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Technology and History in Capitalism: Marxian and Neo-Schumpeterian Perspectives

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The equilibrium models of neoclassical economics fail to account adequately for one of the most striking facts of capitalism, its unprecedented technological dynamism. Extrapolating from Schumpeter's notion of 'creative destruction', contemporary neo-Schumpeterian economists have formulated a devastating critique of the neoclassical theory of technological change.² Their position can be provisionally defined in terms of the following six theses:

- technological change is endogenous to capitalism;
- science tends to become increasingly central to production;
- 'learning by doing' is of fundamental importance in the innovation process;
- technological change cannot be adequately comprehended in abstraction from the institutional context in which it occurs, including the organizational structures of firms and the technology policies of states;

1. I would like to thank Chris Arthur, Riccardo Bellofiore, Fred Moseley, Patrick Murray, Geert Reuten, Nicola Taylor and, especially, Martha Campbell for their many helpful comments and criticisms on earlier drafts of this paper.
2. See Coombs *et al.* (1987) Chapter 2 and Coricelli and Dosi (1988). For the purposes of this chapter the terms 'neo-Schumpeterianism' and 'evolutionary economics' will be used interchangeably. Readers interested in the contrast between Marx and Schumpeter himself should consult Bellofiore (1985a, 1985b).

- capitalism is characterized by radical uncertainty and disequilibrium tendencies due to technological change; and
- different technologies and forms of social organization play leading roles in different periods of capitalist development.³

It is noteworthy that these six theses are all defended in the first volume of *Capital* as well.⁴ Neo-Schumpeterians acknowledge Marx as an important predecessor. Nonetheless, they clearly hold that whatever Marx had to say of continuing validity regarding technology in capitalism can be easily incorporated within their perspective. If this were true, there would be little reason to consider the theory of technology in Volume I besides historical curiosity. But it is not true. In this chapter I shall discuss three crucial issues for which the claim does not hold: the subsumption of technological change under the valorization imperative, the connection between technological change and the capital/wage labour

3. Formal models and extensive empirical evidence in support of these theses are found in the following representative neo-Schumpeterian works: Dosi *et al.*, 1988; Saviotti and Metcalfe, 1991; Freeman, 1992, Part II; Nelson, 1995; Metcalfe, 1997; Freeman and Soete, 1999; Ziman, 2000; and Freeman and Louçã, 2001.
4. A few citations must suffice here (see Smith, 1997 for a fuller account). 'Modern industry never views or treats the existing form of production process as the definitive one. Its technical basis is therefore revolutionary, whereas all earlier modes of production were essentially conservative' (Marx, 1867: 617; unless otherwise noted, all page references are to this text). Marx recognizes that this endogenous process of innovation becomes more science-intensive over time: '(l)arge-scale industry... makes science a potentiality for production which is distinct from labour and presses it into the service of capital' (482). Nonetheless, even science-based innovation requires on-going 'learning by doing' at the point of production: 'The problem of how to execute each particular process, and to bind the different partial processes together into a whole, is solved by the aid of machines, chemistry, etc. But of course, in this case too, *the theoretical conception must be perfected by accumulated experience on a large scale*' (502, italics added). Chapter 15, Section 4 of Marx, 1867 ('The factory') presents an exemplary account of the relationship between the command structure of production within capitalist firms and technological change. Regarding the state, legislation limiting the length of the working day plays a crucial role in Marx's account of the emergence of systems of machinery, to cite only one example (see 533–4, 607). Taken together, these factors ensure that the 'tendency on the part of the various spheres of production towards equilibrium comes into play only as a reaction against the constant upsetting of this equilibrium' (476). Finally, in Volume I Marx describes in great detail the role of technology in the evolution from the epoch of manufacturing to that of big industry.

relation, and the role of technological change in assessments of the world historical significance of capitalism.

1. Technological change and the self-valorization of value

For neo-Schumpeterians the conceptual apparatus of evolutionary biology provides helpful tools for theorizing technological change in capitalism. The flavour of this approach is captured in the following passage from Richard Nelson:

The general concept of evolution that I propose...involves the following elements. The focus of attention is on a variable or set of them that is changing over time and the theoretical quest is for an understanding of the dynamic process behind the observed change; a special case would be a quest for understanding the current state of a variable or a system in terms of how it got there. The theory proposes that the variable or system in question is subject to somewhat random variation or perturbation, and also that there are mechanisms that systematically winnow that variation. Much of the predictive or explanatory power of that theory rests with its specification of the systematic selection forces. It is presumed that there are strong inertial tendencies preserving what has survived the selection process. However in many cases there are also forces that continue to introduce new variety, which is further grist for the selection mill (Nelson, 1995: 54).

Evolutionary accounts of technology in capitalism, then, must address three main questions: What are the basic units of evolution? What mechanisms generate technological variations? And what mechanisms are responsible for selecting the subset of those variations that are evolutionarily successful? A wide range of answers has been given to each question.

Possible units of technological evolution in capitalist markets mentioned by neo-Schumpeterians include technological artefacts, the technological knowledge embodied in those artefacts, the organizational routines of firms, the firms themselves, interfirm networks, geographical regions and national innovation systems.⁵ Evolutionary economists

5. 'Whereas the gene has come to be recognized as the fundamental unit of selection in biology, it is still unclear at what level evolutionary selection and innovation operate in socio-economic systems. In terms of the Schumpeterian model of creative destruction, for example, it is not obvious whether the basic

have explored various mechanisms generating technological variations in these units, including the cognitive processes of individual researchers (Carlson, 2000), the risk-taking disposition of entrepreneurs (Schumpeter, 1934), the organized searches of research and development labs (Schumpeter, 1947), the formal and informal interactions occurring within networks of firms and geographical regions where particular industries are clustered (Schrader, 1991), communication between technologists and users of the technology (Lundvall, 1988), various technology policies of states and interstate regulatory bodies (Dosi *et al.*, 1988: Part V; Nelson, 1993; Freeman, 1997), the cultural values that generate dispositions to engage in scientific research and to innovate (Landes, 1999), and so on. Finally, a plurality of mechanisms responsible for selecting certain technological variations and rejecting others have been proposed as well. These include success in responding to natural constraints discovered through Bayesian learning processes (David, 2000; Constant, 2000), compatibility with established technological paradigms (Dosi, 1988), compatibility with cultural practices and political interests (Nelson, 1993), and, most of all, suitability to human needs as revealed through market success.⁶

It should go without saying that these sorts of factors must be part of any rich and plausible account of technological evolution. Marxists have a great deal to learn from the insights of neo-Schumpeterians on these matters. The problem from a Marxian standpoint is not so much what the above list includes, but rather what it omits. We may begin with a discussion of the relevant unit(s) of economic evolution. In neo-Schumpeterian writings we find technological artefacts, technological knowledge, the routines of firms, interfirm networks, regions and states all considered as possible units of technological evolution in capitalism. But we do not find a discussion of *capital*. And this, as they say, is like staging *Hamlet* without the prince. For Marx the

unit should be the firm, or the innovation or technology itself. In addition, one may attempt to model behavioural strategies, rules of thumb, etc., as subject to an evolutionary process. All of these approaches are represented in the literature. It remains to be seen to what extent they can be reconciled' (Silverberg, 1988: 538).

6. '[T]echniques exist for an unequivocal, deeper purpose – namely to increase the utility of human agents. Each technique, when it is applied, serves an "ultimate" purpose, which, while obviously intertwined and correlated with its fitness, can be treated separately... Ultimately a selector will have to be judged by its success in satisfying human needs, and the survival of each entity is correlated with that criterion' (Mokyr, 2000: 62–3).

various factors discussed by neo-Schumpeterians are all incorporated within a higher-order complex totality, a 'self-moving substance which passes through a process of its own, and for which commodities and money are both mere forms' (256; see Campbell, Chapter 3 in this volume). Whatever other aspects of Marx's account have been assimilated within the neo-Schumpeterian framework, this notion of capital is absent.

Marx is certainly aware of how bizarre it is to assert that capital is a 'self-moving substance' undergoing evolution in the course of technological development. Isn't this way of speaking blatantly guilty of reifying an abstraction, that is, treating it as if it were a thing? But for Marx 'capital' is not merely a formal abstraction, a mere name referring to features common to investment money (M), commodities purchased as inputs to production (C), the production process (P), the inventories of commodities that emerge from production (C'), and the money accumulated after final sale (M'). 'Capital' is the principle of unity underlying the entire M-C-P-C'-M' circuit, forming it into a single dynamic whole. More complexly, 'capital' is a higher-order unity that maintains its identity within countless dispersed chains of particular capital circuits, a unity expressed quantitatively in accumulation on the level of total social capital (Moseley, 2002).

In capitalist societies artefacts, individuals, firms, networks, markets and states are subsumed under capital. They all take on qualitatively distinct and historically specific shapes when subsumed under the capital form, and they can only be adequately comprehended in terms of their contributions to capital's self-reproduction (Murray, 1998). Specifically, they are subjected to certain systematic mechanisms ensuring that they tend to function in a manner fulfilling the immanent goal of the capital form, capital accumulation. Among the most important of these mechanisms are those underlying the processes of variation and selection in technological evolution.

From a Marxian standpoint the myriad factors introduced by neo-Schumpeterians to account for technological variations are all necessary conditions for the possibility of technological change in capitalism. But there is nothing specifically capitalist about individual cognitive processes, risk-taking, interactions within organizations, informal communications across organizations, market transactions, or state formations. The items on this list have all been present in a wide variety of historical contexts. Even the most comprehensive list of this sort is thus unable to account for the unprecedented rate of technological variation in the capitalist mode of production. We need to comprehend how these factors are

essentially transformed once they have been subsumed under the capital form.

Technological variations can be grouped under the heading of product innovations and process innovations. Use-values are the bearers of exchange-values, and so the self-valorization of value demands the production of commodities with some sort of use to those who purchase them (179–80, 201). If a particular unit of capital successfully introduces new products useful to those with disposable income, it can steal market share from the existing product lines of competitors or open entirely new markets. Units of capital that do not engage in this form of innovation lose market share or are shut out of new markets entirely. As a result individual units necessarily tend to act in a manner furthering the accumulation of total social capital. This necessity cannot be comprehended through reference to technological artefacts themselves, or the dispositions, capacities and needs of individuals, or the mere presence of firms, networks, markets and states. The systematic imperative to product innovation arises only when these phenomena are incorporated within the higher-order unity of the self-valorization of value. It is this that accounts for the unprecedented rate of new product variations in the system as a whole.

The necessary tendency for process innovations follows immediately from the thesis that surplus-value, the difference between the money-capital initially invested in a given period and the money-capital accumulated at the conclusion of that period, represents surplus labour. If we assume sufficient demand for the produced commodities, any increase in the self-valorization of value requires an increase of surplus labour. This can be accomplished through extending the workday, a strategy that sooner or later reaches its limits. The other manner of furthering valorization is to reduce the time spent in necessary labour. When technological change increases productivity in sectors producing means of consumption for workers (or in sectors producing the means of production used in wage-goods sectors), the price of these consumption goods tends to decline. Less of the working day now needs to be devoted to producing the economic value equivalent to the wages workers must receive to maintain their given standard of living. This leaves more of the working day for the production of surplus-value on the level of total social capital (432).

While Volume I is mostly written from the standpoint of capital in general, Marx explicitly notes that all of the determinations discussed on this level of abstraction concretely require the interaction of many capitals (Arthur, 2002). The individual capitals that introduce product

and process innovations do so because they face the imperative to 'grow or die'. Growth comes from attaining the power to set prices, and not from passively accepting the prices dictated in the perfectly competitive markets fantasized by neoclassical economists. Successful technological innovation provides this power. Successful process innovations allow firms to produce a given good or service cheaper than their competitors, thereby winning both market share (from lower prices) and 'surplus profits', that is, profits above the average holding in both the economy as a whole and the particular sector (434–6, 436–7, 530; see also Mandel, 1975; Storper and Walker, 1989; Smith, 2002). Successful product innovations enable firms to divert effective demand away from other units of capital. They too allow firms to charge prices sufficiently high to generate surplus profits until competitors are able to imitate or surpass the innovations.

Once the capital form is in place, the 'personifications' of capital (individual entrepreneurs, the managers of joint stock companies, boards of directors, mutual fund managers, etc.) will necessarily tend to use the immense power granted to them by ownership and control of capital to shape individual cognitive processes, formal and informal communication within and across organizations, the material effects of cultural traditions, and so on, in order to harness these energies to the discovery of technological variations. The proximate end of this arrangement is the surplus profit of a particular unit of capital; the ultimate end is capital accumulation on the level of total social capital. In their drive to appropriate surplus profits for the units of capital with which they are associated the owners and controllers of capital are typically quite indifferent to their role in furthering the accumulation of total social capital, just as individual neurons are indifferent to their role in fulfilling the tasks of the brain. But in both cases a macro-level self-reproducing system (the brain in the one case, capital as a 'self-moving substance' in the other) is present that possesses emergent properties irreducible to the properties of more micro-level entities (neurons and individual capitalists, respectively).

Technological evolution in capitalism is not simply a matter of the proliferation of variations of technological artefacts, technical knowledge, corporate routines, industrial districts and national innovation systems. Mechanisms must be in place to select certain of these variations over others. As noted above, neo-Schumpeterians propose a number of considerations to explain why some innovations are successful while others are not: certain variations exhibit a superior response to challenges set by nature, greater compatibility with the given capacities of

organizations and networks of organizations, greater compatibility with established cultural practices and, most of all, greater ability to meet human needs as measured by market success. The problem, once again, is not so much what the list includes, but rather what is absent: the category of capital.

When the self-valorization of value is the organizing principle of social life, the ultimate purpose of technological change is not to respond to the challenges of nature, develop the capacities of firms, meet human needs, or even successfully engage in market transactions. The ultimate end is the accumulation of capital. No adequate account of why certain technological variations are selected over others can abstract from this essential consideration. Here too the sorts of factors discussed by evolutionary economists are certainly relevant. But these other goals are realized only to the extent that their realization furthers the goal of capital; they are not goals in their own right. And there is nothing historically specific about natural constraints, organizational routines, or the other selection mechanisms they examine. To account for technological change in capitalism we need to comprehend how these factors are essentially transformed once they have been subsumed under the capital form. These transformations follow along the same general lines as those introduced in the discussion of the technological variations. Two further considerations can be emphasized here.

First, variations in technologies (technological practices and so on) that fulfil other relevant criteria for selection discussed by neo-Schumpeterians will nonetheless tend to fail to be selected if they do not take the commodity-form. Evolutionary economists recognize the significance of market success, of course. But they do not explicitly acknowledge how the drive to capital accumulation trumps all other considerations. Consider the contrast between variations in agricultural technologies promising to further the production of feed grains for animals consumed in wealthy regions and variations emerging from research on local subsistence crops for poor regions. Or consider the contrast between variations in medical technologies addressing the lifestyle concerns of the affluent and those directed at deadly afflictions of the poor. In both cases the former sort of technological variations necessarily tend to be selected over the latter under the capital form.⁷

7. 'Every year, more than \$70 billion is spent on global health research and development by the public and private sectors. Only about 10 percent of this money is used for research on 90% of the world's health problems' (Singer, 2002: 77).

This dynamic has nothing to do with relative success at resolving challenges posed by natural constraints, or the organizational forms of corporations and states. Nor does it have to do with relative success at meeting human needs. The explanation lies in the fact that the commodity-form is a moment in the self-valorization of value. Capital is accumulated only through the production and sale of commodities, and so technologies will necessarily tend to be selected promising to result in commodities for which effective demand is higher than alternative variations.

It is also worth noting in passing that technological variations will sometimes fail to be selected even when they promise to result in commodifiable products. If a significant portion of the foreseeable profits from selecting the variations in question are likely to 'leak' to units of capital different from the one considering the selection, that unit will necessarily tend to bypass those variations. This illustrates a point widely acknowledged among non-Marxian theorists: capital rationality and social rationality tend to diverge systematically whenever privately appropriable returns on investment in R&D are significantly less than social returns (Mansfield *et al.*, 1967).

Another manner in which the self-valorization of value serves as a mechanism of selection in technological evolution concerns time. Three general cases can be noted here, all of which stem from Marx's thesis that the basic drive of capital is to accumulate as much surplus-value as possible as rapidly as possible (449). Given this drive, it follows that investments in technological change promising returns in a short- to medium-term time-frame are superior from the standpoint of capital to those requiring a medium- to long-term time-frame. This general tendency holds even if from the use-value standpoint of the selection mechanisms discussed by neo-Schumpeterians the latter are equal or superior to the former. Second, this temporal framework of capital is quite different from what David Harvey terms 'ecological time' (Harvey, 1996: 229–31). There is thus a necessary tendency in capital for variations in technologies to be selected that involve higher levels of environmental risks than feasible alternatives.⁸ Finally, this compressed rhythm of capital time conflicts with the temporal rhythm of community life as well. This implies that innovations will necessarily tend to be selected that impose

8. 'Capitalist production, therefore, only develops the techniques and degree of combination of the social process of production by simultaneously undermining the original sources of all wealth – the soil and the worker' (638).

immense social disruptions whenever this furthers the self-valorization of value more than feasible alternatives.⁹

The discussion thus far has abstracted from perhaps the most significant manner in which the self-valorization of value operates as a selection mechanism in technological evolution. When the capital form has been institutionalized paths of technological change necessarily tend to be selected that systematically reproduce the capital/wage labour relation.

2. Technological change and the capital/wage labour relation

In the above discussion of product innovations we have already noted the systematic tendency for technologies increasing the intensity of the labour process to be introduced in capitalism. The capital/wage labour relation affects the selection of specific paths of technological evolution in three other respects as well. First, in Volume I Marx notes a number of instances in which technical advances leading to higher levels of labour productivity were available and yet *not* selected over other technological options. If wages are so low that the projected cost savings from introducing labour-saving technologies are not likely to compensate for the costs of machinery within a relevant time-frame, these technologies tend to not be selected (516–17).

Second, in circumstances where wage levels are considered high by the ‘personifications of capital’, technologies will tend to be selected that promise to lower those levels. It may be possible to replace expensive workers with machinery (791). New technologies will also be selected if they promise to allow production to continue for extended periods in the face of labour strikes.¹⁰ A further consideration stems from the fact that when different sectors of the workforce are set against each other the balance of power in the capital/wage labour relation generally shifts

9. Neo-Schumpeterians categorize these three tendencies as ‘market failures’ that can be reversed through the technology policies of states and international agencies. But capitalist states and interstate agencies are themselves intrinsically tied to the self-valorization of value. And so their technology policies will also tend to exhibit a bias towards selecting technological paths that are most likely to result in commodifiable products in the short to medium term, even when they impose higher environmental risks and greater social disruptions than feasible alternatives. Theories of the state and the interstate system fall on a much more concrete theoretical level than Volume I, and so this point will not be pursued here.
10. ‘It would be possible to write a whole history of the inventions made since 1830 for the sole purpose of providing capital with weapons against working-class revolt’ (563).

in favour of capital, at least for a period of time. If technologies can be introduced that allow production chains to extend across vast geographical distances, there is a systematic tendency for those who control investment capital to make use of them as part of such a 'divide and conquer' strategy (578–80, 591). The same holds for technologies that allow capital to take advantage of gender differences in the workforce (526).¹¹

Finally, technologies will tend to be selected that systematically reproduce authority relations in the production process. In principle the self-valorization of value may be furthered by increasing skill levels in order to raise the level of labour productivity. Or valorization may be furthered by objectifying skills, since lower-skilled – cheaper – workers can be hired when previously necessary skills are embedded in fixed capital. In some contexts the former path may appear more promising for capital; in others the latter may appear the better bet.¹² But necessary skills monopolized by a sector of the workforce threaten capital's control of the labour process. And so the two options just mentioned are not quite equivalent from the standpoint of capital. There is considerable evidence that technologies that mobilize the intelligence and creativity of the workforce in contexts where job security is guaranteed do in fact encourage productivity improvements measured in use-value terms (Freeman, 1988; Schweickart, 1993: Chapter 3; Appelbaum and Batt, 1994). Despite this, industry on a global scale has by and large continued to select technologies and forms of social organization where most labour remains routinized, worker involvement in decision-making is kept within extremely narrow bounds and job security is systematically eroded over time (Parker and Slaughter, 1994; Bellofiore, 1999; Smith, 2000a). The problem is that the alternative path of socio-technological development threatens capital/wage labour relations in the labour process, and thus eventually threatens 'productivity' gains to capital measured in value terms (monetary returns on capital invested). This crucial dimension of technology cannot be comprehended without a theory that acknowledges the self-valorization of value as the overriding

11. There are, of course, no guarantees that the sorts of technologies mentioned in this paragraph will always be available. But if they are available in the short term, they tend to be selected over alternatives that are equally feasible from a technical standpoint. And if they are not available, private (and public) funds will tend to be devoted to making them available in the medium to long term.
12. For two contrasting samples of the vast literature devoted to this topic, see Braverman (1974) and Adler (1990).

variation and selection mechanism for technological evolution in capitalism. This far-reaching point slips through the conceptual grid of neo-Schumpeterianism.

Two additional points need to be made before concluding this discussion. First, it would be quite mistaken to believe that Marx's theory of technological change can be entirely reduced to the role of technology in class struggle. He was well aware that product innovations and innovations reducing circulation time and constant capital costs cannot all be adequately understood solely in terms of capital's drive to exploit wage labour. The need to produce commodities with use-values, that is, commodities that actually meet the wants and needs of consumers with purchasing power, cannot be reduced to class struggle. Neither can the logic of intra-capital competition, or the manner in which technological change in one sector calls forth technological adjustments in another. These considerations are as necessary for the comprehension of technological change in capitalism as the logic of class conflict.¹³ But not all equally necessary factors are equally essential. The capital/wage labour relation is the essential social relation of the capitalist mode of production, defining its most basic differences from other modes of production. Sales to final consumers, inter-capital competition, and the

13. Marx's account of technological change in the Industrial Revolution is hardly devoted exclusively to the capital/wage labour relation. He traces, for example, the way in which technological change in one sector encourages development in another:

The transformation of the mode of production in one sphere of industry necessitates a similar transformation in other spheres. This happens at first in branches of industry which are connected together by being separate phases of a process, and yet isolated by the social division of labour, in such a way that each of them produces an independent commodity. Thus machine spinning made machine weaving necessary, and both together made a mechanical and chemical revolution compulsory in bleaching, printing and dyeing. So too, on the other hand, the revolution in cotton-spinning called forth the invention of the gin, for separating the seeds from the cotton fibre; it was only by means of this invention that the production of cotton became possible on the enormous scale at present required. But as well as this, the revolution in the modes of production of industry and agriculture made necessary a revolution in the general conditions of the social process of production, i.e. in the means of communication and transportation. (505–6)

In passages such as this the crucial neo-Schumpeterian categories of 'technology systems' and 'technological trajectories' are fully anticipated.

cascading effects of technological evolution must thus ultimately be comprehended as moments in the systematic reproduction of the capital/wage labour relation. The Marxian account of technological change in capitalism stands alone in giving this relation the weight it warrants.

Second, in the dialectic of class struggle presented in Volume I of *Capital* wage-labourers are not simply passive victims of technological change. The very communication technologies that allow capital to play different sectors of the workforce against each other may also enable dispersed workers to articulate common concerns. Technologies designed to increase the pace of the labour process may also make the production chain more vulnerable to disruption. Technologies associated with the deskilling of certain sectors of the workforce may require enhanced capacities in other sectors. And attempts by capital to use technology as a weapon in class struggle necessarily tend to provoke counter-struggles by wage-labourers.¹⁴

Our presentation of Marx's theory has focused on the self-valorization of value as a principle of variation and selection in technological evolution. As important as this topic is, it does not bring us to the heart of his account of technology in capitalism. The single most significant thesis of Volume I of *Capital* is that the self-valorization of value simply *is* the class exploitation of wage-labour by capital.¹⁵ But the social relation between capital and wage-labour does not appear directly as what it is; it is mediated through the impersonal value-form, money. The reign of capital as an alien subject standing above the social world rests entirely

14. There are passages scattered throughout Volume I referring to tendencies for workers to become mere 'appendages' in the course of capitalist development. Some refer to the erosion of the social conditions enabling individuals to act as independent producers apart from capital (482). Others concern the manner in which systems of machinery force workers to submit to the pace of machines (614). A third group has to do with the fact that workers' activities to secure their own reproduction are simultaneously moments in the self-reproduction of capital (719). These considerations establish that 'the dice are loaded'; the rules of the game systematically favour capital (793). But they do not establish that the disposition of wage-labourers to engage capital in struggles necessarily tends to dissipate over time: 'By maturing the material conditions and the social combination of the process of production, it [capital] matures the contradictions and antagonisms of the capitalist form of that process, and thereby ripens both the elements for forming a new society and the force tending towards the overthrow of the old one' (635).
15. 'In every case, the working class creates by the surplus labour of one year the capital destined to employ additional labour in the following year. And this is what is called creating capital out of capital' (729).

on the manner in which the essential social relations of capitalism appear in a fetishized form.¹⁶

While neo-Schumpeterians break with the neoclassical perspective in many respects, they have not broken from the neoclassical account of the 'fundamental ontology' of the technological artefacts employed in production and distribution. These artefacts continue to be categorized as 'capital inputs'. Marx, in contrast, categorized them as forms of 'dead labour', objectifications of social labour that appear in the alien form of capital. To think otherwise is to fall into capital fetishism. This is not merely a terminological difference: the use of different categories results in different understandings of the world and different orientations to practical activity. In so far as neo-Schumpeterians persist in treating technological artefacts as capital they simultaneously reflect and reinforce the objective alienation rooted in the capital/wage labour relation. It may appear natural to regard technological artefacts as the results of the creative powers of capital. But there is nothing 'natural' about this mode of appearance; it rests on historically specific social forms.¹⁷

As the productive forces necessarily tend to expand under the capital form, the alienation of wage-labourers from the productive forces necessarily tends to intensify as well. This alienation emerges from, and is reproduced by, the alienation of the individual worker from social collective labour, including especially the growing sector of the

16. 'This natural power of labour [the power to maintain the established value of means of production when producing new value] appears as a power incorporated into capital for the latter's own self-preservation, just as the productive forces of social labour appear as inherent characteristics of capital, and just as the constant appropriation of surplus labour by the capitalists appears as the constant self-valorization of capital. All the powers of labour project themselves as powers of capital, just as all the value-forms of the commodity do as forms of money' (755-6).
17. 'Since past labour always disguises itself as capital, i.e. since the debts owed to the labour of A, B, C etc. are disguised as the assets of the non-worker X, bourgeois citizens and political economists are full of praise for the services performed by past labour, which according to that Scottish genius MacCulloch, ought indeed to receive a special remuneration in the shape of interest, profit, etc. The ever-growing weight of the assistance given by past labour to the living labour process in the form of means of production is therefore attributed to that form of past labour in which it is alienated, as unpaid labour, from the worker himself, i.e. it is attributed to its form as capital. The practical agents of capitalist production and their ideological word-spinners are as incapable of thinking of the means of production separately from the antagonistic social mask they wear at present as a slave-owner is of thinking of the worker himself as distinct from his character as slave' (757).

workforce devoted to scientific–technical labour. From the standpoint of individual labourers, the contributions to innovation made by social collective labour in general, and scientific–technical labour in particular, appear to be the contributions of capital (482, 799). Neo-Schumpeterian accounts do not call these appearances into question. In many respects they even further ‘capital fetishism’, for instance, when they posit ‘the firm’ (a reified legal fiction) as the repository of the capacities required for successful innovation, rather than the collective workforce.¹⁸

Overcoming this alienation from the technological artefacts of production theoretically requires more than a mere acknowledgement of the creative contribution of workers in the ‘learning by doing’ process, whose importance to innovation neo-Schumpeterians rightfully stress. It requires the category of ‘collective social labour’ and an understanding that this category refers to real material ties connecting subjects backwards and forwards in time, as well as across vast geographical spaces. The practical overcoming of this alienation, of course, requires far more than this.

3. Technological change and the world historical significance of capitalism

Neo-Schumpeterians and Marx have both developed future-oriented theories. But the time horizons of the two frameworks are quite different, as are the social agents to whom they are addressed.

The temporal horizon of neo-Schumpeterians extends to a possible future long wave of capitalist expansion. This involves a consideration of incipient technology trajectories with a potential to generate high levels of investment and growth for an extended epoch, combined with a concern for the socio-political frameworks most likely to further the transition to these new paths. Computer technologies, biotechnologies and technologies that significantly reduce environmental risks have been examined at length in this context, along with the forms of corporate organization, financial institutions, and governmental and inter-governmental technology agencies best suited to their development (Freeman, 1992; Archibugi and Michie, 1997; Dosi *et al.*, 1998; Freeman and Louçã, 2001: Chapter 9). These investigations provide immensely valuable assessments of the technologies and technology policies of our day. Nonetheless, from a Marxian standpoint this literature suffers from a drastic constriction of theoretical and political imagination. In Volume I of *Capital* Marx sought to uncover world historical possibilities beyond

18. This criticism was proposed in Perelman (1998).

capitalism, possibilities opened up by capitalism's own technological advances.

Of course the restricted focus of neo-Schumpeterians would count as a defect only if limits to the reign of capital can in fact be discerned in the technologies and forms of social organization of contemporary capitalism. In Volume I Marx points to a number of such limits, all of which remain of immense contemporary significance.

3.1 Technology and uneven development

The heart of inter-capital competition is the drive to appropriate surplus profits through temporary monopolies from product or process innovations. Research and development is obviously a crucial element in these innovations. Units of capital with access to advanced (publicly or privately funded) R&D are best positioned to win this form of surplus profits. They are thus also best positioned to establish a virtuous circle in which surplus profits enable a high level of future R&D funding, which provides important preconditions for the appropriation of future surplus profits, and so on. In contrast, units of capital without initial access to advanced R&D tend to be trapped in a vicious circle. The resulting inability to introduce significant innovations prevents the appropriation of surplus profits, which in turn tends to limit participation in advanced R&D in the succeeding period. This then limits future innovations and future profit opportunities.

This fundamental dynamic of capitalist property relations has profound implications. Units of capital with the greatest access to advanced R&D almost by definition tend to be clustered in wealthy regions of the global economy. Units without such access tend to be clustered in poorer regions. The former are in a far better position to establish and maintain the virtuous circle described above, while the latter have immense difficulty avoiding the vicious circle.¹⁹ When units of capital in poorer regions engage in economic transactions with units of capital enjoying temporary monopolies on process and product innovations, they thus necessarily tend to suffer disadvantageous terms of trade

19. 'The worldwide distribution of R&D performance is concentrated in relatively few industrialized countries. Of the \$500 billion in estimated 1997 R&D expenditures for the 28 OECD [Organization for Economic Cooperation and Development] countries, 85 percent is expended in just 7 countries' (National Science Board, 2000: 2–40). Ninety-seven per cent of all patents are held by nationals of OECD countries; at least 90 per cent of all technology and product patents are held by global corporations (UNDP, 2000: 84).

(579–80). In other words, there is a redistribution of the value produced in the production and distribution chain from the periphery of the global economy to the centre. The drive to appropriate surplus profits through technological innovation – an inherent feature of capitalist property relations – thus tends to systematically reproduce and exacerbate tremendous economic disparities in the world market over time.²⁰ In this manner capitalism systematically limits both the satisfaction of wants and needs essential to human happiness and the opportunities to develop essential human capacities far below what the present state of technological development enables.

3.2 *Technology and the politics of information*

In Volume I Marx discusses how the contribution of scientific and technological knowledge to capital accumulation falls into a special category. Units of capitals with access to this knowledge treat it as a free gift of nature, increasing productive power without requiring further capital investment (508, 754). He argues that the intensification of the real subsumption of scientific and technological knowledge under the capital form results in this ‘free gift’ becoming ever more central to social life over time. We should note that scientific–technological knowledge counts as a type of public good in three respects (Perelman, 1998). First, knowledge is a *non-rivalrous* good. A piece of knowledge fully possessed by one person can simultaneously be fully possessed by another, unlike rivalrous goods such as cars or sandwiches. Second, once a piece of scientific–technological knowledge has been formulated, the marginal cost of distributing it approaches zero, in sharp contrast to the cost of producing additional cars or sandwiches. Finally, excluding others from this knowledge is costly. The extension and enforcement of intellectual property rights, the private ownership of scientific–technological journals, and so on, can prevent scientific–technological knowledge from possessing the ‘non-excludability’ that is a feature of most public goods. But such measures require extensive private expenditures and significantly raise the social costs of diffusing the technology.

Neo-Schumpeterian theorists assume that the market system is the most efficient mechanism for the production and distribution of scarce goods imaginable. They also note that the dynamic of capitalist development is bringing about an ever more information-intensive economy.

20. This is but one of the many social mechanisms underlying the tendency to uneven development. More complete accounts are found in Toussaint (1999) and Went (2000).

But knowledge is not a scarce good. Once it has been formulated it can be endlessly reproduced and more or less costlessly distributed.²¹ This implies that over time the very heart of the capitalist system itself points beyond the logic of this system, based as it is on the private ownership and exchange of scarce products.

3.3 *Technology and overaccumulation crises*

Neo-Schumpeterians have explicitly acknowledged that extended periods of economic decline regularly occur in capitalism; they have made major contributions to the study of long waves of expansion and decline (Freeman and Louçã, 2000: *passim*). In these accounts the blame for the loss of human happiness and the waste of human potential associated with extended economic downturns ultimately lies with an exhaustion of dominant technological trajectories and the institutional inertia that prevents a rapid shift to new socio-technical systems. But all social systems must confront the exhaustion of reigning technological paradigms and the challenge of adjusting institutions in response. In the Marxian framework the cause of downturns in capitalism is rooted in its historically specific social forms.

Building upon scattered remarks in Volume I and elsewhere, Geert Reuten has connected Marx's account of technological change in capitalism with a systematic tendency to crises (580, 785–7; Reuten, 1991). First, the logic of inter-capital competition necessarily tends to lead to the introduction of new firms and plants into an industry that are more technologically advanced than those already established. These firms win surplus profits due to their superior productivity. But established firms and plants do not all automatically withdraw when this occurs. Given that their fixed capital costs are already 'sunk', they may be happy with receiving the average rate of profit on their circulating capital. They also may have established relations with suppliers and customers that would be impossible (or prohibitively expensive) to duplicate elsewhere in any relevant time-frame. Further, their management and labour force may have industry-specific skills. Or they may have access

21. The tremendous successes of publicly funded R&D (the ultimate source of all significant contemporary technological trajectories) suggests that ever more extensive private intellectual property rights are not required for the initial production of scientific-technical knowledge. In fact, *The Economist*, a far from radical publication, has recently argued that the intellectual property rights regime now profoundly hampers innovation (*Economist*, 2002). An extended argument for the technological dynamism of a democratic form of socialism is found in Smith (2000a: Chapter Seven).

to state subsidies for training, infrastructure, or R&D that they would not be able to replace if they shifted investment to other sectors. If enough firms fail to withdraw an overaccumulation of capital crisis erupts, manifested in excess capacity and declining rates of profit. Insufficient surplus-value is now produced to valorize the investments that had been made in fixed capital, leading to a fall in profit rates for an extended historical period (Smith, 2000b).

When overaccumulation crises break out, previous investments in fixed capital must be devalued. At this point the entire system becomes convulsed in endeavours to shift the costs of devaluation elsewhere. Each unit, network and region of capital attempts to shift the costs of devaluation onto other units, networks and regions. And capital as a whole attempts to shift as much of the cost as possible onto labour by increasing unemployment, lowering wages and worsening work conditions.²² As the concentration and centralization of capital proceed, the overaccumulation and devaluation of capital necessarily tend to occur on an ever more massive scale. Global turbulence and generalized economic insecurity increasingly become the normal state of affairs (Brenner, 2002; Smith, 2000a: Chapter 5).

The neo-Schumpeterian response to long waves of capitalist decline is to seek new technological paradigms promising a new wave of growth, and to call for whatever institutional adjustments appear to be required to set those paradigms in place. Once again we find that the absolutely essential questions from a Marxian viewpoint cannot even be formulated within the perspective of evolutionary economics. Will there not come a point at which the social costs of overaccumulation crises force increasing numbers of people to consider alternative social forms? Isn't it just possible that there are feasible forms within which technological evolution can occur without the immense human suffering that follows in the wake of overaccumulation crises?

3.4 Technology and the politics of time

Advances in labour productivity present a fundamental choice. Either the same output can be produced in less time, or a greater output can be produced in the same period of time. The most basic drive of capital is to increase the accumulation of capital, and the accumulation of additional capital generally requires the production and sale of additional

22. The on-going human catastrophes in East Asia in response to the crisis of 1997–98 provide only the most recent example. See Burkett and Hart-Landsberg (2001).

commodities. And so capitalism necessarily tends to proceed down the path of using technology to increase output rather than to reduce labour time.²³

It must be granted that this dynamic has brought about an unprecedented increase in living standards for vast numbers of people. As output expands, unit costs and prices tend to decline. Many products that were initially luxury commodities eventually become more widely affordable. Marxists, of course, are quick to point out that uneven development, overaccumulation crises and other structural tendencies of capitalism profoundly distort the manner in which the increased output due to technological change is socially distributed. Two other considerations are relevant as well. First, technological changes advancing labour productivity in principle allow greater amounts of 'time for education, for intellectual development, for the fulfilment of social functions, for social intercourse, for the free play of the vital forces of [the worker's] body and mind' (375). These are immensely important matters, and are widely regarded as such. Must there not be *some* point beyond which the promise of more commodities fails to compensate for their loss?

A second issue concerns the world historical pattern of evolution from agricultural to heavy industrial and then knowledge-based economies. Neo-Schumpeterians correctly discern that leading sectors of the economy today are characterized less and less by labour intensity or 'capital intensity' in the sense of investment in raw materials and machinery, and more and more by intensity in the use of knowledge resources (Freeman and Louca, 2001). It is also correct to assert that the forms of labour best suited to knowledge-based economies are likely to be quite different from those associated with earlier periods. In this sense the rhetoric of 'knowledge workers' contains an element of truth. Nonetheless, this rhetoric ideologically distorts analysis of the contemporary capitalist workplace. Most factory and office workers simply lack the time to become knowledge workers in any meaningful sense of the

23. When we take into account forced overtime, increased commuting distances and an intensification of labour that leaves workers exhausted when the workday is over, we may even say that there is a tendency for a *greater* appropriation of workers' time as labour productivity advances in capitalism. In Volume I Marx refers to 'the economic paradox that the most powerful instrument for reducing labour-time suffers a dialectical inversion and becomes the most unflinching means for turning the whole lifetime of the worker and his family into labour-time at capital's disposal for its own valorization' (532), a paradox that continues to hold today (Fraser, 2001).

term.²⁴ From a world historical standpoint, then, capitalism systematically limits the evolution of the very knowledge-based economy it has itself generated (Richta, 1968). This limit to social evolution cannot even be articulated within the confines of mainstream evolutionary economics.

3.5 Technology and environmental risks

As we have seen, the tension between 'capital time' and 'ecological time' in the course of technological development necessarily tends to generate an excessive level of environmental risk. The manner in which technological change in capitalism necessarily tends to result in increased output rather than reduced labour time exacerbates environmental risks as well. As a result, the need to subject technological change to some version of the 'precautionary principle' can be expected to intensify in the course of capitalist development. This need conflicts in principle with the forms of technical change imposed by the valorization imperative (Burkett, 1999: 226–7).

4. Conclusion

Neo-Schumpeterian theories are addressed to groups charged with the task of developing new socio-technological paradigms, capable of setting off an extended historical epoch of capitalist growth. But overcoming uneven development, overaccumulation crises and the other limitations connected to the development and use of technology in capitalism demands a break from capitalist production and property relations. The social agents to whom neo-Schumpeterian theories are addressed (scientists, technologists, investors, managers, political elites, and so on)

24. See Fraser (2001) for a discussion of office and professional workers. For a discussion of contemporary factory work see Parker (1999), who examines the manner in which time constraints prevent the emergence of knowledge workers in any substantive sense. One contemporary trend is to eliminate electricians and quality control workers, transferring their duties to line workers. Line workers may then enjoy more variety in their workday. But this sort of 'multitasking' does not leave them with the time required to acquire the level of knowledge attained by specialists workers in the past. When demand increases for a firm's commodities, there is also a tendency to increase output through forced overtime. This too denies workers the time required to become 'knowledge workers' in any meaningful sense of the term. Parker further notes the manner in which the lack of work time devoted to training gives the lie to the talk of 'knowledge workers' in contemporary manufacturing (Parker, 1999).

are unlikely to initiate this world historical project, let alone complete it successfully.

Marx's theory, in contrast, is addressed to working men and women and their communities. Are they capable of undertaking and completing the historical task in question? No definitive answer to such a question can be expected here. But two preliminary points can be proposed. First, if the account of technological change developed in Volume I of *Capital* is accurate, the vast majority of humanity has reason to resist the idea that capitalism is the final stage of social evolution. Second, any effective movement towards a post-capitalist society must occur on a global level, for capitalism is a global system. This latter point brings us to one final social implication of technological change discussed in Volume I. Marx argues that the technological changes enabling interconnections in the capitalist world market simultaneously bring about the material conditions for an effective internationalist movement of workers and their allies. For instance, he discusses how workers in different regions of the global economy are connected in a common learning process. Transportation and communication technologies enable positive and negative lessons from social struggles to be transmitted across borders (Chapter 10). The immense social disruptions associated with technological change in capitalism also set off flows of immigrant labourers (Chapter 25). These flows create the material conditions for extensive and intensive community ties across borders (Sassen, 1998).

Neo-Schumpeterians have not focused on this sort of 'globalization from below'. Evolutionary economists have generally taken the nation as the basic social unit, with contrasts between different 'national innovation systems' one of their central research topics (Nelson, 1993; Freeman, 1997). International issues have been considered only in so far as technological developments create a need for global regulatory institutions, capable of addressing externalities beyond the reach of individual states (Freeman and Soete, 1999: Chapter 18). The manner in which technological developments in capitalism necessarily tend to further the material preconditions for the formation of a world community of wage-labourers and their allies is thoroughly occluded. In contrast, this world historical possibility is a central theme of *Capital*.

The most fundamental practical implication of Marx's theory is that the self-organization of working men and women as a transnational class in-and-for-itself is the major project of the present epoch of world history (Robinson and Harris, 2000). Only such self-organization holds the promise of overcoming the various limitations on technological

development described in this chapter. When all is said and done, this is by far the most profound distinction between Marxian and non-Marxian accounts of technological change in capitalism. In Volume I Marx wrote,

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 utilizes those instruments (554–5).

This process remains to be completed.

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