

INFORMATION AND ECONOMICS: A CRITIQUE OF HAYEK

Allin F. Cottrell and W. Paul Cockshott

October, 1994

1 introduction

Neither the theoretical arguments put forward in the West, nor the fact of the collapse of Soviet socialism, historic landmark as it undoubtedly is, warrant the belief that socialist economic planning *tout court* is an untenable notion whose time has passed. Indeed, modern developments in information technology open up the possibility of a planning system that could outperform the market in terms of efficiency (in meeting human needs) as well as equity. Such are the claims that we have defended in a number of recent publications, designed to re-open a debate over socialist economics.¹ We do not expect that our ideas will meet with immediate political success, but we do venture to hope that open-minded economists will consider our economic arguments on their merits.

We do not intend to reiterate our general arguments in favour of planning here. Our object is to refute the objections to socialist plan-

ning put forward by Hayek in his classic article ‘The Use of Knowledge in Society’ (1945). The relevance of such an argument to the readership of this journal might be questioned. Doesn’t Hayek lie outside of the mainstream of British (increasingly, Anglo-American) professional economics, with its dual roots in Marshallian pragmatism and the formal general equilibrium theory of the Lausanne school? Wasn’t Hayek’s defence of the market always a bit too strident and doctrinaire to suit the sensibilities of a profession that (in Britain at any rate) has traditionally had a broadly social-democratic outlook? Maybe so, but it is our impression that Hayek’s star is on the rise in the post-Communist world, and that even those who baulk at his extreme enthusiasm for the unfettered market are often quite ready to see his arguments used to bury any form of thorough-going socialism.

And so to business. We offer below an exposition and point-by-point contestation of the ideas in Hayek (1945). We should make it clear that some, though by no means all, of our criticisms of Hayek are anachronistic—that is, they depend on advances in information technology that have taken place since Hayek wrote. We think this is justified for two reasons. First, Hayek clearly thought he was putting forward a very general argument, which he did not expect to see undermined by technological change. Second, Hayek’s followers (e.g. Lavoie,

¹Our ideas were first presented in Cockshott and Cottrell (1989), and are set out most fully in Cockshott and Cottrell (1993). Cottrell and Cockshott (1993a) re-examines the historic socialist calculation debate, with emphasis on the arguments of Mises and Lange. In Cottrell and Cockshott (1993b) we stress the differences between our proposals and the system that existed in the Soviet Union. Technical details of the algorithm we propose for short- to medium-term planning are spelled out in Cockshott (1990).

1985) continue to support his arguments of several decades ago, and to assert that developments in information technology are largely beside the point.

In our exposition of Hayek we try to balance concision with the need to produce a sufficiently full and fair account to obviate the suspicion that we may be attacking a straw man. We begin with a brief summary of the philosophical views that inform the argument of ‘The Use of Knowledge in Society’, which are spelled out more fully in *The Counter-Revolution of Science* (Hayek, 1955).

2 hayek’s argument outlined

2.1 The philosophical background

In *The Counter Revolution of Science* Hayek is concerned to contrast the natural and social sciences, whose relation to their subject matter, he claims, is fundamentally different. In the natural sciences, advances involve recognising that things are not what they seem. Science dissolves the immediate categories of subjective experience and replaces them with underlying, often hidden, causes. The study of society on the other hand has to take as its raw material the ideas and beliefs of people in society. The facts studied by social science

differ from the facts of the physical sciences in being beliefs or opinions held by particular people, beliefs which as such are our data, irrespective of whether they are true or false, and which, moreover, we cannot directly observe in the minds of people but which we can recognise from what they say or do merely because we have ourselves a mind similar to theirs. (Hayek, 1955, p. 28)

He argues that there is an irreducible subjective element to the subject matter of the social sciences which was absent in the physical sciences.

[M]ost of the objects of social or human action are not “objective facts” in the special narrow sense in which the term is used in the Sciences and contrasted to “opinions”, and they cannot at all be defined in physical terms. So far as human actions are concerned, things *are* what the acting people think they are. (Hayek, 1955, pp. 27–27)

His paradigm for the social or moral sciences is that society must be understood in terms of men’s conscious reflected actions, it being assumed that people are constantly consciously choosing between different possible courses of action. Any collective phenomena must thus be conceived of as the unintended outcome of the decisions of individual conscious actors.

This imposes a fundamental dichotomy between the study of nature and of society, since in dealing with natural phenomena it may be reasonable to suppose that the individual scientist can know all the relevant information, while in the social context this condition cannot possibly be met.

2.2 The basic economic problem

From this philosophical ground Hayek (1945) poses the question: ‘What is the problem we wish to solve when we try to construct a rational economic order?’

He continues:

On certain familiar assumptions the answer is simple enough. If we possess all the relevant information, if we can start out from a given system of preferences and if we command complete knowledge of available means, the problem which remains is purely one of logic. That is,

the answer to the question of what is the best use of the available means is implicit in our assumptions. The conditions which the solution of this optimum problem must satisfy have been fully worked out and can be stated best in mathematical form: put at their briefest, they are that the marginal rates of substitution between any two commodities or factors must be the same in all their different uses. (Hayek, 1945, p. 519)

He immediately makes it clear, however, that the ‘familiar assumptions’ upon which the above approach is predicated are quite unreal.

This, however, is emphatically not the economic problem which society faces . . . The reason for this is that the data from which the economic calculus starts are never for the whole society given to a single mind which could work out the implications, and can never be so given. (*ibid.*)

Hayek then spells out his own perspective on the nature of the problem:

The peculiar character of the problem of a rational economic order is determined precisely by the fact that the knowledge of the circumstances of which we must make use never exists in concentrated or integrated form, but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess. (*ibid.*)

The true problem is therefore “how to secure the best use of resources known to *any of the members of society*, for ends whose relative importance *only these individuals know*” (Hayek, 1945, p. 520, emphasis added). That this is not generally understood, Hayek claims, is an effect of naturalism or scientism, that is “the erroneous transfer to social phenomena of the habits of thought we have developed in dealing with the phenomena of nature” (*ibid.*).

2.3 Against centralisation

The point at issue between Hayek and the proponents of socialist economic planning is not “whether planning is to be done or not”. Rather it is “whether planning is to be done centrally, by one authority for the whole economic system, or is to be divided among many individuals” (Hayek, 1945, pp. 520–21). The latter case is nothing other than market competition, which “means decentralized planning by many separate persons” (Hayek, 1945, p. 521). And the relative efficiency of the two alternatives hinges on

whether we are more likely to succeed in putting at the disposal of a single central authority all the knowledge which ought to be used but which is initially dispersed . . . or in conveying to individuals such additional knowledge as they need in order to fit their plans in with those of others. (*ibid.*)

The next step in Hayek’s argument involves distinguishing two different kinds of knowledge: scientific knowledge (understood as knowledge of general laws) versus “unorganized knowledge” or “knowledge of the particular circumstances of time and place”. The former, he says, may be susceptible of centralization via a “body of suitably chosen experts” (Hayek, 1945, p. 521) but the latter is a different matter.

[P]ractically every individual has some advantage over others in that he possesses unique information of which beneficial use might be made, but of which use can be made only if the decisions depending on it are left to him or are made with his active cooperation. (Hayek, 1945, pp. 521–22)

Hayek is thinking here of “knowledge of people, of local conditions, and special circumstances” (Hayek, 1945, p. 522), e.g., of the fact

that a certain machine is not fully employed, or of a skill that could be better utilized. He also cites the sort of specific, localised knowledge relied upon by shippers and arbitrageurs. He claims that this sort of knowledge is often seriously undervalued by those who consider general scientific knowledge as paradigmatic.

2.4 The importance of change

Closely related, in Hayek's mind, to the undervaluation of knowledge of local and specific factors is underestimation of the role of *change* in the economy. One key difference between advocates and critics of planning concerns

the significance and frequency of changes which will make substantial alterations of production plans necessary. Of course, if detailed economic plans could be laid down for fairly long periods in advance and then closely adhered to, so that no further economic decisions of importance would be required, the task of drawing up a comprehensive plan governing all economic activity would appear much less formidable. (Hayek, 1945, p. 523)

Hayek ascribes to his opponents the idea that economically-relevant change is something that occurs at discrete intervals and on a fairly long time-scale, and that in between such changes the management of the productive system is a more or less mechanical task. As against this, he cites, for instance, the problem of keeping cost from rising in a competitive industry, which requires considerable day-to-day managerial energy, and he emphasises the fact that the same technical facilities may be operated at widely differing cost levels by different managements. Effective economical management requires that "new dispositions [be] made every day in the light of circumstances not known the day before" (Hayek, 1945, p. 524). He therefore concludes that

central planning based on [aggregated] statistical information by its nature cannot take direct account of these circumstances of time and place, and ... the central planner will have to find some way or other in which the decisions depending upon them can be left to the man on the spot. (*ibid.*)

Rapid adaptation to changing circumstances of time and place requires decentralisation—we can't wait for some central board to issue orders after integrating *all* knowledge.

2.5 Prices and information

While insisting that very specific, localised knowledge is essential to economic decision making, Hayek clearly recognises that the "man on the spot" needs to know more than just his immediate circumstances before he can act effectively. Hence there arises the problem of "communicating to him such further information as he needs to fit his decisions into the whole pattern of changes of the larger economic system" (Hayek, 1945, p. 525) How much does he need to know? Fortunately, only that which is conveyed by prices. Hayek constructs an example to illustrate his point:

Assume that somewhere in the world a new opportunity for the use of some raw material, say tin, has arisen, or that one of the sources of supply of tin has been eliminated. It does not matter for our purpose and it is very significant that it does not matter which of these two causes has made tin more scarce. All that the users of tin need to know is that some of the tin they used to consume is now more profitably employed elsewhere, and that in consequence they must economize tin. There is no need for the great majority of them even to know where the more urgent need has arisen,

or in favor of what other uses they ought to husband the supply. (Hayek, 1945, p. 526)

Despite the absence of any such overview, the effects of the disturbance in the tin market will ramify throughout the economy just the same.

The whole acts as one market, not because any of its members survey the whole field, but because their limited individual fields of vision sufficiently overlap so that through many intermediaries the relevant information is communicated to all. (*ibid.*)

Therefore the significant thing about the price system is “the economy of knowledge with which it operates” (Hayek, 1945, pp. 526–7). He drives his point home thus:

It is more than a metaphor to describe the price system as a kind of machinery for registering change, or a system of telecommunications which enables individual producers to watch merely the movement of a few pointers, as an engineer might watch the hands of a few dials, in order to adjust their activities to changes of which they may never know more than is reflected in the price movements. (Hayek, 1945, p. 527)

He admits that the adjustments produced via the price system are not perfect in the sense of general equilibrium theory, but they are nonetheless a “marvel” of economical coordination. (*ibid.*)

2.6 Evolved order

The price system has not, of course, arisen as the product of human design, and moreover “the people guided by it usually do not know why they are made to do what they do” (*ibid.*).

This observation leads Hayek to a very characteristic statement of his general case against central planning.

[T]hose who clamour for “conscious direction”—and who cannot believe that anything which has evolved without design (and even without our understanding it) should solve problems which we should not be able to solve consciously—should remember this: The problem is precisely how to extend the span of our utilization of resources beyond the span of the control of any one mind; and, therefore, how to provide inducements which will make individuals do the desirable things without anyone having to tell them what to do. (Hayek, 1945, p. 527)

Hayek generalises this point by reference to other “truly social phenomena” such as language (also an undesigned system). Against the idea that consciously designed systems have some sort of inherent superiority over those that have merely evolved, he cites A. N. Whitehead to the effect that the progress of civilisation is measured by the extension of “the number of important operations which we can perform without thinking about them” (Hayek, 1945, p. 528). He continues:

The price system is just one of those formations which man has learned to use... after he had stumbled upon it without understanding it. Through it not only a division of labor but also a coordinated utilization of resources based on an equally divided knowledge has become possible... [N]obody has yet succeeded in designing an alternative system in which certain features of the existing one can be preserved which are dear even to those who most violently assail it such as particularly the extent to which the individual can choose his pursuits and consequently freely use his own knowledge and skill. (*ibid.*)

The outline of Hayek's argument is now, we trust, clearly in view. We are ready to proceed to our criticisms, which are structured as follows. We first challenge the subjectivist philosophy that underpins Hayek's conception of information. We then offer an alternative perspective on the nature of the problem faced by a planned economic system, and we dispute Hayek's claims regarding the benefits of decentralisation. This then leads into a critique of the idea that the market constitutes an efficient telecommunications system. Our critique is developed by means of a formal model of the information exchanges required under market and plan. The penultimate section of the paper deals with the idea that change is all important; and the concluding section takes up the issue of the market as a 'spontaneously evolved' system.

3 hayek's subjectivism: critique

Hayek's radically subjectivist view of the social sciences is open to the objection that its constitutive category, the rational subject, is by no means obviously given. As Lawson (1992) has argued, a wealth of psychological and sociological research has revealed that human behaviour is highly routinized, and coordinated in the main by unconscious brain functions. Indeed, as Dennett (1991) relates, experiments in neuropsychology indicate that people act first and become conscious of their intention to act later.

For the more limited domain of economics, there is the problem that the 'subjects' in question are more likely to be juridical than personal. In the main, the economic actors in industrial production are firms, not human individuals. Nor can the actions of a firm be reduced to the inner subjective life of its man-

aging director. In any large firm, the courses of action taken result from a complex set of practices, reviews, and decision-making procedures involving many people, and in which the procedures can be as important as who fills which particular positions. We would argue that the economic subject that Hayek takes as his starting point is not empirically given at all, but is rather a reification of economic theory. The rational economic subject makes sense only in terms of formalised calculating procedures, which, if they are realised in practice, are more likely to be materialised in the accounting and management practices of firms than in the brains of individuals. Economic theory then projects back these practices, rational for the enterprise as a juridical subject, onto a supposedly constitutive human subject.

The historical conditions for this projection are clear enough. In the early stages of capitalism the distinction between personal and juridical subjects was as yet ill defined. The agent of economic practice thus appeared to be the person of the capitalist or entrepreneur rather than the firm. But from the standpoint of the current state of economic development, it can be seen that the rational calculating subject is the property-maximising juridical subject. To the extent that in a property system some of the juridical subjects are individual human animals, the reified subject of economic theory provides an account of what would be rational action on their part. But the assertion that these animals do engage in such rational action is more an act of faith than an empirical result of science. By starting out with this act of faith Hayek aimed to mark off economics as essentially a branch of moral philosophy rather than science.

But once the category of subject is recognised for what it is, not an empirically existing property of the human animal, but something ascribed to it both by the structures of language and of juridical discourse (Althusser,

1971), then this exclusion of science from the study of society becomes untenable. It becomes just one more of the special pleas by morality to hold the encroachments of science at bay.

Hayek's subjectivist philosophical standpoint has an important bearing on his arguments against socialist planning, since these arguments hinge on the notion of subjective information. Despite the fact that *The Counter-Revolution of Science* was published after the establishment of a scientific information theory by Shannon and Weaver (1949), Hayek's notion of information remains resolutely pre-scientific. Admittedly, it takes time for the discoveries of one discipline to percolate through to others. In the mid-1950s the idea of the objectivity of information had not yet spread far beyond the study of telecommunications. But now, when it has revolutionised biology, become the foundation of our major industries, and begun to transform our understanding of social ideologies (Dawkins, 1982), its absence vitiates Hayek's entire argument.

For Hayek information is essentially subjective; it is knowledge in people's minds. Thus we have the problem of how information that is dispersed in the minds of many can, through the operations of the market, be combined for the common good. By taking this subjectivist standpoint, attention is diverted away from the very practical and important question of the technical supports for information. It becomes impossible to see the production and manipulation of information as both a technology and a labour process in its own right, whose development acts as a constraint upon the possibility of economic relations.

In any but the most primitive of economies, economic relations have depended upon the development of techniques for objectifying information. Consider the relationship between landlord and tenant, and thus rent. This can only stabilise once society has a means for

recording ownership and tenancy contracts, whether as written documents or the mortgage marker stones so hated by the peasantry of Attica.

The development of price relies upon the technology of counting and calculation, which can never in a commercial society be a purely mental operation. Calculation demands a material support, whether it be the calculi or small stones of the early Romans, or the coins and reckoning tables of late Antiquity and the middle ages. Economic rationality is an algorithmic process supported by a machinery for computation and information storage. The fact that until recently the machinery was simple and hand-operated—the abacus, the coin box, or the ledger—allowed it to be ignored in economic theory. But the means of rationality are as essential to economic relations as the means of production. Trade without a technology of calculation and record is as impractical as agriculture without instruments to turn the soil. Once these aspects of information theory and information technology are considered, quite different answers can be given to Hayek's problem of economic information.

4 the calculation problem and its misrepresentation

We have argued elsewhere (Cottrell and Cockshott, 1993a) that the classic 'socialist calculation debate' in the first part of this century took place on the terrain of the neo-classical critics of socialism rather than its Marxian advocates. This had an effect in defining the structure of the problem. In the neoclassical variant, the problem starts with the preferences of the individual agents and their production possibilities. This formulation is vulnerable to Hayek's critique, on the

grounds that individuals' preferences are in no sense 'given' to the planners. But Marxian economists would not accept that these individual preferences have any meaningful pre-existence;² they do not, therefore, form part of the problem.

The practical problem is to bring production potential into alignment with a pattern of social need revealed by a combination of democratic political decisions (as in the case of, say, the appropriate level of public health service provision) and aggregate consumer purchases. Given a reasonable data-collection system reporting on the rates at which consumer goods are selling, and assuming a pricing system based on labour values (Cockshott and Cottrell, 1993), deriving a target net-output vector demands no special telepathic powers on the part of the planning system. It is perhaps harder to gather the information about production possibilities. It is in this practical context that Hayek's discussion of centralised versus decentralised control systems must be placed.

5 to centralise or not?

5.1 'One mind'

Austrian opponents of socialism talk as if socialist planning has to be carried out by one man. Mises (1949) personified him as 'the director'. Hayek continues the metaphor, stating that the "data from which the economic calculus starts are never for the whole society given to a single mind". How then, he asks, can one mind presume to improve on the combined result of the cogitations of millions (as achieved

²Take the homely example of Christmas shopping. Many of us find it impossible to draw up a complete plan for such shopping in advance. We have to go to the shops, look at the goods and their prices, and see what strikes our fancy. Our 'demand functions' are revealed to ourselves in the act of choosing.

via the market)? Surely only a megalomaniac, or at any rate one blinded by scientific hubris, could propose such a thing.

Of course no single individual has the brain-power to understand all of the interconnections of an economy, but when have socialists ever asserted anything so foolish? Not even the most avid personality cultists claimed that Stalin drew up the 5-year plans himself. What socialists have proposed is the replacement of market information processing by the processing of economic information within a planning organisation. In the past, because of technological limitations, the planning organisation has proceeded by a division of mental labour among a large number of people. In the future, the information processing is likely to be done mainly by computing machines.

In neither case—and here our critique of Hayek's subjectivism comes into play—is the information concentrated in one mind. In the former case it is obviously not in the mind of a single worker, but it is not even in the minds of a collection of workers. Instead, the information is mainly in their written records, forms, ledgers, etc. These constitute the indispensable means of administration. From the earliest temple civilisations of Sumer and the Nile, the development of economic administration was predicated upon the development of means of calculation and record. The human mind enters in as an initial recorder of information, and then as a manipulator of the recorded information. By procedures of calculation strings of symbols are read and transformed ones written down. The symbols—whether they be arabic numerals, notches on tally sticks or quipu—represent physical quantities of goods; their transformations model actual or potential movements of these goods.

By posing the question in terms of concentrating the information in a single mind, Hayek harks back to a pre-civilised condition, abstracting from the real processes that make

any form of administration possible. If instead, his objection is that no system of administration can possibly have the information-processing capacity required for the task, then he is liable to the attack that information technology has revolutionised the amount of information that can be effectively administered.

5.2 Forms of knowledge

The dichotomy that Hayek operates between the natural sciences and the social domain also leaves its imprint on his categorisation of forms of knowledge. In his view, there are but two such forms: knowledge of general scientific laws, and (subjective) knowledge of ‘particular circumstances of time and place’. But this leaves out of account a whole layer of knowledge that is crucial for economics, namely knowledge of specific technologies. Such knowledge is not reducible to general scientific law (it is generally a non-trivial problem to move from a relevant scientific theory to a workable industrial innovation), but neither is it so time- or place-specific that it is non-communicable. The licensing and transfer of technologies in a capitalist context shows this quite clearly. A central registry of available technologies would form an essential component of an efficient planning system. How would such information be assembled? Again, Hayek’s notion of knowledge existing solely ‘in the mind’ is an obstacle to understanding. It is increasingly common—indeed, it is by now all but universal practice—for firms to keep records of their inputs and outputs in the form of some sort of computer spreadsheet. These computer files form an image of the firm’s input–output characteristics, an image which is readily transferable.³

³Admittedly, such an image does not of itself provide any information on how, for instance, a particularly favourable set of input–output relations can be *achieved*, only that it is *possible*. We offer some fur-

Further, even the sort of ‘particular’ knowledge which Hayek thought too localised to be susceptible to centralisation is now routinely centralised. Take his example of the information possessed by shippers. In the 1970s American Airlines achieved the position of the world’s largest airline, to a great extent on the strength of their development of the SABRE system of computerised booking of flights (Gibbs, 1994). Since then we have come to take it for granted that our local travel agent will be able to tap into a computer network to determine where and when there are flights available from just about any A to any B across the world. Hayek’s appeal to localised knowledge in this sort of context may have been appropriate at the time of writing, but it is now clearly outdated.

We would not dispute, however, that some localised knowledge, important for the fine-grained efficiency of the system, may be too specific for any meaningful centralisation. Our objection here is that Hayek seems to overlook the possibility that this sort of knowledge may simply be *used* locally, without prejudice to the operation of a central plan. The question here concerns the degree of recursiveness of planning, that is, the extent to which plans can be formulated in general terms by the higher planning authorities, to be specified in progressively fuller detail by successively lower or more local instances. Nove (1977, 1983) has argued persuasively that as regards the composition of output, the degree of recursiveness of planning is rather small. If a central authority sets output targets in aggregated terms, and leaves it to lower instances to specify the details, the result is bound to be incoherent. In the absence of the sort of horizontal links between enterprises characteristic of the market system, the enterprises simply cannot know

ther thoughts on the transmission of such ‘know how’ in Section 6 below.

what specific sort of output will be needed, unless they are told this by the planning authority. This may be granted.⁴ But low recursiveness with respect to decisions on the composition of output does not imply that all decisions relating to production have to be taken centrally. Consider the knowledge, at the level of the enterprise, of which particular workers are best at which tasks, who is the fastest worker and who the most reliable and so on (and similarly for the particular machines operated within the enterprise). Why shouldn't such knowledge just be used locally in drawing up the enterprise's own detailed schedules for meeting an output plan given from the 'centre'? Isn't this precisely what happens at plant level in the context of planning by a large (multiplant) capitalist enterprise?

5.3 Disadvantages of dispersal

Having argued that the centralisation of much economic information is feasible, we now consider its desirability. When economic calculation is viewed as a computational process, the advantages of calculation on a distributed or decentralised basis are far from evident; the question hinges on how a multiplicity of facts about production possibilities in different branches of the economy interrelate. Their interrelation is, partially, an image in the field of information of the real interrelation of the branches of the economy. The outputs of one activity act as inputs for another: this is the *real* interdependence. In addition, there are *potential* interactions where different branches of

⁴Although Nove's case is surely exaggerated in one respect: if the central plan calls for enterprise A to supply intermediate good x to enterprise B, where it will be used in the production of some further good y , and if the planners apprise A and B of this fact, surely there is scope for horizontal discussion between the two enterprises over the precise design specification of x , even in the absence of market relations between A and B.

production function as alternative users of inputs.

It is important to distinguish the two types of interaction. The first represents real flows of material and is a static property of a snapshot of the economy. The second, the variation in potential uses for goods, is not a property of the real economy but of the phase space of possible economies. The latter is part of the economic problem insofar as this is considered to be a search for optimal points within this phase space. In a market economy, the evolution of the real economy—the real interdependencies between branches—provides the search procedure by which these optima are sought. The economy describes a trajectory through its phase space. This trajectory is the product of the trajectories of all of the individual economic agents, with these individual agents deciding upon their next position on the basis of the information they get from the price system.

Following up on Hayek's metaphor of the price system as telecoms system or machinery for registering changes, the market economy as a whole acts as a single analog processor. A single processor, because at any one point in time it can be characterised by a single state vector that defines its position in the phase space of the economic problem. Moreover, this processor operates with a very slow cycle time, since the transmission of information is bounded by the rate of change of prices. To produce an alteration in prices, there must be a change in the real movement of goods (we are abstracting here from the small number of highly specialised futures markets). Thus the speed of information transmission is tied to the speed with which real goods can be moved or new production facilities brought on line. In sum, a market economy performs a single-threaded search through its state space, with a relatively slow set of adjustments to its position, the speed of adjustments being deter-

mined by how fast the real economy can move.

Contrast this now with what can potentially be done if the relevant facts can be concentrated, not in one place—that would be impossible—but within a small volume of space. If the information is gathered into one or more computing machines, these can search the possible state space without any change in the real economy.

Here the question of whether to concentrate the information is very relevant. It is a basic property of the universe that no portion of it can affect another in less time than it takes for light to propagate between them. Suppose one had all the relevant information spread around a network of computers across the country. Assume any one of these could send a message to any other. Suppose that this network was now instructed to simulate *possible* states of the economy in order to search for optima. The evolution from one simulated state to another could proceed as fast as the computers could exchange information regarding their own current state. Given that electronic signals between them travel at the speed of light this will be far faster than a real economy can evolve.

But the speed of evolution will be much faster still if we bring all of the computers into close proximity to one another. Massively parallel computers attempt to place all the processors within a small volume, thereby allowing signals moving at the speed of light to propagate around the machine in a few nanoseconds, compared to the hundredths of a second required for telecoms networks. Hence, in general, if one wishes to solve a problem fast, the information required should be placed in the smallest possible volume.

It may be objected that the sheer scale of the economic problem is such that although conceivable in principle, such computations would be unrealisable in practice

(Hayek, 1955;⁵ see also Nove, 1983). We have established elsewhere (Cockshott and Cottrell, 1993; Cottrell and Cockshott, 1993b) that given modern computer technology this is far from the case.

6 inadequacy of the price form

Prices, according to Hayek, provide the telecoms system of the economy. But how adequate is this telecoms system and how much information can it really transmit?

Hayek's example of the tin market bears careful examination. Two preliminary points should be made. First, the market system does manage to achieve a reasonable degree of coordination of economic activities. The "anarchy of the market" (Marx) is far from total chaos. Second, even in a planned system there will always be scope for the disappointment of expectations, for projects that looked promising ex ante to turn out to be failures and so on. Failures of coordination are not confined to market systems. That said, it is nonetheless clear that Hayek grossly overstates his case. In order to make rational decisions relating to changing one's usage of tin, one has to know whether a rise in price is likely to be permanent or transient, and that requires knowing *why* the price has risen. The current price signal is never enough in itself. Has tin become more expensive temporarily, due, say, to a strike by the tin miners? Or are we approaching the exhaustion of readily available reserves? Actions that are

⁵The specific reference here is to p. 43, and more particularly to note 37 on pp. 212–213, of *The Counter-Revolution of Science*. In the note, Hayek appeals to the judgment of Pareto and Cournot, that the solution of a system of equations representing the conditions of general equilibrium would be practically infeasible. This is perhaps worth emphasising in view of the tendency of Hayek's modern supporters to play down the computational issue.

rational in the one case will be quite inappropriate in the other.

Prices *in themselves* provide adequate knowledge for rational calculation only if they are at their long-run equilibrium levels, but of course for Hayek they never are. On this point it is useful to refer back to Hayek's own theory of the trade cycle (Hayek, 1935; see also Lawlor and Horn, 1992; Cottrell, 1994), in which the 'misinformation' conveyed by disequilibrium prices can cause very substantial macroeconomic distortions. In Hayek's cycle theory, the disequilibrium price that can do such damage is the rate of interest, but clearly the same sort of argument applies at the micro level too. Decentralised profit-maximising responses to unsustainable prices for tin or RAM chips are equally capable of generating misinvestment and subsequent chaos.

At minimum, prices may be said to carry information regarding the terms on which various commodities may currently be exchanged, via the mediation of money (so long as markets clear, which is not always the case). It does not follow, however, that a knowledge of these exchange ratios enable agents to calculate the profitability, let alone the social usefulness, of producing various commodities. A commodity can be produced at profit if its price exceeds the sum of the prices of the inputs required to produce it, using the production method which yields the least such sum, but the use of current prices in this calculation is legitimate only in a static context: either prices are unchanging or production and sale take zero time. Hayek, of course, stresses constant change as the rule, so he is hardly in a position to entertain this sort of assumption. Whether production of commodity x will in fact prove profitable or not depends on future prices as well as current prices. And whether production of x currently appears profitable depends on current expectations of future prices.

If we start from the assumption that prices will almost certainly not remain unchanged in future, how are agents supposed to form their expectations? One possibility is that they are able to gather sufficient relevant information to make a definite forecast of the changes that are likely to occur. This clearly requires that they know much more than just current prices. They must know the process whereby prices are formed, and form forecasts of the evolution of the various factors (at any rate, the more important of them) that bear upon price determination. Hayek's informational minimalism is then substantially breached. A second possibility is that described by Keynes (1936, esp. chapter 12): agents are so much in the dark on the future that, although they are sure that some (unspecified) change will occur, they fall back upon the convention of assuming that tomorrow's prices will equal today's. This enables them to form a conventional assessment of the profitability of producing various commodities, using current price information alone; but the cost of this approach (from the standpoint of a defender of the efficiency of the market) is the recognition that those *ex ante* assessments will be regularly and perhaps substantially wrong.

6.1 Prices, efficiency and 'know how'

It is one of the progressive features of capitalism that the process of competition forces some degree of convergence upon least-cost methods of production (even if the cost in question is monetary cost of production, which reflects social cost in a partial and distorted manner). Hayek reminds us, and rightly so, that this convergence may in fact be far from complete. Firms producing the same commodity (and perhaps even using the same basic technology) may co-exist for extended periods despite having quite divergent costs of pro-

duction. If the law of one price applies to the products in question, the less efficient producers will make lower profits and/or pay lower wages. This situation can persist provided the mobility of capital and labour are less than perfect.

The question arises whether convergence on best practice could be enforced more effectively in a planned system. We believe this is so. If all workers are paid at a uniform rate for work done, it will be impossible for inefficient producers to mask their inefficiency by paying low wages. Indeed, with the sort of labour-time accounting system we have advocated elsewhere (Cockshott and Cottrell, 1989, 1993), differentials in productive efficiency will be immediately apparent. Not only that, but there should be a broader range of mechanisms for eliminating differentials once they are spotted. A private firm may realise that a competitor is producing at lower cost, but short of industrial espionage may have no way of finding out how this is achieved. Convergence of efficiency, if it is attained at all, may have to wait until the less efficient producer is driven out of business and its market share usurped by more efficient rivals. In the context of a planned system, on the other hand, some of the managers or technical experts from the more efficient enterprises might, for instance, be seconded as consultants to the less efficient enterprises. One can also imagine—in the absence of commercial secrecy—economy-wide electronic bulletin boards on which the people concerned with operating particular technologies, or producing particular products, share their tips and tricks for maximising efficiency. The present popularity of this sort of thing amongst users of personal computers suggests that it might easily be generalised.

7 information flows under market and plan

One of Hayek's most fundamental arguments is that the efficient functioning of an economy involves making use of a great deal of distributed information, and that the task of centralising this information is practically impossible. In what follows we attempt to put this argument to a quantitative test. We compare the communications costs implicit in a market system and a planned system, and examine how the respective costs grow as a function of the scale of the economy. Communications cost is a measure of work done to centralise or disseminate economic information: we will use the conceptual apparatus of algorithmic information theory (Chaitin, 1982) to measure this cost.

Our strategy is first to consider the dynamic problem of how fast, and with what communications overhead, an economy can converge on equilibrium. We will demonstrate that this can be done faster and at less communications cost by the planned system. We consider initially the dynamics of convergence on a fixed target, since the control system with the faster impulse response will also be faster at tracking a moving target.

Consider an economy $E = [\mathbf{A}, \mathbf{c}, r, w]$ with n producers each producing distinct products under constant returns to scale using technology matrix \mathbf{A} , with a well defined vector of final consumption expenditure \mathbf{c} that is independent of the prices of the n products, an exogenously given wage rate w and a compatible rate of profit r . Then there exists a possible Sraffian equilibrium $e = [\mathbf{U}, \mathbf{p}]$ where \mathbf{U} is the commodity flow matrix and \mathbf{p} a price vector. We will assume, as is the case in commercial arithmetic, that all quantities are expressed to some finite precision rather than being real numbers. How much information is required

to specify this equilibrium point?

Assuming that we have some efficient binary encoding method and that $I(s)$ is a measure in bits of the information content of the data structure s using this method, then the equilibrium can be specified by $I(e)$, or, since the equilibrium is in a sense given in the starting conditions, it can be specified by $I(E) + I(p_s)$ where p_s is a program to solve an arbitrary system of Sraffian equations. In general we have $I(e) \leq I(E) + I(p_s)$. In the following we will assume that $I(e)$ is specified by $I(E) + I(p_s)$.

Let $I(x|y)$ be the conditional or relative information (Chaitin, 1982) of x given y . The conditional information associated with any arbitrary configuration of the economy, $k = [\mathbf{U}_k, \mathbf{p}_k]$, may then be expressed relative to the equilibrium state, e , as $I(k|e)$. If k is in the neighbourhood of e we should expect that $I(k|e) \leq I(k)$. For instance, suppose that we can derive \mathbf{U}_k from \mathbf{A} and an intensity vector \mathbf{u}_k which specifies the rate at which each industry operates then

$$I(k|e) \leq I(\mathbf{u}_k) + I(\mathbf{p}_k) + I(p_u)$$

where p_u is a program to compute \mathbf{U}_k from some \mathbf{A} and some \mathbf{u}_k . Since \mathbf{U}_k is a matrix and \mathbf{u}_k a vector, each of scale n , we can assume that $I(\mathbf{U}_k) > I(\mathbf{u}_k)$.

As the economy nears equilibrium the conditional information required to specify it will shrink, since \mathbf{u}_k starts to approximate to \mathbf{u}_e .⁶ Intuitively we only have to supply the difference vector between the two, and this will require less and less information to encode, the smaller the distance between \mathbf{u}_k and \mathbf{u}_e . A

⁶Note that this information measure of the distance from equilibrium, based on a sum of logarithms, differs from a simple Euclidean measure, based on a sum of squares. The information measure is more sensitive to a multiplicity of small errors than to one large error. Because of the equivalence between information and entropy it also measures the conditional entropy of the system.

similar argument applies to the two price vectors \mathbf{p}_k and \mathbf{p}_e . If we assume that the system follows a dynamic law that causes it to converge on equilibrium then we should have the relation $I(k_{t+1}|e) < I(k_t|e)$.

We now construct a model of the amount of information that has to be transmitted between the producers of a market economy in order to move it towards equilibrium. We make the simplifying assumptions that all production process take one timestep to operate, and that the whole process evolves synchronously. We assume the process starts just after production has finished, with the economy in some random non-equilibrium state. We further assume that each firm starts out with a given selling price for its product. Each firm i carries out the following procedure.

1. It writes to all its suppliers asking them their current prices.
2. It replies to all price requests that it gets, quoting its current price \mathbf{p}_i .
3. It opens and reads all price quotes from its suppliers.
4. It estimates its current per-unit cost of production.
5. It calculates the anticipated profitability of production.
6. If this is above r it increases its target production rate \mathbf{u}_i by some fraction. If profitability is below r a proportionate reduction is made.
7. It now calculates how much of each input j is required to sustain that production.
8. It sends off to each of its suppliers j , an order for amount \mathbf{U}_{ij} of their product.
9. It opens all orders that it has received and
 - (a) totals them up.
 - (b) If the total is greater than the available product it scales down each order proportionately to ensure that what it can supply is fairly distributed among its customers.

- (c) It dispatches the (partially) filled orders to its customers.
 - (d) If it has no remaining stocks it increases its selling price by some increasing function of the level of excess orders, while if it has stocks left over it reduces its price by some increasing function of the remaining stock.
10. It receives all deliveries of inputs and determines at what scale it can actually proceed with production.
 11. It commences production for the next period.

Experience with computer models of this type of system indicates that if the readiness of producers to change prices is too great, the system could be grossly unstable. We will assume that the price changes are sufficiently small to ensure that only damped oscillations occur. The condition for movement towards equilibrium is then that over a sufficiently large ensemble of points k in phase space, the mean effect of an iteration of the above procedure is to decrease the mean error for each economic variable by some factor $0 \leq g < 1$. Under such circumstances, while the convergence time in vector space will clearly follow a logarithmic law—to converge by a factor of D in vector space will take time of order $\log_{\frac{1}{g}}(D)$ —in information space the convergence time will be linear. Thus if at time t the distance from equilibrium is $I(k_t|e)$, convergence to within a distance ϵ will take a take a time of order

$$\frac{I(k_t|e) - \epsilon}{\delta \log(\frac{1}{g})}$$

where δ is a constant related to the number of economic variables that alter by a mean factor of g each step. The convergence time in information space, for small ϵ , will thus approximate to a linear function of $I(k|e)$ which we can write as $\Delta I(k|e)$.

We are now in a position to express the communications costs of reducing the conditional

entropy of the economy to some level ϵ . Communication takes place at steps 1, 2, 8 and 9c of the procedure. How many messages does each supplier have to send, and how much information must they contain?

Letters through the mail contain much redundant pro forma information: we will assume that this is eliminated and the messages reduced to their bare essentials. The whole of the pro forma will be treated as a single symbol in a limited alphabet of message types. A request for a quote would thus be the pair $[R, H]$ where R is a symbol indicating that the message is a quotation request, and H the home address of the requestor. A quote would be the pair $[Q, P]$ with Q indicating the message is a quote and P being the price. An order would similarly be represented by $[O, \mathbf{U}_{ij}]$, and with each delivery would go a dispatch note $[N, U_{ij}]$ indicating the actual amount delivered, where $U_{ij} \leq \mathbf{U}_{ij}$.

If we assume that each of n firms has on average m suppliers, the number of messages of each type per iteration of the procedure will be nm . Since we have an alphabet of message types (R, Q, O, N) with cardinality 4, these symbols can be encoded in 2 bits each. We will further assume that $(H, P, \mathbf{U}_{ij}, U_{ij})$ can each be encoded in binary numbers of b bits. We thus obtain an expression for the communications cost of an iteration of $4nm(b + 2)$. Taking into account the number of iterations, the cost of approaching the equilibrium will be $4nm(b + 2)\Delta I(k|e)$.

Let us now contrast this with what would be required in a planned economy. Here the procedure involves two distinct procedures, that followed by the (state-owned) firm and that followed by the planning bureau. The firms do the following:

1. In the first time period:
 - (a) They send to the planners a message listing their address, their technical in-

put coefficients and their current output stocks.

- (b) They receive instructions from the planners about how much of each of their output is to be sent to each of their users.
 - (c) They send the goods with appropriate dispatch notes to their users.
 - (d) They receive goods inward, read the dispatch notes and calculate their new production level.
 - (e) They commence production.
2. They then repeatedly perform the same sequence replacing step 1a with:
- (a) They send to the planners a message giving their current output stocks.

The planning bureau performs the complementary procedure:

- 1. In the first period:
 - (a) They read the details of stocks and technical coefficients from all of their producers.
 - (b) They compute the equilibrium point e from technical coefficients and the final demand.
 - (c) They compute a turnpike path (Dorfman, Samuelson and Solow, 1958) from the current output structure to the equilibrium output structure.
 - (d) They send out for firms to make deliveries consistent with moving along that path.
- 2. In the second and subsequent periods:
 - (a) They read messages giving the extent to which output targets have been met.
 - (b) They compute a turnpike path from the current output structure to the equilibrium output structure.
 - (c) They send out for firms to make deliveries consistent with moving along that path.

We assume that with computer technology the steps b and c can be undertaken in a time that is small relative to the production period (Cockshott 1990, Cockshott and Cottrell 1993).

Comparing the respective information flows, it is clear that the number of orders and dispatch notes sent per iteration is invariant between the two modes of organisation of production. The only difference is that in the planned case the orders come from the center whereas in the market they come from the customers. These messages will again account for a communications load of $2nm(b+2)$. The difference is that in the planned system there is no exchange of price information. Instead, on the first iteration there is a transmission of information about stocks and technical coefficients. Since any coefficient takes two numbers to specify, the communications load per firm will be: $(1+2m)b$. For n firms this approximates to the $nm(b+2)$ that was required to communicate the price data.

The difference comes on subsequent iterations, where, assuming no technical change, there is no need to update the planners' record of the technology matrix. On $i-1$ subsequent iterations, the planning system has therefore to exchange only about half as much information as the market system. Furthermore, since the planned economy moves on a turnpike path to equilibrium, its convergence time will be less than that of the market economy. The consequent communications cost is $2nm(b+2)(2+(i-1))$ where $i < \Delta I(k|e)$.

The consequence is that, contrary to Hayek's claims, the amount of information that would have to be transmitted in a planned system is substantially lower than for a market system. The centralised gathering of information is less onerous than the commercial correspondence required by the market. In addition, the convergence time of the market system is slower. The implication of faster convergence

for adaptation to changing rather than stable conditions of production and consumption are obvious.

In addition, it should be noted that in our model for the market, we have ignored any information that has to be sent around the system in order to make payments. In practice, with the sending of invoices, cheques, receipts, clearing of cheques etc., the information flow in the market system is likely to be twice as high as our estimates. The higher communications overheads of market economies are reflected in the numbers of office workers they employ, which in turn leaves its mark on the architecture of cities—witness the skylines of Moscow and New York.

8 the argument from dynamics

Does Hayek's concentration on the dynamic aspect of prices, price as a means of dynamically transmitting information, make any sense?

In one way it does. Consider the price of a cup of coffee. Notionally this can be written in a couple of digits—80 pence, say—which would imply that on information theoretic grounds it transmits about 7 bits of information. But look more closely, and this is almost certainly an overestimate. Not only is the price likely to be rounded up to the nearest 5 pence, implying an information content of about 5 bits, but yesterday's price was probably the same. If the price changes only once a year, then for 364 days the only information that it conveys is that the price has not changed. The information content of this, $-\log_2 \frac{364}{365}$, is about 0.0039 of a bit. Then when the price does change its information content is $-\log_2 \frac{1}{365} + b$ where b is the number of bits to encode the price increase. For a reasonable

value of the increase, say 10 pence, the whole amounts to some 12 bits. So on the day the price changes, it conveys some 3000 times as much information as it did every other day of the year.

So it is almost certainly true that most of the information in a price series is encoded in the price changes. From the standpoint of someone observing and reacting to prices, the changes are all important. But this is a viewpoint internal to the dynamics of the market system. One has to ask if the information thus conveyed has a more general import. The price changes experienced by a firm in a market economy can arise from many different causes, but we have to consider which of these represent information that is independent of the social form of production.

We can divide the changes into those that are direct results of events external to the price system, and those which are internal to the system. The discovery of new oil reserves or an increase in the birth rate would directly impinge upon the price of oil or of baby clothes. These represent changes in the needs or production capabilities of society, and any system of economic regulation should have means of responding to them. On the other side, we must count a fall in the price of acrylic feedstocks and a fall in the price of acrylic sweaters, among the second- and third-order internally generated changes consequent upon a fall in oil prices. In the same category would go the rise in house prices that follows an expansion of credit, any fluctuation in share prices, or the general fall in prices that marks the onset of a recession. These are all changes generated by the internal dynamics of a market system, and as such irrelevant to the consideration of non-market economies.

Hayek is of course right that the planning problem is greatly simplified if there are no changes, but it does not follow from this that all the changes of a market economy are po-

tential problems for a planned one. We have demonstrated elsewhere that the problem of computing the appropriate intensities of operation of all production processes, given a fully disaggregated input–output matrix and a target final output vector, is well within the capacity of computer technology. The compute time required is sufficiently short for a planning authority, should it so wish, to be able to perform the operation on a daily basis. In performing this calculation the planners arrive at the various scales of production that the market economy would operate at were it able to attain general equilibrium. Faced with an exogenous change, the planners can compute the new equilibrium position and issue directives to production units to move directly to it. This direct move will involve the physical movement of goods, laying of foundations, fitting out of buildings etc, and will therefore take some considerable time.

We now have two times, the time of *calculation* and the time of *physical adjustment*. If we assume that the calculation is performed with an iterative algorithm, we find that in practice it will converge acceptably within a dozen iterations. Since each of these iterations would take a few minutes on a supercomputer the overall time would probably be under an hour. In a market economy, even making the most favourable assumptions about its ability to adjust stably to equilibrium, the individual iterations will take a time proportional to the physical adjustment time. The overall relaxation period would be around a dozen times as long as that in the planned system.

But of course these assumptions are unrealistically favourable to the market system. Long before equilibrium was reached, new external shocks would have occurred. Even the assumption that the system seeks equilibrium is questionable. There is every reason to believe that far from having stable dynamics, it is liable to oscillatory or chaotic behaviours.

Hayek is to be commended on his ability to make the best of a bad case, to make virtues out of necessities. The unavoidable instabilities of the market are disguised as blessings. The very crudity of prices as an information mechanism are seen as providentially protecting people from information overload.

9 conclusion: evolution and history

Hayek contrasts the ‘spontaneously evolved’ price system with the artificiality of conscious attempts to control the economic process, a contrast that he feels is to the disadvantage of the latter. At best, this is no more than the maxim that one is better to ‘hold tightly onto nurse for fear of meeting something worse’. At worst it degenerates into a Panglossian complacency about the existing order of things. Voltaire’s rejoinder on earthquakes—these too are spontaneous—is apposite. But while we can hope to do no more than forecast earthquakes, it fallacious to think that we are forced endure their economic equivalent with the same stoicism.

By writing of spontaneous evolution, Hayek surreptitiously slips in connotations from biology, with its associations of fitness of form to function. But the analogy of a market economy with a naturally evolved order is superficial, with regard both to its operation and genesis. If we consider the operation of a market economy as the procedural search for an optimum, it obvious that while there is a great deal of parallelism going on—lots of people making decisions at the same time—it remains the case that the whole search is single-threaded. Taken as a whole, the state space of the economy is a Cartesian product of the state spaces of its components, and within this total state space the economy is located at a unique point

at every moment in time. As such, it can only visit a small proportion of the possible set of solutions, and for it to progress towards anything other than a local optimum presupposes a particular and very simple topology to the space.

In this sense, the movement of a market economy differs from the process of biological evolution. A species evolves towards increasing adaptation to its environment by a highly parallel process. The state space in this case consists of the genetic code. But a species is not in one position in this space at any one time: it is at as many positions as there are individual members of the species, each with a unique combination of genes. A species represents a neighbourhood in gene space. It applies a parallel search procedure: millions of alternative designs are produced and compared each generation. Although a market economy can to some extent emulate this in the area of product development within individual competitive markets, the economy as a whole acts as a single processor.

It is equally invalid to treat the genesis of the capitalist world system as an evolutionary outcome. It is an historical outcome, but history and evolution are not the same thing. Evolutionary adaptation is impossible without variation, competition and selection. To apply evolutionary concepts one would have to hypothesise a substantial population of simultaneously existing international economic systems. In fact there is only one. For a while there were two, of which only one has survived. That is not a statistically valid sample. To say that one economic order was evolutionarily better adapted than another, one would need a large enough ensemble for stochastic effects to cancel out—an ensemble including instances where the market system was restricted to one poor and backward economy surrounded by an industrialised socialist world.

The logic of the analogy with evolution, con-

tra Hayek, is to let a hundred flowers bloom.

References

- Althusser, L. (1971).** ‘Ideology and ideological state apparatuses’. In *Lenin and Philosophy and Other Essays*. London: NLB.
- Chaitin, G. J. (1982).** ‘Algorithmic information theory’. In *Encyclopedia of Statistical Sciences*, vol. 1. New York: Wiley, pp. 38–41.
- Cockshott, W. P. (1990).** ‘Application of artificial intelligence techniques to economic planning’. *Future Computing Systems*, vol. 2, pp. 429–43.
- Cockshott, W. P. and Cottrell, A. (1989).** ‘Labour value and socialist economic calculation’. *Economy and Society*, vol. 18, pp. 71–99.
- Cockshott, W. P. and Cottrell, A. (1993).** *Towards a New Socialism*. Nottingham: Spokesman.
- Cottrell, A. (1994).** ‘Hayek’s early cycle theory re-examined’. *Cambridge Journal of Economics*, vol. 18, 197–212.
- Cottrell, A. and Cockshott, W. P. (1993a).** ‘Calculation, complexity and planning: the socialist calculation debate once again’. *Review of Political Economy*, vol. 5, pp. 73–112.
- Cottrell, A. and Cockshott, W. P. (1993b).** ‘Socialist planning after the collapse of the Soviet Union’. *Revue Européenne des Sciences Sociales*, vol. 31, pp. 167–185.
- Dawkins, R. (1982).** *The Extended Phenotype*. Oxford: Oxford University Press.
- Dennett, D. C. (1991).** *Consciousness Explained*. Boston: Little, Brown.
- Dorfman, R., Samuelson, P. A., and Solow, R. M. (1958).** *Linear Programming and Economic Analysis*. New York: McGraw Hill.

- Gibbs, W. W. (1994).** ‘Software’s chronic crisis’. *Scientific American*, vol. 271, pp. 86–95.
- Hayek, F. A. (1935).** *Prices and Production*, revised edition. London: Routledge.
- Hayek, F. A. (1945).** ‘The use of knowledge in society’. *American Economic Review*, vol. 35, pp. 519–30.
- Hayek, F. A. (1955).** *The Counter-Revolution of Science*. New York: The Free Press.
- Keynes, J. M. (1936).** *The General Theory of Employment, Interest and Money*. London: Macmillan.
- Lavoie, D. (1985).** *Rivalry and Central Planning: The Socialist Calculation Debate Reconsidered*. Cambridge: Cambridge University Press.
- Lawlor, M.S. and Horn, B.L. (1992).** ‘Notes on the Sraffa–Hayek Exchange’, *Review of Political Economy*, vol 4.
- Lawson, T. (1992).** ‘Realism and Hayek: a case of continuous transformation’, mimeo, University of Cambridge.
- Mises, L. (1949).** *Human Action: A Treatise on Economics*. New Haven: Yale University Press.
- Nove, A. (1977).** *The Soviet Economic System*. London: George Allen and Unwin.
- Nove, A. (1983).** *The Economics of Feasible Socialism*. London: George Allen and Unwin.
- Shannon, C. E., and Weaver, W. (1949).** *The Mathematical Theory of Communication*. Urbana, Ill.: University of Illinois.