital, and rent. Marx also planned to write subsequent volumes on the state, foreign trade, and the world market. Although these topics are all relevant to the Marxian theory of technical change in capitalism, I shall conclude my presentation here. I believe that the above account, compressed as it is, is sufficient to allow a critical comparison of the Marxian and the neoclassical perspectives on the issue at hand.

C. Critical assessment of the competing theories

The neoclassical and Marxian theories of technology could hardly be more different. And yet both claim to provide a framework for explaining technology in capitalism. Is it possible to assess these competing claims?

It has been fashionable in recent years to say that in cases of this sort the theories are incommensurable and cannot be compared rationally. All we can do is opt for one 'entry point' rather than another,[11] or pick one or another view to defend rhetorically.[12] I believe that there is no good reason to rule out *a priori* the possibility that rational argumentation can establish that one theory is more sound than another, at least in some cases. Of course, there are no guarantees this will occur. But the radical scepticism of postmodernism and rhetoricism dogmatically rule this out, and therefore should be avoided, at least initially.

And so the question arises once again: how should an assessment of these sorts of theories proceed? Much more is involved than simply verifying or falsifying theories separately. The comparative component is essential: how well does each theory measure up to its main competitors? A corroborated account should still be rejected in the face of a stronger theoretical viewpoint; a perspective that has been falsified in certain respects can still be maintained if there are no satisfactory alternatives.

Building upon Lakatos's work on the methodology of scientific research programs, I believe that there are five criteria relevant to a comparison of competing theories: i) their explanatory scope; ii) the internal consistency of their foundational categories; iii) the status of the abstractions they employ; iv) their compatibility with social practice; and v) their empirical accuracy.[13] One of the most vexing questions in the philosophy of the social sciences is how to weigh these different criteria in cases where they lead to conflicting assessments. I shall postpone that issue for now, and examine the neoclassical and the Marxian theories of technology with reference to each of these yardsticks.

i) Scope of phenomena explained

A first criterion that can be used in comparisons of competing theories has to do with the range of empirical phenomena brought within the scope of the relevant theories. This is a distinct matter from a considera-

tion of the extent to which the competing theories have been confirmed or falsified by empirical evidence, a topic that will be taken up below.

The neoclassical approach to technology concentrates on the drive to keep the cost of factor inputs as low as possible for a given level of output. This underlies the selection of the technique represented by the point of tangency between the production function and an isocost line, rather than some other point of intersection between the production function and an isocost line. And neoclassical theory emphasises the drive to produce a given output more efficiently, which accounts for the shift from a given production function to one closer to the origin. Further, neoclassical theory explicitly acknowledges that both processes make use of scientific knowledge as a free good.

The Marxian theory of technology provides explanations for the sorts of things neoclassical theory addresses. We can derive from Marx's account of the circuit of capital accumulation a necessary tendency for innovations to be sought that lower wage costs and that lower capital costs (including the costs of storage and waste). We can also derive a drive to introduce process innovations from the imperative to increase the surplus-value produced by (and the surplus profits distributed to) an enterprise. And Marx explicitly and repeatedly noted the importance of science to the innovation process in modern capitalism.[14]

The reverse does not hold. The neoclassical theory of technology does not address the entire range of phenomena with which Marxian theory is concerned. The most significant reason for this is that neoclassical theory reduces all questions of technology to the rational response of economic agents to demand, factor prices, and given scientific-technical knowledge. For the Marxist, technological development in capitalism involves much more than this. Specifically, there are four areas where the scope of the Marxian theory of technology goes beyond that of neoclassical economics.

For the neoclassical economist labour is considered solely as a 'factor' of production, an object that can be purchased. For the Marxist the working class is a collective *subject*, albeit one treated as a commodity under the capital form. Workers have the capacity to engage in 'learning by doing', unlike other so-called factors of production. To quote a key passage,

> [A]ll these economies [in the use of constant capital] arising from the concentration of means of production and their employment on a massive scale, presuppose ... the social combination of labour ... Even the constant improvements that are possible and necessary arise solely from the social experiences and observations that are made possible and promoted by the large-scale production of the combined collective worker.[15]

There are a number of reasons why learning by doing is significant. For one thing, it calls into question one of the central assumptions of the production function approach, the assumption that it is possible to consider the marginal productivity of labour and the marginal productivity of capital separately. The phenomenon of learning by doing implies that the productivity of capital goods is a function of the capacities of the workforce. Also, the incremental innovations arising from the learning

by doing process are the most profound sources of productivity advances in the long term.[16] Most importantly, wage-labourers alone have the capacity to resist the social power of capital. Machines and raw materials do not ask for wage increases, benefits, or breaks during the working day; they do not band together into organisations, or engage in slow-downs and strikes; and they do not possess the potential to call into question the legitimation of a social order in which those making decisions are not accountable to the vast majority of those affected by these decisions. These phenomena affect the development of technology. The owners and controllers of capital regularly seek innovations that keep social relations on terms favourable to themselves, while labourers continually attempt to modify these innovations. As a result, the nature of technical change in production cannot be concretely grasped in abstraction from the dynamic of class relations.[17] This crucial feature of technology in capitalism does not come within the scope of neoclassical theory.

Second, the production function approach emphasises process innovations at the cost of neglecting product innovations. It does not address the ceaseless development of new needs that is part of the dynamic of the capital form.[18] In contrast, this is a central part of the Marxian story of technology in capitalism. For Marx, 'one precondition for the sale [of] the commodity [is] that the commodity should have use-value, and thus satisfy a social need'.[19] As capital accumulation expands, new social needs arise, as well as new products to meet them: 'The discovery, creation and satisfaction of new needs arising from society itself ... is likewise a condition of production founded on capital.'[20]

Third, neoclassical economics abstracts from time. This is obvious with respect to static equilibrium theory. It holds for dynamic equilibrium theory as well; a theoretical comparison of one time-slice with another time-slice is not a theory of the temporal process connecting them. As a result of its atemporal nature, neoclassical theory neglects the importance of reducing circulation time, a central issue in Marxian theory. And in so far as the question of circulation time is ineluctably connected with spatial issues, neoclassical theory can be criticised for neglecting space as well.[21]

Finally, in neoclassical theory there is no recognition that the introduction of technologies is generally connected with negative externalities, that is, burdens imposed on workers and communities. Social movements and state regulations necessarily tend to arise in response to capital's externalisation of the social costs of technical change. These movements and regulations profoundly shape the subsequent direction of technical change. Marxian theory includes these phenomena within its explanatory scope,[22] while neoclassical theory does not.

The scope of the Marxian theory of technical change in capitalism incorporates the phenomena considered by neoclassical theory. Marxian theory also considers matters that are beyond the scope of neoclassical theory. Of course, this in itself does not resolve the comparison of the competing theories. We must investigate further to discover whether neoclassical theory might has sufficient advantages in other respects to compensate for its deficiencies here.

ii) Internal consistency of foundational categories

A second way to assess competing theories is to ask whether their foundational categories can be stated in a consistent fashion. The production function framework for explaining technology has a number of serious difficulties in this regard. Each point of this function is defined by a capital co-ordinate ('K') and a labour co-ordinate ('L'). What is this K? It is a number representing the aggregate of all the non-labour inputs in production measured in physical terms. But it is conceptually impossible to add x tons of raw materials to y machines and z factories and come up with a number that means anything.

Neoclassical economists have introduced the distinction between capital as clay and capital as putty in order to deal with this difficulty.[23] When capital takes on distinct forms that cannot be reduced to a common framework (raw materials, machines, factories), it is considered as hardened 'clay'. When it is aggregated together in the production function it is considered as 'putty' that can take on any number of different forms while remaining identical. Assuming that the same thing at the same time has both the indefinite malleability of putty and the fixed form of hardened clay does not remove the conceptual incoherence here. The incoherence is merely institutionalised in terminology.[24]

In the Marxian framework this incoherence in the treatment of capital goods is avoided. Raw materials, machinery, and so on, can be aggregated together under the money form as the total sum of money capital invested in constant capital. But when so-called capital goods are considered in physical (use-value) terms they are disaggregated into different means of production.

When we turn to the role of labour-power, here too the charge of incoherence can be brought against the neoclassical framework. The 'L' co-ordinate of a point on the production function assigns a single number to an aggregate of incommensurable physical and mental activities, and this cannot be done in a meaningful way. This time, however, it appears that Marxian theory suffers from the precisely the same sort of problem. In passages devoted to the labour theory of value Marx wrote of a reduction of complex labours to simple labours, and of the way in which simple homogeneous labour provides a measure for the value embodied in commodities. This too appears to assign a single number to an aggregate of incommensurable physical and mental activities.

Despite this surface similarity I believe that the two theories are still in a quite different position. Marx's theory of value shows that money is the alpha and omega of the valorisation process.[25] Money received after the successful sale of some commodity, not some simple and homogeneous labour time pre-existing sale, provides the only socially objective measure of abstract labour. While different concrete labours cannot be made commensurate, the problem thus does not arise for abstract labours, which are by definition commensurable in money terms. Talk of simple and homogeneous labour 'embodied' in commodities and measuring their value is a residue of Ricardian theory that Marx never fully overcame.[26] Once this residue is overcome, the incoherence of treating incommensurable labours as if they were commensurable disappears from the foundations of Marxism.

The balance sheet must now be drawn. There is an irreducible inco-

herence at the foundation of the neoclassical perspective on technology. In contrast, the incoherence at the foundations of Marxism can be removed by purging Marxism of its Ricardian residues. We must conclude that Marxian theory is superior according to this second criterion for evaluating competing theories.

iii) Status of abstractions employed

All theories make use of abstractions. Neoclassical theory and Marxian theory are no exceptions. But there are different sorts of abstraction, and some sorts are more appropriate for certain theoretical purposes than others. If a theory employs a type of abstraction that is not suited to attaining its objectives, this surely must count against it. We can begin with an examination of three abstractions at the heart of neoclassical theory.

a) Mathematically, there are an infinite number of points on the isoquant representing the production function. When the isoquant is used to represent technological reality, the assumption is made that an infinite number of possible techniques are accessible, that is, that an infinite number of combinations of capital and labour can produce the desired output at the given level of technology. This abstracts from the fact that in reality the set of available techniques from which capitalist enterprises must select is always restricted.

b) Neoclassical economists also assume that firms have perfect information regarding all of the techniques represented by the production function. But even in a world of static technology, no firm actually possesses anything approaching perfect information regarding all existing techniques. The dynamism of technical change in capitalism makes the assumption of perfect information even more untenable. The results of research and development are inherently unpredictable. Firms must make decisions regarding technical change in situations of fundamental uncertainty.[27]

c) In neoclassical economics, profit maximisation motivates technological decisions. The technique corresponding to the point of tangency is selected because it minimises costs and maximises profits. Once we recognise that the assumption of perfect information abstracts from the concrete reality, we must grant that the assumption of optimising behaviour does so as well. A given firm has reliable information regarding only a subset of all possible techniques. Any attempt to expand that subset involves costs, and it can never be known beforehand whether those costs will be recouped. At some point the search must cease. But if the firm's decision is thus based on only a subset of all possible techniques, then it can never know whether its selection truly minimises costs and maximises profits. It must be content to 'satisfice'.[28]

Neoclassical economists themselves readily admit that the assumptions of infinite techniques, perfect information, and maximising behaviour abstract from features of concrete technological activity in capitalist markets. But they still insist that neoclassical theory generates results that illuminate this concrete reality. Neoclassical models, they claim, are 'ideal-types' that capture the intelligibility of the world even if they are too pure to provide literal descriptions of the world.

The most straightforward Marxian response is simply to deny the claim. The three abstractions just considered are not abstractions *of* the workings of capitalism; they are abstractions *from* the mechanisms at work in this mode of production. They distort, rather than illuminate, the state of affairs under investigation.

A second response is a bit more involved. It refers to the tension between the avowed theoretical purpose of the above abstractions and their actual nature. These abstractions are supposed to contribute to the scientific explanation of technological activity. But the assumption of an infinite number of techniques, perfect information, and maximising behaviour are actually used by neoclassical economists to define what they believe ideally rational agents would do in ideal situations. In other words, these abstractions are used to define a *normative* model of behaviour.[29] It is in principle legitimate for social theorists to abstract from concrete reality in order to construct a normative model.[30] But normative assumptions do *not* provide an appropriate framework for the explanation of empirical phenomena. And so the sorts of abstractions employed by neoclassical economics are not suited to the theoretical purpose neoclassical economists set for themselves.

The abstractions employed in Marxism are of a quite different sort. In the beginning stages of Marx's theory, abstraction is made from certain complex social forms (finance capital, the state, etc.) so that more elementary social forms (for example, the commodity form, the money form) can be considered in themselves. But these abstractions are 'real abstractions'. Even the most abstract social forms in Marx's theory are instituted in the material practices of capitalist society. And these forms define tendencies that continue to operate in concrete instances of capitalism.

Marx's ultimate theoretical purpose was to reconstruct the capitalist mode of production in thought, starting from relatively simple social forms and progressing step-by-step to ever-more complex forms. The sorts of abstractions he employed are fully congruent with his theoretical purpose. The abstractions of the neoclassical economics, in contrast, incoherently waver between normative idealisations and empirical claims. This provides a third reason to consider Marxian theory superior to its neoclassical competitor.

4. Compatibility with relevant social practices

In general, a theory's soundness cannot be assessed in terms of its capacity to orient practical activity. Quite mistaken views have guided people's actions for extended periods of time. But if a theory proves incompatible with the very type of social practice it claims to address, this is quite significant. Neoclassical theory certainly informs the practical life of many on the political Right, legitimating their adherence to capitalist market society. But it is astonishing how little practical relevance the neoclassical theory of technology in capitalism has to technological activity in capitalism.

Let us consider the area of technological activity where we would expect neoclassical theory to be most at home, the selection of techniques by managers of capitalist enterprises. Neoclassical economists assume that market constraints and the given level of technology suffice

to determine the selection of techniques. This view completely ignores the role of strategic decision-making in a world of profound uncertainty and dynamic competition.[31] Examples of the sort of strategic decisions regarding technology that must be made include: setting the size of the Research and Development budget, allocating R&D resources among the different divisions of the firm, establishing the general technical objectives to be pursued by the firm, allocating resources to particular projects, and deciding whether to continue or to conclude R&D projects that are underway. *Not a single one of these decisions follows automatically from market demand, factor prices, and the given level of technology.* Among other considerations, these sorts of decisions depend upon whether the management of a firm wishes to protect its existing market, expand its share of an existing market, enter a market in which it does not now participate, or create a new market that does not presently exist. This in turn depends upon estimates of the future behaviour of labourers, consumers, state officials, competitors, etc., that are in principle uncertain. Neoclassical theory is therefore almost completely irrelevant to the technological activity of managers, and almost completely ignored by management theorists examining that activity.[32]

If we turn to the area of technological activity where we would expect Marxian theory to be most at home, the response of workers to technological change, there is a clear contrast. An extended series of practical maxims follows directly from Marxian theory, three examples of which must suffice here: 'Do not accept uncritically utopian claims regarding the social effects of new technologies'; 'Investigate how new technologies might shift the balance of power between capital and labour'; 'When struggling to shift the direction of technological change so that it better reflects workers' interests, attempt to make as broad an alliance as possible among the different sectors of the working class.' Marxian theory, in brief, emphasises the practical necessity for the working-class and other social agents to formulate a strategic response to decisions regarding technology made by the owners and controllers of capital.

Needless to say, this does not imply that every practical recommendation ever uttered by a Marxist has been successful in practice. Nor does it mean that there have never been neoclassical economists capable of giving sound pragmatic advice to the economic agents they choose to address. But the above discussion does suggest that in principle neoclassical theory is incompatible with the very technological practices most relevant to it in a way that Marxian theory is not.

We still are not in a position to offer a decisive judgement between the two competing theories. If adherents of neoclassical theory could plausibly claim that their framework more accurately grasps the empirical state of affairs of technology in capitalism, this could in principle compensate for any or all of the shortcomings considered thus far. And so the fifth and final criterion for evaluations of competing theories may be the most significant of all.

5. Empirical adequacy

The notion that empirical adequacy serves as an important criterion in assessing theories seems rather straightforward. But things are more complicated than they might appear at first glance. In the early part of

this century many philosophers of science thought that empirical facts could provide a direct verification or falsification of scientific theories. It is, however, impossible to discuss empirical facts without employing the categories of some theory or other. This leads to the following problem: if there are no theory-free observations, how can observations provide an independent test for the validity of theories?

Consider a familiar Marxian criticism of the neoclassical production function, which presupposes that both investment capital and machinery used in production can be considered apart from labour. Marxists insist that the ultimate source of investment capital is the exploitation of wage-labour in production. Similarly, from this perspective machinery is simply embodied ('dead') labour, that is, the fruit of past labouring activity.[33] Investment capital and capital goods are both objectifications of labour, albeit objectifications that take on forms alien to labour. For a Marxist, this provides a compelling empirical refutation of the neoclassical framework. For the neoclassical economist, however, 'exploitation' and 'alienation' are not at all neutral empirical facts. Describing states of affairs in these terms presupposes the very theory whose validity is in dispute; anyone rejecting Marxian theory would also reject the accuracy of these alleged empirical descriptions.

Does this imply that references to empirical matters have no place in comparisons of competing theories? It would do so only if there were no *relatively* uncontroversial empirical facts to consider, i.e. facts that cannot reasonably be disputed within either framework.[34] In the case at hand there are a great number of such facts available. And so, in principle, we should be able to assess which position may claim greater empirical adequacy, using these relatively uncontroversial empirical facts as the measure. I shall argue that there are five central areas where the Marxian theory of technology is superior to neoclassical theory according to this criterion.

In the neoclassical approach, technology is treated as if it were exogenous to economic activity. Firms simply accept as given the various techniques depicted in a production function, and the technical advances that permit a jump to a new production function. Yet capitalist enterprises can be empirically observed to engage in searches for both techniques and new technologies. Marxian theory can account for the indisputable empirical fact that technical change is endogenous to capitalism; neoclassical theory cannot. Marx showed in great detail how the logic of the capital/wage-labour relation, capital's need to reduce circulation time and constant capital costs, and inter-capital competition, all tend to lead enterprises to introduce technical innovations. As a result,

> The bourgeoisie, during its rule of scarcely one hundred years, has created more massive and more colossal productive forces than have all preceding generations together. Subjection of Nature's forces to man, machinery, application of chemistry to industry and agriculture, steam-navigation, railways, electric telegraphs, clearing of whole continents for cultivation, canalisation of rivers, whole populations conjured out of the ground – what earlier century had even a presentiment that such productive forces slumbered in the lap of social labour?[35]

To treat technical change as exogenous in the light of all this is surely to be in tension with an indisputable feature of the capitalist world.

A closely related point to be made in this context concerns the economic role of capitalist enterprises. In the standard neoclassical account, firms simply respond to the quantity of output demanded, input prices, and the given technology. In selecting a given technique they do not so much initiate a state of affairs as merely note the point of tangency between the isocost line and the production function. But it is a fairly uncontroversial fact that capitalist enterprises do not passively respond to price signals and given technologies. In capitalist markets innovative firms are able to set prices sufficiently high to provide surplus profits, thanks to higher levels of productivity and/or growing markets. Marx's theory of capital, in which the drive to accumulate is the spark setting off technical change, accounts for the aggressive behaviour of capitalist enterprises far better than the neoclassical framework.[36]

The third issue concerns equilibrium states in the economy. The neoclassical model is explicitly based on the supposition that there is a dominant tendency for the economy to attain equilibrium. Once the technique represented by the point of tangency between the isocost line and the production function has been selected, there is no internal dynamic leading away from this technique. Of course neoclassical theory is not limited to static models of this sort. There are also dynamic models that incorporate economic growth. But these models too are based on the supposition that the economy tends towards an equilibrium state, albeit one of dynamic equilibrium in these cases.[37]

Relatively uncontroversial empirical evidence suggests that it is wrong to see divergences from equilibrium as infrequent and temporary. An economic environment in which firms are constantly introducing innovations in the hopes of shifting the balance of class forces, winning surplus profits, and increasing the rate of accumulation, is not conducive to either static or dynamic equilibrium. Capitalism is not characterised by the attainment of a stable response to already given conditions, but by the generation of a ceaseless flux of new economic conditions.[38] In a world of ceaseless technical change disequilibrium is the norm, not the exception.[39] Marxian theory can account for this empirical state of affairs, while neoclassical theory cannot.

Fourth, in the neoclassical model, any shift in the ratio of factor prices leads to a shift from one technique to another. This implies that any choice is reversible; a technique abandoned when the ratio of factor prices changes can be reinstated if this ratio shifts back. This also does not correspond to relatively uncontroversial empirical evidence. In the course of employing a given technique the workforce develops skills specific to that technique. These competencies are not likely to be equally applicable to all other techniques. This implies that a decision to operate one technique cannot easily be reversed with every shift of the ratio of factor prices. History matters; technical choices made in the past restrict the choices that can be made later. Marx's theory of labour-power and its capacity to engage in learning by doing can account for this 'path dependency', while production function models cannot.

Finally, the production function model assumes that there is always and everywhere completely substitutability of labour and capital, i.e. that

the same output can be attained whether we use more capital-intensive or more labour-intensive techniques. There are certainly cases where this assumption makes some empirical sense. With sufficient extra labour the same amount of firewood can be produced with a handsaw as with a chainsaw. But it is a fairly straightforward empirical fact that some tasks cannot be accomplished if the right machines are not available, no matter how many extra labourers might be hired to compensate.[40] Other tasks simply cannot be completed if labourers with specific skills are absent, no matter how many additional machines are purchased.[41] There is nothing in the Marxian framework that contradicts these states of affairs.

In conclusion, the rational assessment of competing theories is a complex matter. There are a number of quite different criteria that must be employed. It is always possible that one of the competing theories may appear more adequate when assessed by one criterion, while another appears stronger when a different criterion is invoked. In such circumstances it may be unclear what weight each yardstick should be given, or how the necessary trade-offs ought to be made. It would seem from the above, however, that we are in the fortunate position of not having to decide such vexing questions here. The relevant criteria for evaluating the respective strengths of the neoclassical and the Marxist accounts of technology in capitalism are explanatory scope, internal consistency of foundational categories, the appropriateness of abstractions, compatibility with relevant social practices, and empirical adequacy. The Marxian perspective appears to be far stronger on all five counts. The conclusion that Marxism provides a theoretically superior account of technical change in capitalism is thus rationally warranted.

Notes

1. Ferguson 1969; Elster 1983; Coombs et al. 1987.
2. Hicks 1932, p. 125
3. Salter 1960, pp. 43–44; see Elster 1983, pp. 101–02
4. See Smith 1990, 1993.
5. Marx 1976, p. 756; see Ramtin 1991, p. 68
6. See Smith 1994a, 1994b, for a discussion of these matters in the context of the technologies and forms of social organisation associated with lean production.
7. As Marx wrote regarding savings in the use of fixed capital, 'Finally, however, it is only the experience of the combined worker that discovers and demonstrates how inventions already made can most simply be developed, how to overcome the practical frictions that arise in putting the theory into practice – its application to the production process, and so on.' Marx 1981, pp. 198–99.
8. Negri 1989, p. 48.
9. These other moments, however, remain connected to the capital/wage-labour relation. Their ultimate social significance lies in their contribution to the reproduction of that relation.
10. 'During its circulation time, capital does not function as productive capital, and therefore produces neither commodities nor surplus-value ... The more that the circulation metamorphoses of capital are only ideal, i.e. the closer the cir-

culation time comes to zero, the more the capital functions, and the greater is its productivity and self-valorisation'. Marx 1978, p. 203; see also pp. 326, 388–9, 391–2.

11. Wolff and Resnick 1987.
12. McCloskey 1983.
13. See Smith 1997.
14. For example, 'It is only after a considerable development of the science of mechanics, and an accumulation of practical experience, that the form of a machine becomes settled entirely in accordance with mechanical principles, and emancipated from the traditional form of the tool from which it has emerged.' Marx 1976, p. 505.
15. Marx 1981, p. 172.
16. Dertouzos et al. 1991.
17. 'It took both time and experience before the workers learnt to distinguish between machinery and its employment by capital, and therefore to transfer their attacks from the material instruments of production to the form of society which utilises those instruments.' Marx 1976, pp. 554–55; see also Noble 1984, Shaiken 1985.
18. This is quite ironic, given the emphasis on consumer sovereignty found in other parts of the neoclassical paradigm.
19. Marx 1981, p. 283.
20. Marx 1973, p. 409.
21. Storper and Walker, 1989.
22. The classic example of how social movements and state regulations affect the technical change process is found in volume I of *Capital*. Marx described how overwork in factories led to social movements to reduce the working day. Once regulations were passed limiting the length of the working day, large-scale machinery was introduced in order to extract the same (or greater) amount of surplus-value in the shorter working day.
23. Baumol 1977, pp. 641–42.
24. General equilibrium theory does avoid the problem of aggregating capital, through the simple expedient of disaggregating the various capital inputs in the production function: $P = f(K1, K2, K3,...Kn, L)$. But general equilibrium theory avoids this problem only at the cost of even more unrealistic assumptions, such as complete future markets for all goods and complete knowledge of future technology. And so it is even further removed from a realistic theory of technology than the standard production function approach.
25. 'As the dominant subject of this process [i.e. the capital circuit], in which it alternately assumes and loses the form of money and the form of commodities, but preserves and expands itself through all these changes, value requires above all an independent form by means of which its identity with itself may be asserted. Only in the shape of money does it possess this form. Money therefore forms the starting-point and the conclusion of every valorisation process.' Marx 1976, p. 255.
26. Reuten 1993.
27. If perfect information regarding the most efficient production function and the given isocost line were available to all, there would be no diffusion process. All firms would simultaneously jump from one technique to another whenever changes in technology or in the ratio of relative factor prices occurred. But diffusion does extend in time; not all firms adopt innovations at once. Attempts to explain why this is so solely in psychological terms – 'Some agents are more

disposed to innovate than others' – are not plausible. Another crucial variable in diffusion is knowledge about the innovation, which differs from firm to firm at different points in time (Davies 1979). Hence if we are to account for the phenomenon of diffusion, we need a theory that does not presuppose perfect information for all firms at all times. Also, there are many mechanisms available to firms to prevent perfect information, trade secrets being one obvious example.

28. Simon 1954, p. 10.
29. Of course, the normative principles embedded in this model (for example, the ethical primacy of self-interested individual agents) are extremely dubious. This does not affect the present point.
30. Smith 1992, chapter I.
31. Botwinick 1993.
32. Szakonyi 1992.
33. To say that the means of production and circulation are objectifications of labour should not be taken to imply that they are only objectifications of labour. They have a material dimension that is irreducible to their social form, as theorists attempting to synthesise Marxism and environmentalism have correctly stressed (Benton 1989).
34. Sayer 1984, chapter 2.
35. Marx 1977, p. 225.
36. Botwinick 1993.
37. Coombs et al. 1987, chapter 6.
38. Storper and Walker 1989.
39. This point is freely admitted by many non-Marxist economists: 'When the inflow of major product innovations is high, as it clearly is in most of the world today, giving birth to many new industries and rapidly shifting the demand in old industries, industries tend to be out of equilibrium all the time. Equilibrium conditions could then be expected to be at variance with the empirical evidence, the latter mirroring the constantly transitory non-equilibrium situations of industries.' Gomulka 1990, pp. 160-1.
40. For example, how could the addition of more people allow space exploration in the absence of rockets? The same point holds for producing polymers, slicing genes, etc.
41. General Motors found this out to its great cost when its attempts to build totally automated factories in the early eighties failed (Hoerr et. al. 1989, p. 363).

References

Baumol, William 1977, *Economic Theory and Operations Analysis,*. fourth Edition, Englewoods Cliffs, NJ: Prentice-Hall.

Benton, Ted 1989, 'Marxism and Natural Limits: An Ecological Critique and Reconstruction', *New Left Review,* 178.

Botwinick, Howard 1993, *Persistent Inequalities: Wage Disparity under Capitalist Competition*, Princeton: Princeton University Press.

Coombs, Rod, P. Saviotti, and V. Walsh 1987, *Economics and Technological Change*, London: MacMillan.

Davies, S. 1979, *The Diffusion of Process Innovations*, Cambridge: Cambridge University Press.

Dertouzos, Michael, R. Lester, R. Solow, and the MIT Commission on Industrial Productivity 1991, *Made in America: Regaining the*

Productive Edge, Cambridge, MA: MIT Press.
Elster, Jon 1983, *Explaining Technical Change*, Cambridge: Cambridge University Press.
Ferguson, F.E. 1969, *The Neoclassical Theory of Production and Distribution*, Cambridge: Cambridge University Press.
Forester, John, (ed.) 1989, *Computers and the Human Context*, Cambridge MA: MIT Press.
Gomulka, Stanislaw 1990, *The Theory of Technological Change and Economic Growth*, New York: Routledge.
Hicks, John 1932, *The Theory of Wages*, London: Macmillan.
Hoerr, John, M. Pollock, and D. Whiteside 1989, 'Management Discovers the Human Side of Automation', in Forester 1989.
Marx, Karl 1973, *Grundrisse*, New York: Vintage Press.
Marx, Karl 1976, *Capital*, volume I, New York: Penguin.
Marx, Karl 1977, *Karl Marx: Selected Writings*, edited by David McLellan, New York: Oxford University Press.
Marx, Karl 1978, *Capital*, volume II, New York: Penguin.
Marx, Karl 1981 *Capital*, volume III. New York: Penguin.
McCloskey, Donald 1983 'The Rhetoric of Economics', *Journal of Economic Literature*, XXI.
Moseley, Fred, ed. 1992, *Marx's Method in 'Capital'*, Atlantic Highlands, NJ: Humanities Press.
Moseley, Fred, and M. Campbell, (eds.) 1997, *New Investigations of Marxian Method*, Atlantic Highlands, NJ: Humanities Press.
Negri, Antonio 1989, *The Politics of Subversion*, Cambridge: Polity Press.
Noble, David 1984, *Forces of Production*, New York: Knopf.
Ramtin, Ramin 1991, *Capitalism and Automation*, London: Pluto Press.
Reuten, Geert 1993, 'The Difficult Labour of a Theory of Social Value: Metaphors and Systematic Dialectics at the Beginning of Marx's Capital', in Moseley 1992.
Salter, W.G. 1960, *Productivity and Technical Change*, Cambridge: Cambridge University Press.
Sayer, Andrew 1984, *Method in Social Science: A Realist Approach*, London: Hutchinson.
Shaiken, Harley 1985, *Work Transformed: Automation and Labour in the Computer Age*, New York: Holt, Reinhart and Winston.
Simon, Herbert 1978, 'On How to Decide What to Do', *Bell Journal of Economics*, 9.
Smith, Tony 1990, *The Logic of Marx's 'Capital'*, Albany: State University of New York Press.
Smith, Tony 1992, *The Role of Ethics in Social Theory*, Albany: State University of New York Press.
Smith, Tony 1993, *Dialectical Social Theory and Its Critics*, Albany: State University of New York Press.
Smith, Tony 1994a, 'Flexible Production and the Capital/Wage Labour Relation in Manufacturing', *Capital and Class*, 53.
Smith, Tony 1994b, *Lean Production: A Capitalist Utopia?*, Amsterdam: The International Institute for Research and Education.
Smith, Tony 1997, 'Marx's Systematic Dialectic and Lakatos' Methodology of Scientific Research Programs', in Moseley and Campbell 1997.

Storper, Michael, and R. Walker 1989, *The Capitalist Imperative: Territory, Technology, and Industrial Growth*, Oxford: Blackwell.
Szakonyi, Robert, (ed.) 1992,*Technology Management: Case Studies in Innovation*, Boston: Auerbach Publications.
Wolff, Richard, and S. Resnick 1987, *Economics: Marxian versus Neoclassical*, Baltimore: Johns Hopkins University Press.