THE ENVIRONMENTAL IMPACTS OF TECHNICAL CHANGE

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The thesis is concerned with relationships between profit, technology and environmental change. Existing work has concentrated on only a few questions, treated at either micro or macro levels of analysis. And there has been something of an impasse since the neoclassical and neomarxist approaches are either in direct conflict (macro level), or hardly interact (micro level). The aim of the thesis was to bypass this impasse by starting to develop a meso level of analysis that focusses on issues largely ignored in the traditional approaches - on questions about distribution.

The first questions looked at were descriptive - what were the patterns of distribution over time of the variability in types and rates of environmental change, and in particular, was there any evidence of periodization? Two case studies were used to examine these issues. The first looked at environmental change in the iron and steel industry since 1700, and the second studied pollution in five industries in the basic processing sector. It was established that environmental change has been markedly periodized, with an apparently fairly regular 'cycle length' of about fifty years.

The second questions considered were explanatory - whether and how this periodization could be accounted for by reference to variations in aspects of profitability and technical change. In the iron and steel industry, it was found that diffusion rates and the rate and nature of innovations were periodized on the same pattern as was environmental change. And the same sort of variation was also present in the realm of profits, as evidenced by cyclical changes in output growth. Simple theoretical accounts could be given for all the empirically demonstrable links, and it was suggested that the most useful models at this meso level of analysis are provided by structural change models of economic development.

ENVIRONMENT TECHNOLOGY PROFIT

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Chapter 1: Approaches to the role of technology in environmental change

1A INTRODUCTION

In general terms, this thesis is concerned with the role of technology in producing patterns of environmental change.[1] Relevant to this concern is a large body of literature dealing with relations between 'man' and nature - an interaction in which technology plays an important part. However, this literature is made up of several different strands, only one of which is particularly important to the thesis. The others are mentioned in order to provide a context, and so as to make explicit the main areas of thought that, although relevant, are not being considered.

The first distinction we can draw is between those works which see technological change itself as being causal, and those which see it as a factor that mediates the relationships.[2] The first position covers the 'autonomous technology' or 'technology-gone-wild' tradition, in which the development of science and technology is seen as responding to its own internal logic or teleology. Though much of this work concerns the influences of technological change on human social relations, there are some authors in this tradition who have also tried to draw out the systematic implications for the environment.[3]

The second position covers a number of separable strands. We can distinguish particularly between those works which locate the causal nexus in aspects of human nature and those which locate

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[1] Environmental change can be seen as being either essentially random, or as conforming to some sort of patterns. The latter view is a basic assumption of the thesis. The former would lead to no analysis at all.

[2] In practice, things are not this black and white. Rather, it is a question of degrees of causal primacy.

[3] For a review, see L Winner (ref: 52).

it in aspects of material reality.[4] Where human nature is seen as being the most important causal factor, we are usually referred to 'universal' aspects, such as 'instrumental rationality'. Under the compulsion of our own nature, we try to exert control over the laws and processes of nature in order to manipulate them for specific human purposes. Science and technology are seen as particular manifestations of this rationality, in contrast, say, to animistic religion. The argument generally continues to the effect that the sort of technological development engendered by this rationality tends to be antagonistic to the natural, self-regulation of ecosystems, and, on balance, is therefore environmentally harmful. Although found as an argument in a great deal of writing, the most detailed exposition is given by Critical Theory.[5]

Where causality is located in aspects of reality other than human consciousness, social structure and social relations are the key concepts. By far the majority of these works focus on capitalism or aspects of capitalism when looking for social structural forces which, when mediated by technological change, tend to produce systematic patterns in environmental outcomes. Within this literature, it is those focussing particularly on profits that are of special importance to the thesis, and which are discussed in greater detail in Section B below.

Before going on, however, we should also mention a second, and recently emerged strand of social structural analysis. This is feminist work, in which gender relations are seen as being of prime importance, rather than class relations, and in which the key causal concept is patriarchy, rather than capitalism.[6]

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[4] Again, the distinction really revolves around degrees of causal importance. Both traditions allow for the interplay between consciousness and material reality.

[5] See particularly W Leiss (ref: 34).

[6] See, for example, S Griffin (ref: 18).

1B TRADITIONAL APPROACHES

The underlying objective of the thesis is a response to what are seen as limitations of the traditional approaches to relations between profits, technology and environmental change. In this section, those approaches are characterised, their limitations are identified and the basic aim of the thesis is stated.

When looking at relationships between these three elements, the central empirical fact which acts as the starting point is variability in outcomes. Whether talking about pollution levels or rates of resource use, we can readily point to both increases and decreases. This observable variability gives rise to a number of theoretical issues, and the relevant literature focusses on two of these.

First of all, the immediate question to arise is how these contrasting outcomes result from technological change that is oriented towards maximising profits.[7] Why does this objective sometimes lead to increases in pollution, say, and sometimes to decreases?

The second issue concerns the social evaluation of these changes. Clearly, not all increases in resource use or pollution are 'bad', since they may result from the introduction of technologies which give rise to social benefits that more than compensate. Equally,

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[7] The idea that the main objective of the firm is to maximise profits is one which has received much criticism, but it is broadly accepted here. Many of the alternatives put forward can be seen either as specific profit-maximising strategies, or as more limited goals that can be subsumed within a broad, profit-maximising objective. Such goals include cost-minimisation, maximising the rate of turnover and maximising market share. And many of the other alternatives put forward can be seen as attempts to secure maximum profits in the long run, rather than, and possibly conflicting with short term profit-maximisation. These objectives include corporate growth, securing control over sources of material inputs and maintaining trouble-free relationships, with both the consumer and the labour force.

not all reductions are necessarily 'good'. Whatever definition of social welfare we use, all commentators accept that, in reality, technological change in the service of profit gives rise to a mixture of good and bad outcomes. And the question that has received particular attention is whether there is any general, underlying bias.

There are two main bodies of work that relate to these issues. They are referred to as neoclassical and neomarxist on the basis of their roots in more general political economic theory. The essences of these traditions are characterised in turn below.

(B1) Neoclassical Positions

Much of the work in this tradition was carried out in the late 1960s and early 1970s, and, in general, it can be seen as a response to the rising tide of environmental consciousness and concern, especially in the United States. More particularly, it represents an attempt to refute the criticism that mainstream economic theory was unable to deal with environmental issues. And, as such, the tradition developed a strong theoretical base, a base that can be seen as a specific application of the more general framework of neoclassical welfare economics.

Accordingly, the central explanatory model refers to individual 'actors' who try to maximise their own self-interest in conditions that are given from the outside. Under the assumptions of perfect competition, their behaviour can be accurately predicted.[8] To illustrate the use of the model, we consider changes in the level of pollution produced by a firm per unit of output. Figure 1.1 below demonstrates procedures used to determine whether pollution levels increase or decrease, and by how much.

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[8] For a full list of these assumptions, reference should be made to a general economics text (see, for example, B J McCormick, ref: 37, pp 320-322). Environmental economics texts often give a less than complete list (see, for example, A Kneese et al, ref: 33, p 66).

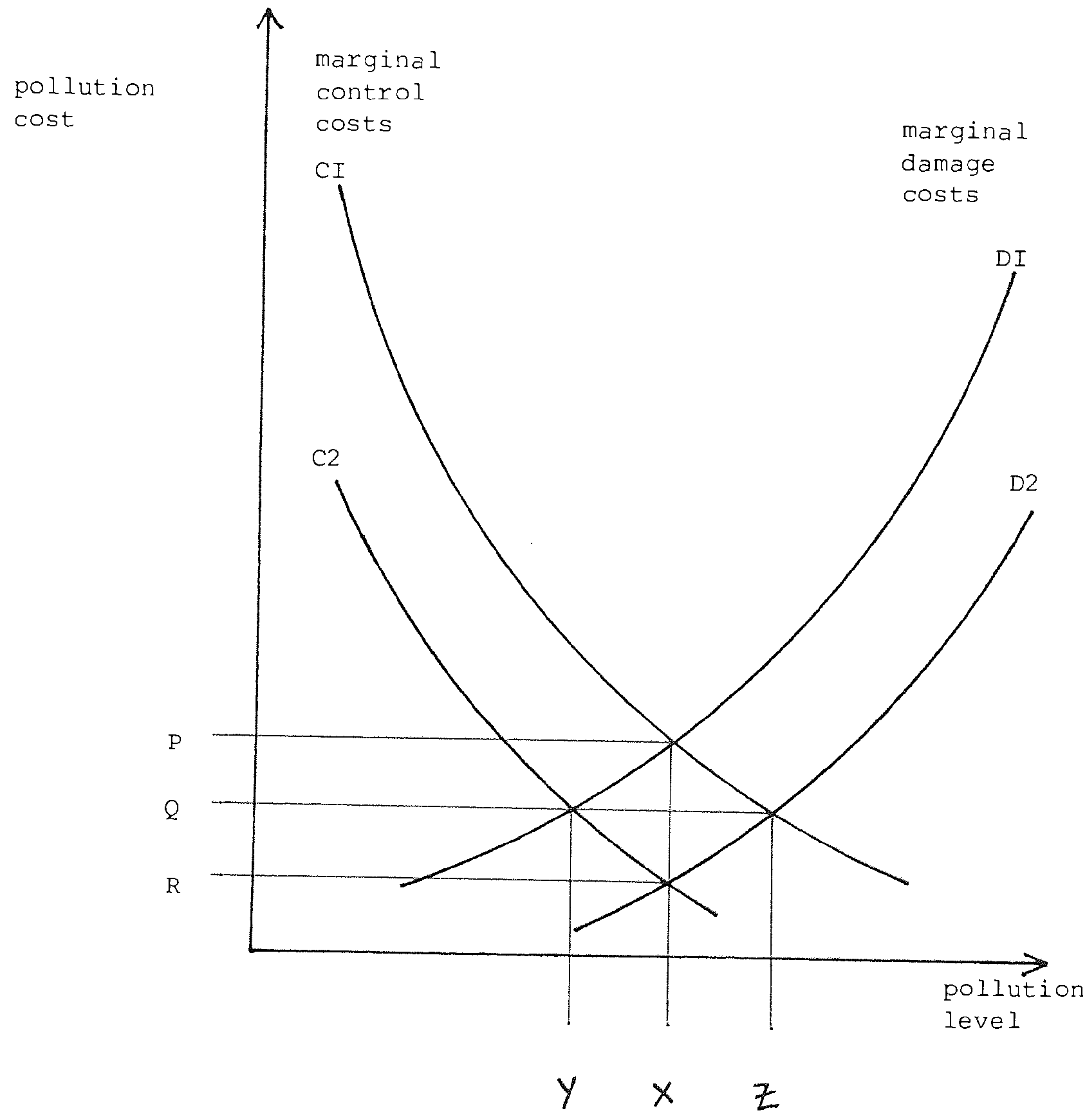

Figure 1.1 - Changing levels of pollution produced by the firm

For any given level of pollution, the total costs to the firm can be divided into damage and control costs. In both cases, the marginal cost curves are assumed to be positive[9] - ie each extra unit of pollution produced is assumed to result in more damage (and greater cost), and control costs are assumed to increase with successive unit reductions in pollution levels. Total pollution costs are least when marginal damage and marginal control costs are equal - at the intersection of the two cost curves.

In an initial equilibrium state, the cost curves facing the firm are given by C1 and D1. At the least cost point, the firm produces X amount of pollution per unit of output, at a total cost P(x2). For any reason, either or both of the cost curves facing the firm may change. If the control cost curve changes to C2, a new least-cost equilibrium point will emerge, where C2 intersects D1. In moving to this new position, the total pollution costs of the firm will fall from P to Q, and the level of pollution produced will fall from X to Y. If the damage cost curve changes to D2, but the control cost curve remains at C1, the least-cost equilibrium will also reduce total pollution costs from P to Q, but will increase levels of pollution from X to Z. If both cost curves change, the least-cost equilibrium point will be the intersection of the curves C2 and D2. At this point the total pollution costs facing the firm will be reduced still further to R, but the level of pollution produced will be the same as it was in the initial equilibrium - ie X.

Each of these three changes mean that the firm has to alter its production strategy in order to continue to make maximum profits. One of these profit-maximising moves results in decreasing pollution levels, one in increasing pollution levels and the third in no change

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[9] This is always the case in theory, though there is some debate about the shape of the curves in practice. See, for example, P Burrows (ref: 7, pp 34-40).

at all. Any particular outcome can be explained by reference to the model, and the observable variability in outcomes can therefore be accounted for.

In this illustration, the changes in the cost environment facing the firm are seen as being given from the outside. Any technical change that is necessary in order to move to the new profit-maximising position is therefore adaptive. But innovation is often part of an aggressive strategy to try and gain an advantage over competitors, rather than part of a responsive package. In the context of Figure 1.1, however, this would make no difference, either to the objectives of technical change - the reduction of damage costs, control costs or both, or to the pollution impacts that might result - increase, decrease or no change in unit pollution levels. The observable variability in outcomes can therefore be accounted for, irrespective of whether technical change is seen as part of an active strategy for gaining competitive advantage, or as a response to changing conditions that is necessary to firms simply in order to stay in business.

Figure 1.1 has been used to illustrate the basic nature of the neoclassical micro level models, but there are others, operating on similar principles, that are now reviewed here. First of all, in the 'cost/cost' formulation in Figure 1.1, the level of pollution by the firm is given by the 'Pareto' efficient position. But there are other criteria for efficiency, such as 'Potential Pareto', and there are other formulations such as 'cost/benefit' or 'benefit/benefit'.[10] Secondly, whilst Figure 1.1 relates to pollution levels, very similar models are used to theoretically determine the most efficient rates of resource use.[11] Thirdly, the individual actor considered in Figure 1.1 is the producer. Also relevant is the behaviour of consumers, which is predicted under the same assumptions, by the use of indifference curves rather than cost curves.

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[10] For a discussion of these alternatives, see D Pearce (ref: 39, Ch.1).

[11] See, for example, G Heal & P Dasgupta (ref: 21).

When we turn to consider the evaluation of environmental change, and, in particular, the balance between socially good and bad outcomes, we start by looking at a stable equilibrium under perfect competition assumptions. In this situation, the interests of producers trying to maximise profits and consumers trying to maximise utility will be perfectly balanced, and the total social welfare at maximum. The level of pollution produced by each individual firm will therefore be socially optimal as well as being the most profitable for the firm concerned. And, by aggregating over all producers, the mixture of different levels of the various pollutants produced will also be the optimum for society as a whole.

Disequilibrium may arise because of localised disruption in a single market, and the mix of environmental outcomes would then become sub-optimal. Adjustments by relevant producers and consumers to maximise their private profits/utility would, in these circumstances, lead to the restoration of an equilibrium that maximised total social welfare. The mix of environmental outcomes would again become socially optimal, and the changes resulting from private profit maximisation could be evaluated unequivocably as improvements from the social viewpoint.

In reality, of course, the conditions for perfect competition do not hold. Disruptions occur in many rather than single markets, and are widespread rather than localised. Under these circumstances, it is accepted that the mix of environmental outcomes produced is not the social optimum. And private profit-maximising changes no longer necessarily represent social improvements.[12] Those deviations from the conditions of perfect competition that are often cited as being responsible for a socially sub-optimal mix of environmental

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[12] And when the conditions of perfect competition do not hold, there is also a theoretical problem in trying to specify what is the 'second best' mix of environmental outcomes. In turn, this means that there is no single, simple yardstick against which particular outcomes can be measured to determine whether or not they are socially beneficial changes.

outcomes include the following:[13]

a) The existence and functioning of monopolies

b) Imperfect ownership/lack of market values for some environmental resources

c) Production indivisibilities

d) Uncertainty about the future -resource prices, the direction of technological change, government policy, etc

e) Unequal bargaining power between producers and consumers.

However, these deviations tend to be seen as resulting from the imperfections of real world capitalism, rather than from its fundamental nature, and are, in this sense, marginal. If capitalism were to be perfected, then the conditions of perfect competition would be systematically reproduced, and private profit-maximising moves would result in environmental changes that were socially beneficial. And, in this sense, the traditional neoclassical approach holds that the basic nature of capitalism is conducive to producing socially beneficial environmental outcomes (even though, in the real world, the imperfections mean that actual outcomes are often not socially beneficial). This idea - that private profit-maximisation is potentially able to deliver environmental outcomes that are systematically socially beneficial - is found in a variety of forms in most of the neoclassical texts, one such form being as follows:

> "The problem is to get the state to price common resources (inputs and the waste assimilative capacity of the environment), then, once we have faced and solved the problem of common property resources, the profit motive can once again resume its role as the engine which drives the allocation of resources in the direction of social interests."
>
> A Kneese in relation to environmental problems in general (Ref: 53, p 224).

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[13] Not all of these deviations are held to consistently result in excessive levels of pollution or rates of resource use. For example, monopolies are generally seen as using resources too slowly, and, by some authors, are seen as producing pollution levels that are too low. For discussions in relation to resource use, see D Pearce (ref: 39, pp 147-155), and in relation to pollution, see P Burrows (ref: 7, chapter 2).

The 1980s has seen the development of another body of work which argues, in a different way, that private profit-maximisation could be associated with environmental changes that are generally socially beneficial. I refer to this as the 'pragmatic neoclassical' approach, in order to distinguish it from the works illustrated above, which have a strong theoretical bias.[14] It is pragmatic in the sense that it is oriented towards the real world, and especially towards managerial policy. However, it is still essentially neoclassical in that the terms and arguments relate easily to the micro-level models of the type shown in Figure 1.1 above. It lends support to the theoretical neoclassical assertion since it argues that, even though the costs of using environmental resources are not fully represented in the market, increasingly rational behaviour by private producers should result in environmental changes that are generally socially beneficial.

For various reasons, it is argued that the pollution damage costs facing firms tend to be greater in reality than is often assumed, whereas the benefits of pollution control are generally underestimated.[15] If producers acted in a fully rational way, not only would total pollution costs be reduced, and profits increased, but levels of pollution emitted would also be reduced towards socially optimal levels. The argument is illustrated in Figure 1.2 below, using the same cost/cost formulation as in Figure 1.1.

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[14] The original, influential work was 'Pollution prevention pays' by M Royston in 1979, detailing and explaining the profitable introduction of pollution abatement technologies by the 3M company. Since then, as well as a growing literature, the impetus has led to the setting up of a register of such technologies (the 'Compendium on low and non-waste technologies' - UN Economic Commission for Europe) and to competitions being organised in order to promote their development (the 'Pollution Abatement Technology Award Scheme', devised by the CBI).

[15] For a detailed exposition, see M Royston (ref: 44, Chs 3-7).

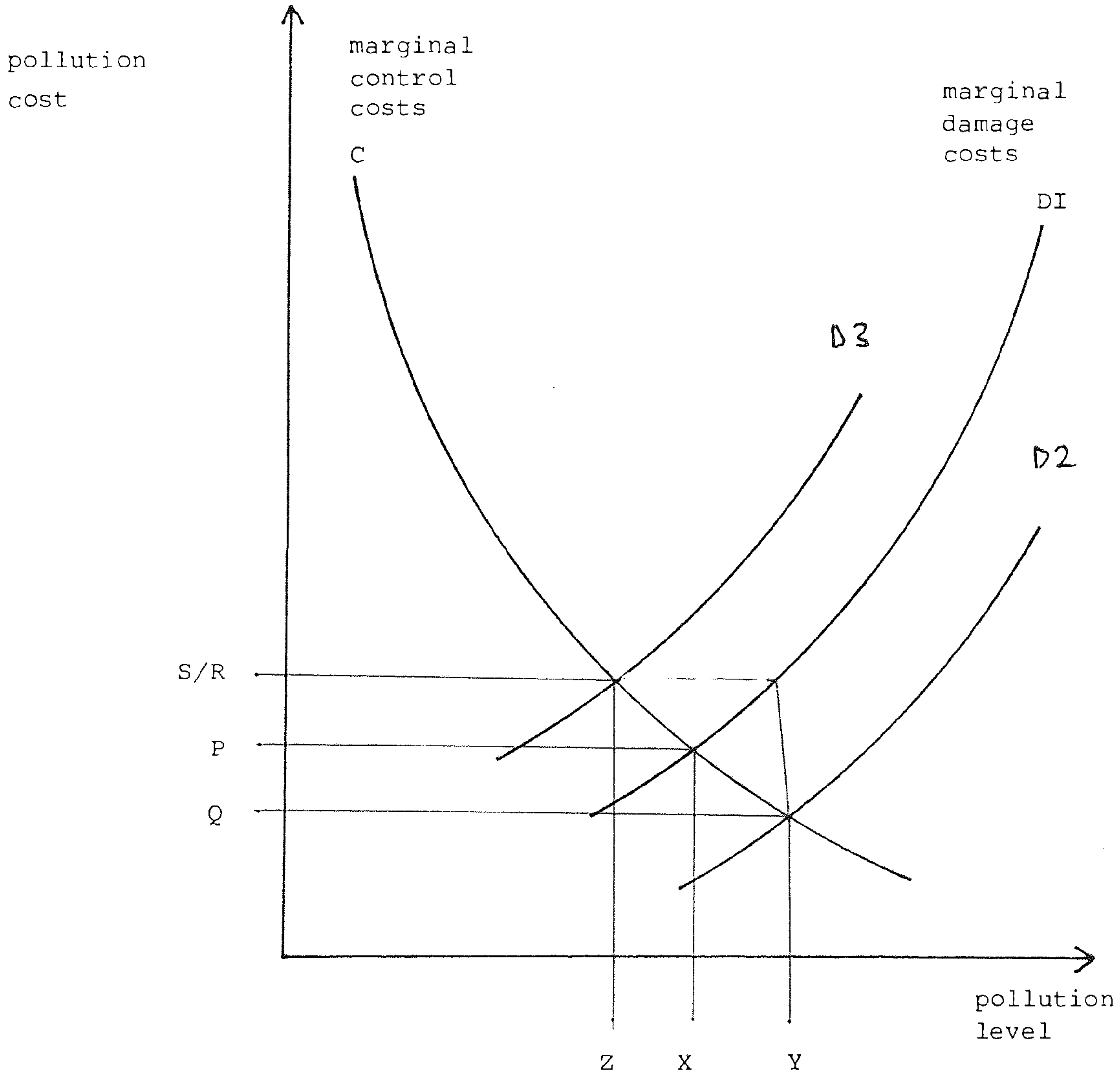

Figure 1.2 - Pollution prevention pays

The actual damage cost curve facing the producer is given above as D1, and, if acting fully rationally, production would be at the intersection of C and D1. The level of pollution emitted would be X, and total pollution cost would be P(x2). However, due to misperception on the part of management, the damage costs are assumed to be lower than they really are, and production takes place at the intersection of C and D2. At this point, the level of pollution emitted is Y, and total pollution costs are Q plus R, which is greater than P x 2. If the bias due to these misperceptions was removed, the profit-maximising adjustment would always involve reducing pollution levels.

Also, such changes would always be improvements, in the sense that they would be moves towards the theoretically given socially optimal pollution level. This is because other, real-world deviations from perfect competition conditions give rise to a bias towards excess pollution levels. This bias is shown above as the difference between X and Z, Z being the level of pollution which would be emitted if all remaining assumptions of perfect competition were met, and the damage cost curve was at the higher level of D3. In this case, the total pollution costs facing the firm would also be higher, at S x 2.

(B2) Neomarxist Positions

It is not so easy to succinctly characterise the neomarxist position since there is no central, theoretical model as there is in the neoclassical tradition. Marx himself did not deal explicitly with the issues being considered, and those who have tried to piece together his implicit views on man and nature have had to draw on widely scattered references.[16] Those works which are relevant to the issues of interest, and which can be seen collectively as representing a neomarxist tradition therefore vary considerably.[17]

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[16] See, for example, the work of A Schmidt (ref: 47).

[17] As regards how explicitly they are linked back to marxist theory, as regards the parts of marxist theory taken as key starting points and as regards the scope of the analysis defined on marxist dimensions (such as the political, economic and ideological 'spheres', or the 'interests' of capital, labour and the state).

However, the individual works are bound together, and the unifying factor is their opposition to the neoclassical assertions about the underlying macro level bias in relationships. The flavour of the neomarxist position is illustrated with the following quotations:

> "Environmental disruption cannot be seen as a case of market failure unless we mean the failure of the whole market allocative system."
>
> K W Kapp (ref: 53, p 86).

> "Much pollution abatement occurs in response to profits and growth, with no state intervention ... |but| ... the imperatives of the capitalist economy mean that the uptake of non-polluting, resource-conserving technologies is limited."
>
> F Sandbach (ref: 46, pp 10, 47).

> "The relation between increased profit and environmental deterioration is not accidental - the former is based on the latter."
>
> B Commoner (ref:10, p 15).

This macro level position, which is in direct conflict with the neoclassical one, is based on either one or both of two types of reasoning. First of all, it is often argued that the factors giving rise to, say, excess pollution levels, are not deviations away from the essential nature of capitalism (as enshrined in the assumptions of perfect competition). Rather, they themselves are seen as resulting from its inherent nature and development. The perfection of capitalism would give rise to a situation that conformed less closely, rather than more closely to the conditions of perfect competition. And private profit-maximisation would lead to a mix of environmental outcomes that is likely to be even less socially beneficial than at present. This sort of argument relates especially to the monopolisation of capital,[18] and to the fact that

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[18] For an analysis of the environmental implications, see eg A Schnaiberg (ref: 48, pp 221-230), and for a broader presentation of the necessity for the growth of monopolies, see eg E Mandel (ref: 35, pp 398-400).

producers have been able to externalise many of the costs of resource use (because of the unequal, class-related bargaining powers of producers and consumers; and because the state, in intervening mainly on behalf of capital, has failed to force the internalisation of such costs).[19] In this sort of argument, it is suggested that, even if we accept the neoclassical definitions of socially optimal levels of pollution and rates of resource use, the nature of capitalism is such that profit-maximising behaviour by producers will give rise to outcomes which, on balance, lead away from that optimum.

The second line of reasoning is based on a rejection of the neoclassical definition of optimal social welfare, which, in perfect competition, is de facto equivalent to the actual mix of goods and services produced and consumed at different levels. The essential point of the neoclassical model that is attacked is the use of subjectively expressed preferences of individual consumers for defining the social utility of consumption patterns. It is asserted that individual preference, as revealed in market demand, often fails to reflect what are objectively the best interest of either the individual or society as a whole.[20] Whilst in practical terms it is easy to agree with the assertion, the problem with this line of argument is that the marxist tradition has been unable to generate an adequate general definition of objective interest or utility to set against the neoclassical one. Even if we had the means to do it empirically, it would therefore not be possible to quantify the extent of, say, excess pollution that was due to the 'deficient' neoclassical definition of socially optimal welfare. However, it would be possible for neomarxists to argue that, say, pollution levels would be greater than the real socially optimal level, even

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[19] See eg A Schnaiberg (ref: 48, p 418 and pp 241-250).

[20] For example, there is a clear revealed preference of many for tobacco products, which are nonetheless against their objective (health) interests (ref: 50, pp 64-67). Equally, the consumption of luxury items may increase the welfare of the few, but in a world where poverty exists, this is not socially useful production, and any resources used and pollution arising therefore has no social necessity (ref: 50, p 68).

if the amount of excess could not be quantified. The main point here is that marxist economics sees capital as having a structurally located necessity to expand.[21] As part of the response to this imperative, there will inevitably be great advertising pressure on consumers to buy goods and services which they do not really want or need. In this sense, the attack on the market demand definition is that the preferences revealed are not ones that are 'freely' arrived at by consumers, but are ones that are partly determined by the needs of capital.[22]

Neomarxist explanations for particular increases or decreases in, say, pollution levels are not, as has been noted, tied to a single, central model. So a point by point comparison with the neoclassical position is not possible. What we have is a very different kind of approach, which generates an alternative sort of explanation. The neoclassical approach focusses directly on the costs and benefits of pollution and pollution control. In the dynamic equilibrium model, the other factors affecting the profitability of the firm are held constant (costs of other inputs, volume and price of goods sold, etc). In contrast, the neomarxist approach tries to explain particular outcomes in terms of the different ways that producers can increase profits in different circumstances, and, particularly, in terms of the technical strategies that may be employed.

Since most of the authors are attempting to back up the macro level assertion, the examples given are biassed towards showing how environmental deterioration is technologically linked to particular profit-maximising strategies. As the Sandbach quotation above shows, there are authors who accept that some strategies also produce a systematic bias towards improvement, but, in the approach as a whole, these cases receive scant attention. The literature contains sevel lines of argument which recur frequently, and that are applied in many different, concrete contexts.

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[21] In contrast to other classical economists, such as J S Mill, who accepted zero-growth capitalism as a theoretical possibility. See, for the arguments, P Mattick (ref: 36, pp 57-64 and pp 109-114), and E O Wright (ref: 55, pp 122-124).

[22] See, for example, A Schnaiberg (ref: 48, pp 157-161).

First of all, there are many examples which hinge on the argument that environmental improvements are hindered by the need to reduce costs in a competitive market structure. This logic has been applied both to the slow 'cure rate' for existing problems,[23] and also to the less than satisfactory 'prevention rate' for the emergence of new problems.[24]

Secondly, there are many examples where deterioration is linked, in one way or another, to the need to expand output. Though this is a constant pressure, the best way to achieve it may vary with circumstances, and the technological and environmental implications will also vary. Where total demand for existing products is expanding rapidly, there may be relatively little technical change, since output can be increased by adding further units of existing capital (plant, materials and labour). Providing the products in question are 'socially useful', then increases in resource use and pollution would be offset by increases in social welfare.

Where demand for existing products is weaker or falling, there are two common types of strategy, both of which may produce technical change of more questionable social utility. Among the strategies used to try and buoy up the markets for existing products are reductions in product life in order to increase turnover rates,[25] focussing

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[23] In this context, technology may obviously refer to hardware. Many pollution reduction techniques have been developed to prototype stage, but have not been taken up by industry because they are seen as 'unproductive' costs. See, for example, JURUE (ref: 40, pp 6-10). Less obviously, it can also apply to scientific and technological expertise. Such expertise may be mobilised in order to delay the general acceptance of, or legislation on particular problems, and so to avoid the costs that are perceived to be likely. See, for example, F Sandbach's case study of the asbestos industry (ref: 46, Ch 8).

[24] With particular reference to the stringency of testing of new products or processes for possible health or environmental side-effects.

[25] The effect of variations in product life on environmental demands is outlined in theoretical terms by D Pearce (ref: 39, p 167), and is cited as being of particular importance by, for example, A Gorz (ref: 16, pp 23, 24) and T Emerson (ref: 50, p 68).

the sales drive on smaller and smaller consumer 'units'[26] and increased dependence on packaging to sell products.[27] In all these cases, the increases in consumer utility are seen as being small in relation to the increases in environmental demands.

When demand for existing products is weak, as well as trying to prop up that demand, there will also tend to be greater pressure to develop new products as a means of increasing sales, and to increase product quality in order to capture a larger share of the market. These strategies have been technically linked to deterioration on several counts. The use of new techniques, to make new products, possibly using new inputs, implies a rate of emergence of new problems that is probably greater than in other strategies for increasing output.[28] If the development represents a major investment for the industry, and problems do arise, then the problem of a slow cure rate may be particularly acute. Relative to the high risk of environmental degradation, the potential increases in social welfare are, again, seen as being very questionable.[29]

Although not the main concern of neomarxist writers, it is worth pointing out that particular cases of environmental improvement are amenable to the same sort of explanations. For example, as a response to the pressure to reduce input costs, one technical strategy that is biassed towards improvement would be to reduce physical amounts of material inputs per unit of output - by increasing conversion efficiency, recycling, etc. Similarly, where the qualities of products under consideration are directly relevant to

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[26] Such as the shift from collective to private consumption (eg M Barrat-Brown, ref: 50, p 8), or the focus on the individual, rather than the family, as the basic unit of consumption.

[27] Cited, for example, by B Commoner (ref: 10, p 11) and T Emerson (ref: 50, pp 64, 68).

[28] See, for example, the case of product change in the detergents industry - H Rothman (ref: 43, pp 159-172).

[29] Either because increases in product quality are small, or because, in aiming the development of new products towards where the buying power is, they are often luxury items, which do little to increase the welfare of society as a whole.

the environment, then changes in product quality that are designed to increase market share may produce improvements. For example, fuel economy and resistance to rust are both attributes that have been perceived as being important by manufacturers in the drive to increase their share of the mass car market.

(B3) The limitations of traditional approaches

As regards the enquiry into relations between profits, technological change and environmental change, the problem with the traditional approaches, as characterised above, is that, collectively, they leave us in rather an impasse. Considering first the macro level question, on the social balance of good and bad outcomes, the positions of the two approaches are in direct conflict. Furthermore, one can never be proved to be correct at the expense of the other. On the theoretical side, it would be impossible since the approaches do not share the same basic assumptions about the nature of capitalist society or growth, nor do they share the same definitions for central concepts such as social welfare (and such as profit). In the last analysis, we are faced with conflicts in belief - conflicts which cannot be resolved with factual evidence alone. On the empirical side it would be even more difficult. There is, first of all, the problem that some outcomes would be evaluated as good by one approach and bad by the other. But there is also the problem that empirical work will only ever amount to a small sample of real world cases. This means, for example, that however many cases are thrown up of the 'pollution prevention pays' type, the neoclassical position will never be proved by them, since an equal number of countervailing cases could probably be found where pollution prevention would not pay. By the same token, with the inevitably small total sample, the neomarxist position could never be proved through the accumulation of supportive individual cases.

As regards the micro level, the problem is different. Although the explanatory frameworks of the two approaches are based on conflicting assumptions at the macro level, there is not necessarily any direct conflict between the two when it comes to explaining any particular outcome. Rather, they would provide alternative accounts, which might be equally good relative to their own terms of reference. And to say that one was better than the other would be virtually impossible without accepting some of the ontological and/or epistemological assumptions made by one of the approaches.

The scope for important new work on these two issues is therefore very limited. At the macro level, the basic positions are well established. And although there is some scope to develop further supportive work within each approach, such work could never resolve the fundamental conflicts between them. At the micro level, there is scope within each tradition, both for the 'fine tuning' of the explanatory frameworks, and for their application to new substantive areas. But such work is never likely to amount to more than minor improvements to the bodies of knowledge and technique already established within each tradition.

However, this problem does not mean that no more useful work can be done on relations between profits, technology and environmental change. And the underlying objective of the thesis is to try and move the enquiry into these relations beyond the impasse created by the work done in the traditional approaches. The way this is to be done, and the more specific objectives of the thesis are discussed in Section C below.

1C THESIS OBJECTIVES

The basic aim of the thesis is to try to begin to develop an analysis of relationships between profits, technological change and environmental change that lies between the micro and macro levels used in the traditional approaches - ie a 'meso level' approach. The emphasis of the micro analytic level has been on explaining the existence of the variability in outcomes, and the macro analytic level has been concerned with the general balance between different outcomes. The central issues for this meso level of analysis concern the distribution of that variability in outcomes.

The first set of questions we might look at are purely descriptive - what are the distributional patterns, if any? And there are several important dimensions on which we could look for such patterns. For example, we might ask whether different types and/or rates of environmental change have been concentrated into different historical periods. Similarly, in a given period, we might ask whether improvement and deterioration were concentrated in different sectors of the economy, or in different areas of the country. And there is also the social dimension that might be considered - which groups or classes of people were experiencing improvements or deterioration of their environment in a particular period?

To answer such questions, we have to develop descriptive categories that are appropriate to a meso level analysis. The very general categories used at the macro level may be far too broad. For example, a concept such as pollution is likely to be of little use when we are trying to map out the variations in levels or rates of change in pollution of different types. In this sense, we have to disaggregate down from the macro level of analysis. And, by the same token, we have to aggregate up from the micro level. The particular outcomes examined at this level are, in the last resort, unique, and will have no distributional characteristics at all. Clearly, we would need to deal in classes of outcome that are internally similar and could be easily distinguished from contrasting classes.

Assuming that patterns of distribution are not totally random, the second stage in developing this analysis would relate to the explanation of patterns observed. And again, this would mean using a different approach to those adopted at micro or macro levels. Clearly, if we are trying to explain patterns of distribution of variation, it is going to be useless to refer to those features that are held up as characterising the basic nature of capitalism, since such universals do not change. Instead, we would have to look at those aspects that may be subject to systematic variation over time, space and so on. Similarly, this would mean jumping up from the micro level. The neoclassical model explains a particular outcome in terms of given changes in conditions governing outcomes. But in the meso level analysis, it would be those changes in conditions that themselves needed to be explained. Alternatively, the neo-marxist approach would account for a particular outcome by reference to a particular type or blend of profit-maximising strategies. But, in the meso level analysis, we would have to explain why that blend of strategies varied as it did across the economy, over time, etc.

And to develop an explanation adequate at the meso level, we would again have to use descriptive categories that were appropriate. General concepts such as profit or technical change are not likely to be much help when we might need to look at patterns of variation in the different rates and types of each. On the other hand, the particular profit-maximising strategies or technical innovations that are important in micro level explanations may be too specific to be of much help. We would need to consider aspects of profitability and technical change that are broad enough so that their distributional characteristics could be easily studied.

As regards the impasse identified, this meso level approach may be useful in two respects. First of all, it may provide a way of partially reconciling the macro level conflict between the traditional approaches. If it can be demonstrated that the balance between improvement and deterioration, say, varies significantly between different sectors of the economy or between different historical periods, then any ultimate bias becomes relatively unimportant. In practical terms, this would mean that neither macro level assertion was <u>generally</u> either right or wrong, and that both would have some validity, but at particular and different times, or in particular and different sectors of the economy.

Secondly, the meso level of analysis may provide a way of bringing together the alternative micro level approaches. At present, the higher levels of theory to which they relate are in direct conflict at many points, and the two frameworks appear as being almost completely isolated. Any meso level explanation would invoke realities of capitalism that are less fundamental than those basic features over which the conflicts arise. The potential therefore exists for a theoretical model in which these conflicts are not inherent. And, in turn, the possibility therefore arises of a single, higher model to which both micro level frameworks can be related without necessarily bringing them into conflict with each other.

Chapter 2: Description of environmental change in the United Kingdom iron and steel industry (1700 to 1980)

2A INTRODUCTION

Following on from the issues raised above, this chapter set out to try and answer the question of whether or not the variability in environmental outcomes has been randomly distributed over time. In particular, we wanted to find out whether environmental change has been periodized - ie can we pick out distinct periods that were characterised by contrasting types and/or rates of environmental change, and, if so, what were they? As a first approach to these questions, a longitudinal study was carried out into aspects of environmental change in the UK iron and steel industry.

2B DATA AND METHODS

Three sets of data were used to look for any periodization of environmental change. However, not all the variables used were statistically independent. The details and implications of the dependencies are discussed below, in conjunction with the descriptions of each data set.

(B1) Impact potential data

'Hard' data on environmental change is virtually impossible to get hold of for any time but the fairly recent past, and in order to look for possible periodization over the longer term, it is therefore necessary to use 'softer' indicators. In this study, the approach used involved looking at the environmental impacts of the technical innovations in the industry. Innovations are seen as creating the 'potential' for environmental change. The extent to which the potential embodied in each innovation is translated into reality will depend on further factors, but these other things being equal, we would expect that variations in this potential for environmental change would be a reasonable indicator for actual variations.

The production of the impact potential variables involved three stages. First of all, a list of the innovations in the industry between 1700 and 1970 was compiled from existing technical and economic histories. The full list is given in table 2.1 (annex 1). At the same time, the enviornmental impacts associated with each innovation were recorded in as much detail as was possible. In order to do this, various environmental sources were used in addition to the technical and economic histories. These included the environmentally relevant research papers of the industry, annual reports of the Alkali Inspectorate (responsible for air pollution in the industry) and more general environmental texts which included reference to iron and steel. But, even so, it was only possible to record the impacts in qualitative terms. For example, it was clear from the literature that the introduction of the hot blast led to a substantial reduction in the amount of coke needed to produce a ton of pig iron, and, therefore, to a reduction in the amounts of coking wastes per ton of pig iron, but the exact amounts are not known. Most of the impacts recorded were therefore in the form of increases or decreases in amounts of given inputs and wastes for a particular output (such as pig iron) or operation (such as strip milling). In addition, where appropriate, changes in the nature of inputs and wastes were also recorded (such as changes in the acidity of slags from various furnace processes). The full list of impacts recorded is given in table 2.2 (annex 1).

The second stage involved classifying the innovations, on the basis of their impacts, as regards three aspects of environmental change. We were concerned with whether the resulting changes were quantitative or qualitative, whether they represented improvement or deterioration and with their environmental importance - the degree of improvement, for example. The three classification systems are dealt with in turn below.

In distinguishing between quantitative and qualitative change, the difference we were trying to pin down is between those innovations resulting in increases or decreases in amounts of existing inputs and wastes, and those innovations which changed the nature of inputs or wastes (for a given output or operation). But the distinction is not an absolute one given by the physical impacts of the innovation. The classification is also contingent on two further factors. First of all, it depends on how finely the relevant inputs and wastes are defined in the first place. For example, the bulk use of oxygen in crude steel production was associated with the evolution of large amounts of orange, iron oxide fume. If the distinction is made between this and other types of particulate matter emitted, then the innovation would be classified as resulting in a qualitative change in wastes from crude steel production - ie the evolution of a new type of waste. But if wastes are less finely differentiated, then the innovation might be classified as resulting in quantitative change - an increase in the amount of particulate matter produced per unit output of steel.

Secondly, the proportion of innovations classified as resulting in quantitative or qualitative change depends on the breadth of the industry sector in relation to which we consider the impacts. For example, the eighteenth century saw steam power replacing water or human labour power in many different parts of the industry, with, in each case, a variety of impacts. If the industry is considered as infinitely divided, then, in each such case, the innovation would be classified as resulting in qualitative changes to the inputs and wastes associated with that particular output or operation. But if we consider a discreet sector of the industry, such as wrought iron rolling, then, once steam power had been introduced to the operation, succeeding substitutions of the same type would be classified as resulting in changes in the amounts of inputs and wastes already associated with it.

The classification of innovations according to whether they resulted in quantitative or qualitative change is therefore dependent on the definitions made in relation to these two contingent factors. On one set of definitions we would get virtually all innovations classified as resulting in quantitative change. But at the other end of the spectrum, another set of definitions would lead to virtually all innovations being classified as resulting in qualitative change. Clearly, in neither case would we be able to look for any periodic variation in the bias of innovations towards the different types of change. And, in this sense, to make the conceptual distinction empirically workable, it was necessary that both categories should contain reasonable numbers of innovations. To achieve this, the innovations were classified on the basis of their impacts on six divisions of the industry. These were: (1) blast furnace and input preparation; (2) wrought iron production; (3) wrought iron processing and products; (4) cast iron; (5) crude steel production; (6) steel processing and products. The classification of innovations according to the type of change in which they resulted, and in which sector, is given in table 2.3 (annex 1).

As regards improvement and deterioration, those innovations with any recorded impacts were placed into one of three principal categories - improvement only, deterioration only or both (improvement and deterioration, in relation to different inputs or wastes). The main criterion used to evaluate innovations was their impact on the unit materials balance situation. Those causing reductions in the amounts of inputs or wastes per unit of output were classified as leading to improvement, and those causing increases were classified as leading to deterioration. On first sight, it would seem that this criterion can be applied only to those innovations already classified as resulting in quantitative change, and that other criteria would be needed to evaluate innovations classified as resulting in qualitative change. But, on closer inspection, this is not so. The distinction between innovations that only change amounts of inputs and wastes and those that change their nature is not synonymous with whether or not they can be evaluated by reference to the materials balance criterion.

With respect to wastes, for example, we can consider seven types of impact we might get, as follows:

1) increases in some or all existing wastes
2) increases in some existing wastes and decreases in others
3) decreases in some or all existing wastes
4) new wastes produced, with no existing ones stopped or reduced
5) new wastes produced, but some existing ones stopped or reduced
6) old wastes stopped, with no new ones produced or existing ones increased
7) physical amounts of wastes stay the same, but their nature changes.

In this breakdown, the first three impact types result in changes only in the amounts of existing wastes, while the next four lead to changes in the nature of wastes. However, impact types one and four can both be evaluated on the materials balance basis (as deterioration only), even though type four changes the nature of wastes. Similarly, impact types three and six can both be given a materials balance evaluation (as improvement only), even though impact type six changes the nature of wastes. Conversely, impacts of type two cannot be given a materials balance evaluation (as improvement or deterioration only), even though they only change amounts of existing wastes. They would therefore be classified as resulting in 'both', as would impacts of type five. The two contingencies that affected the classification of innovations as resulting in qualitative or quantitative change do not, therefore, affect their classification as regards whether they result in improvement only, deterioration only or both. The definitions used in relation to those contingencies would affect the question of whether impacts were classed as type one or four, say, but would not alter the evaluation of that innovation as resulting in deterioration only. And the same holds for the other pairs of impact types (three and six, two and five). The unit materials balance evaluation therefore cuts across the quantitative/qualitative change distinction, and allows us to classify more innovations than is at first apparent as regards their improvement/deterioration effects.

However, not all innovations could be classified on this materials balance basis - those with impact type seven, for example, and two further criteria were used. Add-on cleaners and arrestors (principally for air pollution) were classified as resulting in improvements. And, although this might be contentious in particular cases, there are two reasons why it is justifiable in general. First, in many instances, the residues from such systems are recycled, so that there actually is a materials balance improvement, rather than merely the transformation of the problem from the air to water or land. Second, even when there was no evidence for recycling, such innovations were classified as resulting in improvements becuase many were designed to alter, in a beneficial way, the conditions under which pollutants are added into the atmosphere - by dilution, or by the aggregation of very fine particles into coarser and less harmful ones.

The third criterion, relevant to impact type seven, concerned the acidity of wastes (slags, electrolytes and pickling liquors). Changes towards neutral were defined as improvements, and vice versa, the assumption being that the ecological optimum is roughly neutral.

These three criteria are not exhaustive, of course, particularly as regards those cases in which the nature of wastes was changed. We might also have used criteria such as persistence or toxicity. Clearly, the advantage of using further criteria is that more innovations can be classified as leading to improvement or deterioration, rather than as both by default. But there are also problems. First, the more criteria we use, the greater is the chance that we conflate types of improvement or deterioration that have different patterns of variation over time. Second, we also increase the chance of innovations being classified one way on one criterion and another way on a different one. The use of three criteria gave a reasonable balance between the opposing pressures. The addition of the second and third criteria allowed an increase in the number of innovations that could be classified as improvement or deterioration only (from 48 to 67), and did not lead to any conflicts. The final classification is given in table 2.3 (annex 1).

The third classification of innovations was according to their environmental importance. Their improvement and/or deterioration impacts were classified as being either major or minor. The assessment was subjective, but took four factors into account. First, there was the question of how much change was involved. We have noted that, when impacts were recorded, it was not possible to quantify them. But, in some cases, we had reference to them being large or small. For example, many innovations led to reductions in the coke rate. And we know that those reductions associated with the introduction of the hot blast were substantial, whilst those due to the bell and hopper were marginal. Second, we took into account the importance of the particular operation where the innovation occurred to the industry's total consumption of a given input or production of a given waste. For example, the use of oxygen in blast furnaces and for scarfing resulted in increases in oxygen consumption and the production of iron oxide fumes, but these were very small relative to the problems of bulk oxygen use in steel production. The third factor taken into account was the number of different inputs and wastes affected by the innovation. For example, the kaldo process steel furnace was environmentally noteworthy because it produced substantially lower emissions of carbon monoxide than existing alternatives. But this improvement seems minor compared to those brought about by the introduction of the by-product coke oven (including the recovery of oils, tars and sulphur from sulphur oxides). Lastly, as regards wastes, some account was taken of how badly polluting they were. This is not a very precise concept, nor easy to grade very finely, but there were some wastes that could clearly be seen as either major or minor. For example, reductions in flourine, arsenic, phenols and sulphur oxides were all seen as major improvements in this context, whereas reductions in waste heat, neutral slags and the coarser particulate matter were seen as minor. The full classification of innovations as regards the degree of improvement and/or deterioration associated is given in table 2.3 (annex 1).

The third stage in the production of the impact potential variables, so we could look at patterns of variation, involved aggregating with respect to time. Two procedures were used. First, in order to give a visual representation, moving averages (over twenty-five years) were calculated of the annual frequencies with which innovations in the various categories occurred. When plotted against time, these allowed us to see whether or not there appeared to be any periodization in the potential for the various aspects of environmental change. As a rough guide to identifying times when frequencies were particularly high or low, the underlying, long run changes were represented using semi-average trend lines.

But some method was also needed for assessing the statistical significance of any apparent periodization. Any time series data, when superimposed onto its underlying linear trend, will have high and low periods. The question is, how likely is it that any such pattern has arisen by chance? To answer this question, the runs test was used to analyse sequences of positive versus negative residuals. The clustering of residuals was taken as an indication of periodization, whose significance was assessed using Z tests. However, this analysis could not be applied to residuals in the moving average plots since the use of such long moving averages would introduce a large bias towards clustering. To avoid this problem, a second method of aggregating with respect to time was used. For each decade, the number of innovations in each category was counted. For each category of innovation, this process therefore yielded twenty-seven values - each a separate, period frequency count. And it was these period frequencies which were regressed on time, providing the residuals sequences analysed using runs tests. Linear regression was used since the moving average plots suggested that non linear regression would not give a substantially better fit. In this analysis, to give a more accurate representation of underlying trends, least-squares regression was used, rather than the semi-averages procedure.

The various systems of classifying innovations, and the two methods of aggregating with respect to time allowed the following annual and period frequency variables to be calculated and used:

1) fIM All innovations with environmental impacts
2) fQT Innovations resulting in quantitative change
3) fQL Innovations resulting in qualitative change

The variables fQT and fQL are mutually exclusive and collectively cover all innovations with environmental impacts. For the other two aspects of environmental potential, it was not possible to generate variables that were both mutually exclusive and covered the whole set of innovations with recorded impacts. On the one hand, we could generate pairs of variables that were mutually exclusive but that did not cover all relevant impacts. For example, those innovations classified as resulting in improvement or deterioration only are mutually exclusive subsets, but do not pick up all improvement or deterioration impacts. The pairs of variables that were of this type are as follows:

4) fIO Innovations resulting in improvements only
5) fDO Innovations resulting in deterioration only
6) fMAJI Innovations resulting in major improvements
7) fMINI Innovations resulting in minor improvements
8) fMAJD Innovations resulting in major deterioration
9) fMIND Innovations resulting in minor deterioration
10) fMAJO Innovations resulting in only major impacts
11) fMINO Innovations resulting in only minor impacts

On the other hand, by aggregation, we could generate pairs of variables that do collectively cover all relevant impacts, but which are not mutually exclusive. These are as follows:

12) fAI Innovations with any improvements associated
13) fAD Innovations with any deterioration associated
14) fMAJ All innovations with major impacts
15) fMIN All innovations with minor impacts.

However, all these variables were calculated from the same set of innovation data, and the dependencies between them limit the uses to which they can be put. Two points can be illustrated by considering the variables fQL and fQT. First of all, there are two mathematical links between the pair. The values of both variables are partly dependent on the overall frequency of innovations with environmental impacts (fIM). Clearly, when fIM is especially low, then neither fQT nor fQL can be very high. And, conversely, when fIM is high, then, other things being equal, we would expect that both fQT and fQL would also be high. But both variables are also partly dependent on a single ratio - that between fQT and fQL as proportions of fIM. Since both variables are dependent on the same two sources of variation, either one of them may provide evidence for periodization, but if the other is also periodized, then this will not constitute additional, independent evidence for periodization. The same is true for the remaining pairs of variables.

But although we know that these statistical dependencies exist, we do not know the detailed nature of the links. For example, if fQT is high at a particular time, we cannot specify what is the probability that fQL will also be high. So it is not possible to predict the pattern of variation in one variable from a knowledge of variation in the other. It may be that fQT and fQL are both high or low at the same time, or it may be that one tends to be high when the other is low. Clearly, these are different types of periodization, but knowing that dependencies exist does not allow us to specify which is more likely. So, although all the evidence for the existence or otherwise of periodization can be supplied by one of the pair of variables, we need to look at both variables to establish the nature of any apparent periodization. Again, the same is true for the other pairs of variables.

The third point concerns the difference between the 'basic' variable pairs (4 to 11) and those 'derived' from them (12 to 15). Clearly, each of the derived variables is partly dependent on its corresponding basic variable. For example, fAI is partly dependent on fIO. These are therefore alternative, but not independent ways of illustrating any periodization in the potential for improvement. The pairs of variables fIO/fDO and fAI/fAD are, similarly, alternative but not independent ways of illustrating any periodic bias in the potential for environmental change towards improvement or deterioration. And the same is true for the other cases in which pairs of basic variables are matched with pairs of derived variables. The value of having these alternatives lies in the fact that neither of them gives an unequivocably better picture of the variations we are concerned with - such as the bias towards improvement or deterioration.

(B2) Materials input data

The input data is statistically independent of the impact potential data outlined above, and variables measured actual rather than potential change. Data was collected on nine inputs to iron and steel production processes. The inputs fell into the three following groups. 'Old' inputs included coke, iron ore and total blast furnace solids. 'New' inputs included sinter, oxygen and electricity. 'Scrap' inputs included iron scrap, steelmaking scrap and total industry scrap. All variables measured physical amounts of inputs per year, though different timespans were covered. The last date at which readings for all variables were obtained was 1979, and no data was obtained earlier than 1920.

When considering patterns of change in input levels, there are two descriptive levels we can look at - the gross consumptions of inputs by the industry or sector, and the consumption per physical unit of relevant output. Eighteen variables were therefore used to examine patterns of variation in these nine inputs at the two descriptive levels. The full sets of data are given in tables 2.4 and 2.5 for unit input and gross consumption levels respectively (annex 1).

However, it was not possible to get hold of independent data for all eighteen variables, and, again, this limited the uses to which some of the variables could be put. Independent data was available in existing sources for five inputs at the unit level (ore, coke, blast furnace solids, sinter, iron scrap), and for six inputs at the gross level (coke, sinter, oxygen, electricity, total scrap, steel scrap). For the remaining seven variables, values were calculated using relevant output level data (ie unit input level = gross consumption level/output level, or gross consumption level = unit input level x output level). Details of the data sources and/or calculations relevant to the eighteen variables are given in table 2.6 (annex 1).

Within both the unit input and gross consumption level data sets, any one of the computed variables (but only one) is also independent, as well as those variables whose values were taken from published sources. The independent evidence for or against the existence of periodization at the unit input level is therefore provided by six variables, and at the gross consumption level by seven variables. The remainder of the variables cannot be seen as providing additional, indepenedent evidence for or against the existence or periodization at either level, but they were used in trying to characterise the nature of patterns observed. This was felt to be justified because it can be demonstrated that the use of output level data does not introduce substantial errors, and it is therefore a reasonable way of 'estimating' values for variables where no independent data exists. The cases of coke and sinter were used to compare gross consumption levels as given by independent data with those estimated using output level and unit input level data. As shown in figures 2.1 and 2.2 below, for both inputs, the patterns of change in estimated values conform very closely to those given by the independent data.

The same two methods were used to look for periodization in both sets of input data. First of all, the data was plotted against time in order to make a purely visual assessment. To assess the significance of any apparent periodization, the sequences of positive and negative residuals around linear regression trends were again analysed using the runs test to look for significant clustering.

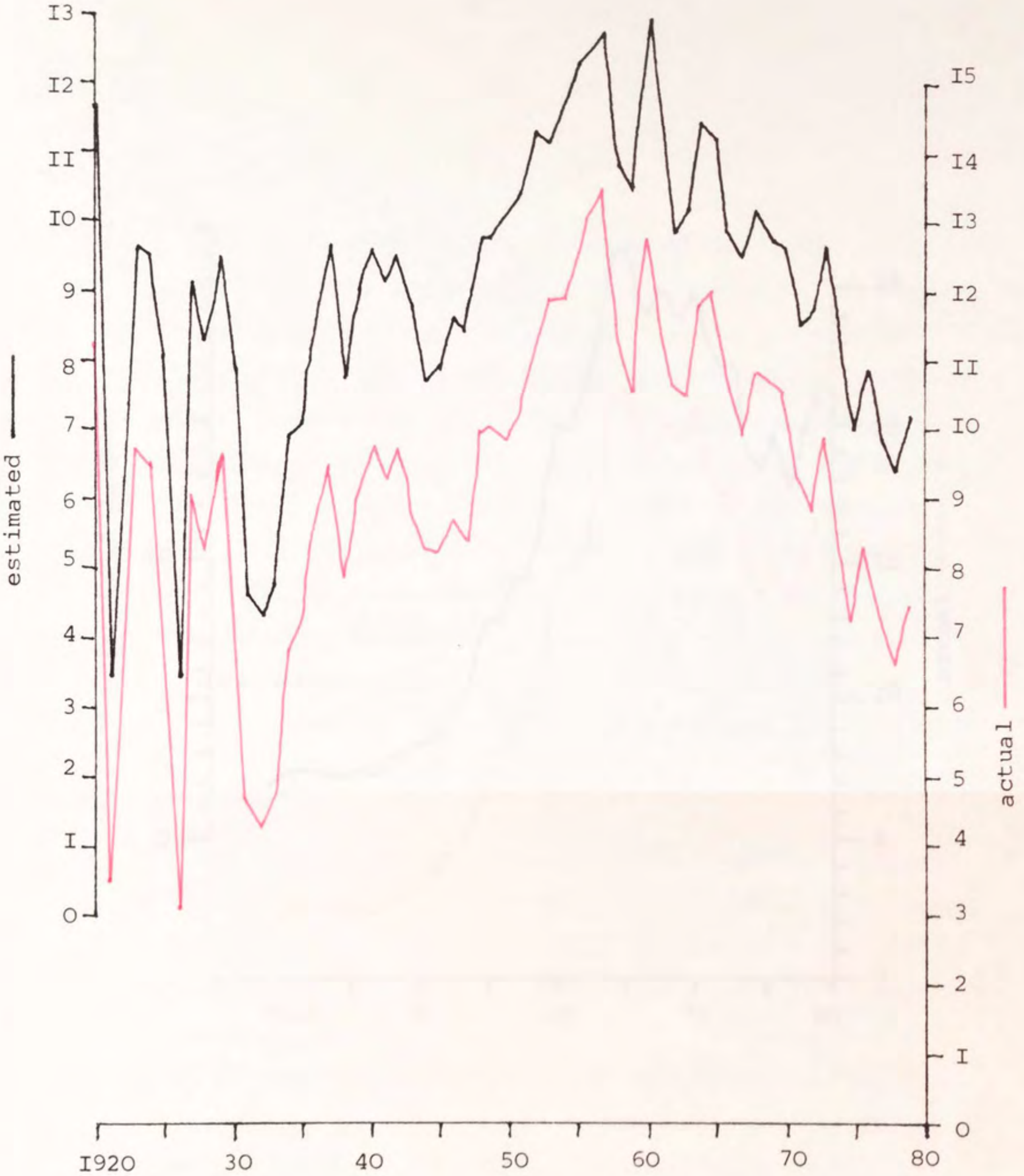


Figure 2.1 – Variations in gross coke consumption levels: actual and estimated (million tons)

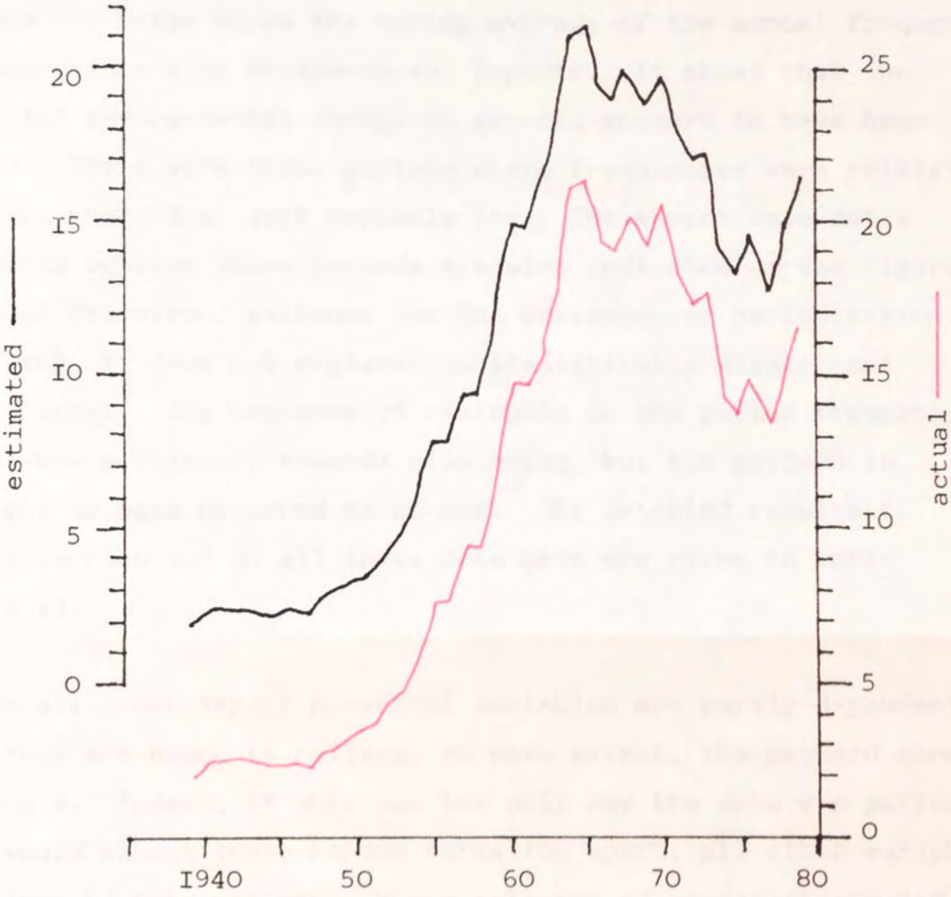


Figure 2.2 - Variations in gross sinter consumption levels: actual and estimates (million tons)

2C RESULTS

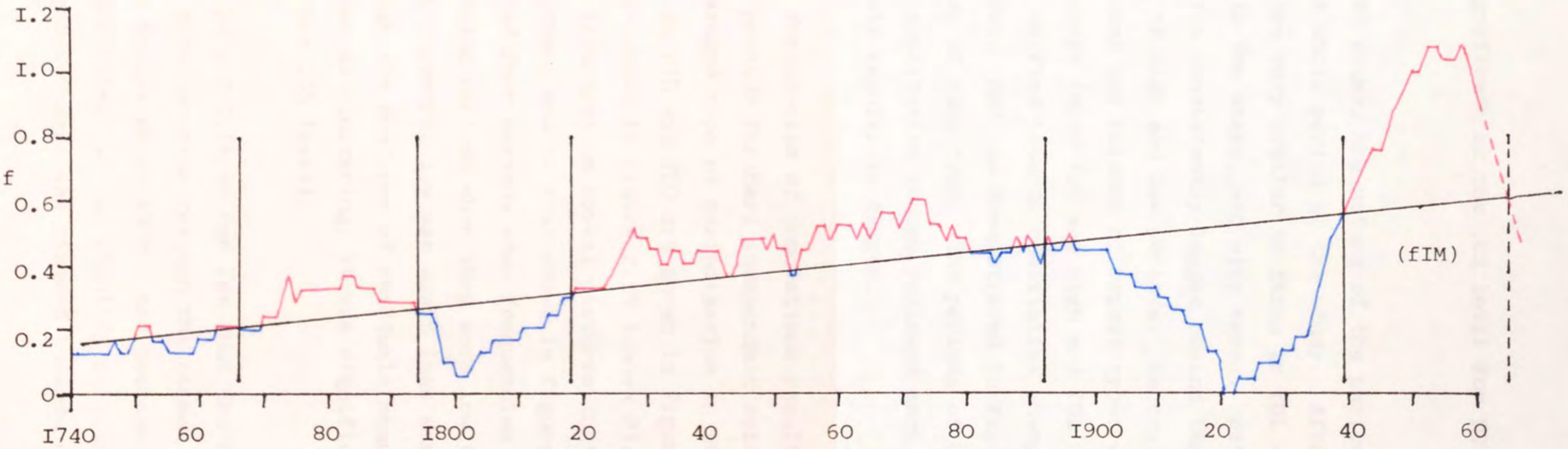
(C1) Impact potential

Figure 2.3 below shows the moving average of the annual frequency of all innovations with environmental impacts. It shows that the potential for environmental change in general appears to have been periodized. There were three periods where frequencies were relatively high and two where they were markedly low. The approximate dates of boundaries between these periods are also indicated on the figure. But although the visual evidence for the existence of periodization is compelling, it does not register as statistically significant at the .10 level. The sequence of residuals in the period frequency data does show a tendency towards clustering, but the pattern is quite likely to have occurred by chance. The detailed results of runs tests carried out on all three data sets are given in table 2.7 (annex 1).

Since all other impact potential variables are partly dependent on fIM, they are bound to reflect, to some extent, the pattern shown in figure 2.3. Indeed, if this was the only way the data was periodized, we would expect that, random variation apart, all other variables would conform to this pattern. Where patterns of variation are different from that in figure 2.3, we therefore have reason to think that the variables involved are picking up some other way in which the data is also periodized. And, in fact, patterns of change in the other variables do differ in important respects from that shown in figure 2.3.

Variations in the frequencies of innovations resulting in quantitative and qualitative changes provide one piece of evidence for the existence of a second type of periodization in the data. As shown in figure 2.13 (annex 2), when this is compounded with the periodization in the overall frequency of innovations with environmental impacts, the resulting patterns in fQT and fQL appear to have four periods of high frequencies and three periods of low frequencies (though the central low is less pronounced than the other two). The analyses of residuals sequences indicated clustering tendencies

Figure 2.3 - Variations in the potential for environmental change in general



for both variables, significant at the .02 level for fQT and at the .20 level for fQL.

As figure 2.13 also shows, the nature of the periodization was not consistent over the whole period of the study. After about 1920, the variations in fQT are very similar to those in fQL - when one frequency is high, so is the other, and vice versa. Beforehand, however, the plot for fQL consistently lagged behind that for fQT in the common sequence of high and low periods. We could therefore identify some periods when the balance of impact types was shifted towards quantitative change (when fQT was high and fQL was low), and others when it was shifted towards qualitative change (when fQL was high and fQT was low). And, as demonstrated in figure 2.4 below, there were three periods of each type. The periods of bias towards either quantitative or qualitative change followed each other in sequence, and were fairly regular in length.

Variations in the frequencies of innovations resulting in improvement and deterioration provide further, independent evidence for the existence of this second type of periodization in the data. The patterns of change in fIO and fDO are shown in figure 2.14, and those in fAI and fAD are shown in figure 2.15 (annex 2). These alternative methods of illustration reveal pictures that are very similar, both to each other, and to that shown in figure 2.13. Each of the four variables had four periods when frequencies were relatively high, and three intervening periods when they were low (though with the exception of fDO, the central low was again less marked than the other two). Although the analyses of residuals sequences again indicated tendencies towards clustering, it was significant only in the case of fIO (at the .05 level).

In both figures 2.14 and 2.15 we can see that the improvement plots consistently led deterioration through the common sequence of high and low periods before about 1920. And because of this, as figure 2.5 below illustrates, we can identify periods when the potential for environmental change was biassed towards either improve-

Figure 2.4 - Periods of bias towards either quantitative or qualitative change

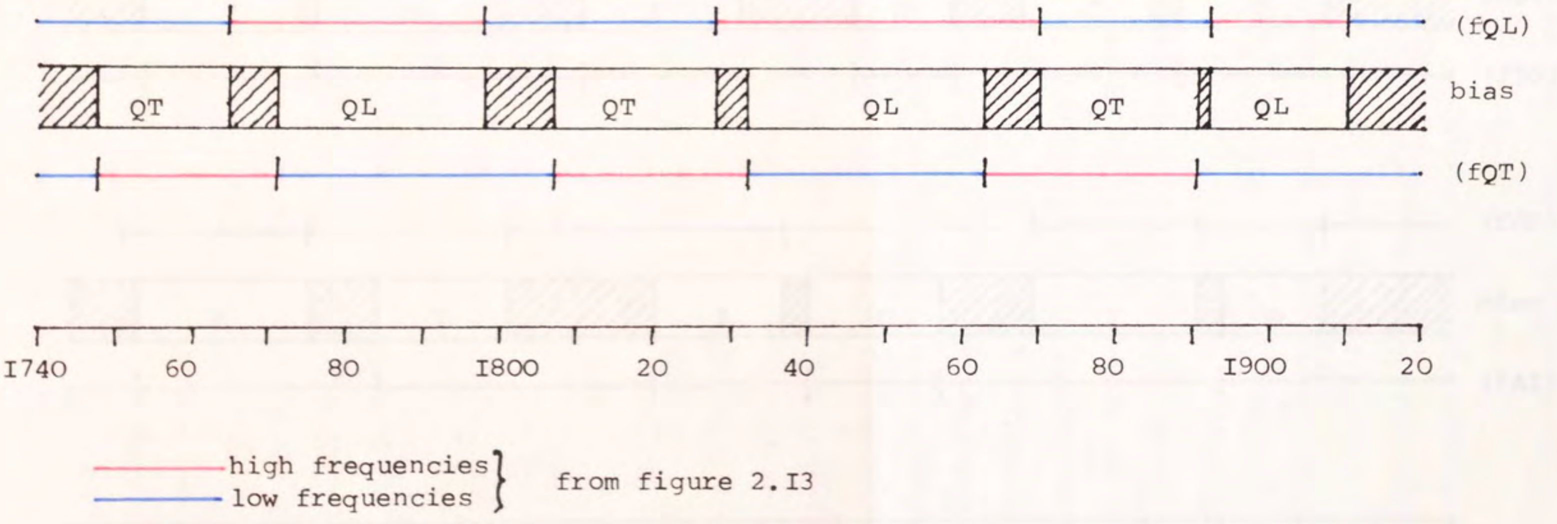
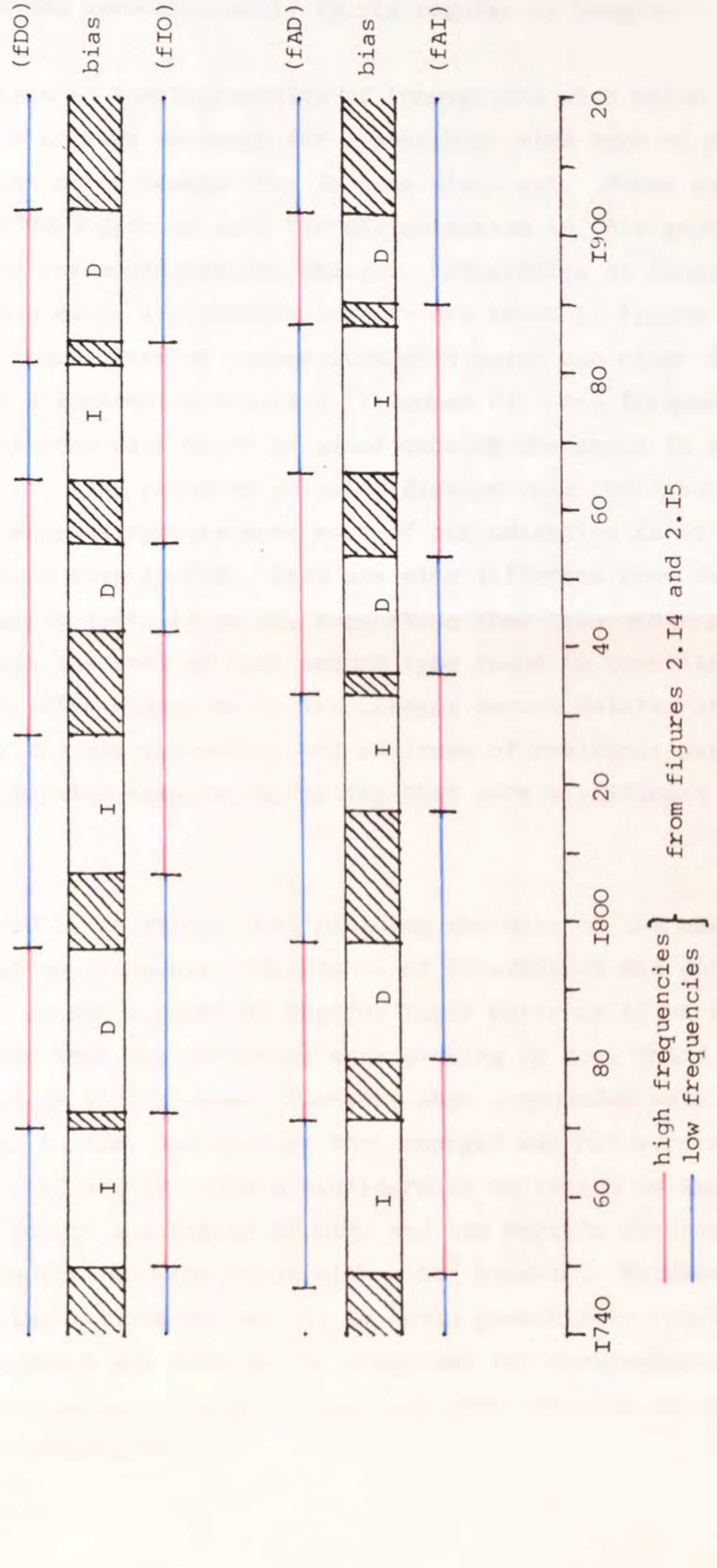


Figure 2.5 - Periods of bias towards either improvement or deterioration

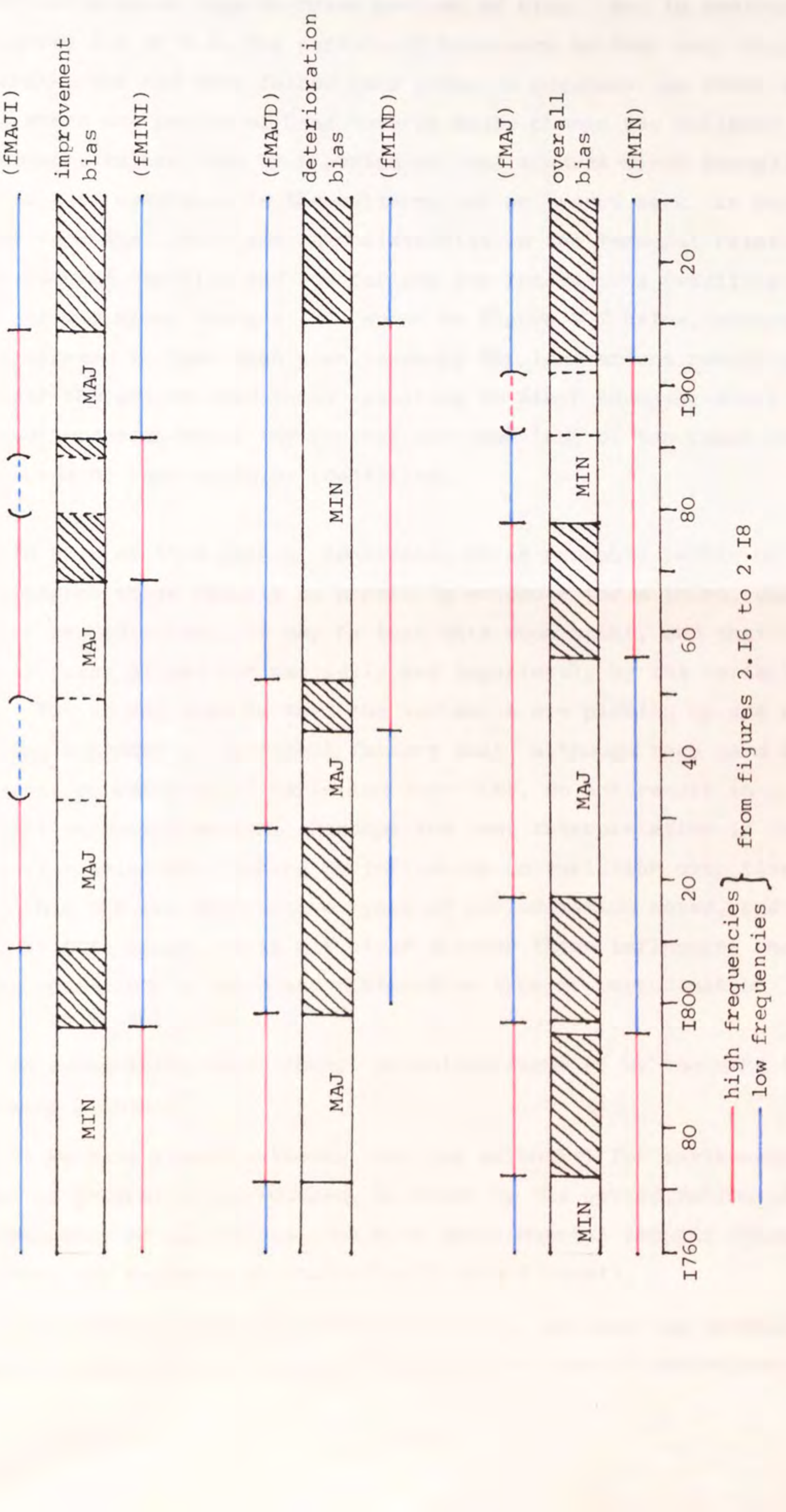


ment or deterioration. Again, whether using the basic or derived variables as illustration, these periods of bias followed each other in sequences and were apparently fairly regular in length.

Variations in the frequencies of innovations with major and minor impacts provide evidence for a possible third type of periodization in the data, though this is less clear cut. Three pairs of variables were used to look for periodization in this aspect of the potential for environmental change. Frequencies of innovations with major and minor improvement impacts are shown in figure 2.16 (annex 2). Frequencies of innovations with major and minor deterioration impacts are shown in figure 2.17 (annex 2). And frequencies of all innovations with major or minor impacts are shown in figure 2.18 (annex 2). The patterns revealed diverge from that shown in figure 2.3, suggesting that some sort of periodization is at work other than just that in fIM. They are also different from those shown in figures 2.13, 14 or 15, suggesting that this other periodization is not the same as that second type found in quantitative versus qualitative change or in improvement versus deterioration. For three of the six variables, the analyses of residuals sequences revealed tendencies towards clustering that were significant at the .02 level.

It seemed clear enough that dividing the data on the basis of the degree of environmental importance of innovations did not just give rise to random subsets as regards their patterns of variation over time, and that the variables were picking up some third type of periodization in the data. However, when compounded with the periodization in fIM, the picture that emerged was not very coherent. Figures 2.16, 17 and 18 contain considerable variation as regards the number, length and timing of high and low periods for innovations with major impacts and for those with minor impacts. Whichever of the three illustrations we use, it is again possible to identify periods when there was bias in the potential for environmental change, towards either major or minor change, and these periods are shown in figure 2.6 below.

Figure 2.6 - Periods of bias towards either major or minor change



However, the three alternative illustrations generate very different patterns as regards these periods of bias. And in contrast to figures 2.4 or 2.5, the periods of bias were neither very regular in length, nor did they follow each other in sequence (ie there are cases where one period of bias towards major change was followed by another, rather than by a period of bias towards minor change). This lack of coherence in the patterns can be traced back, in part, to the fact that there are inconsistencies in the temporal relationships between the high and low periods for innovations resulting in major and minor changes. As shown in figure 2.7 below, although there appears to have been some tendency for innovations resulting in major changes to lead those resulting in minor changes, there are two instances where the reverse was true (out of ten cases where such leads or lags could be identified).

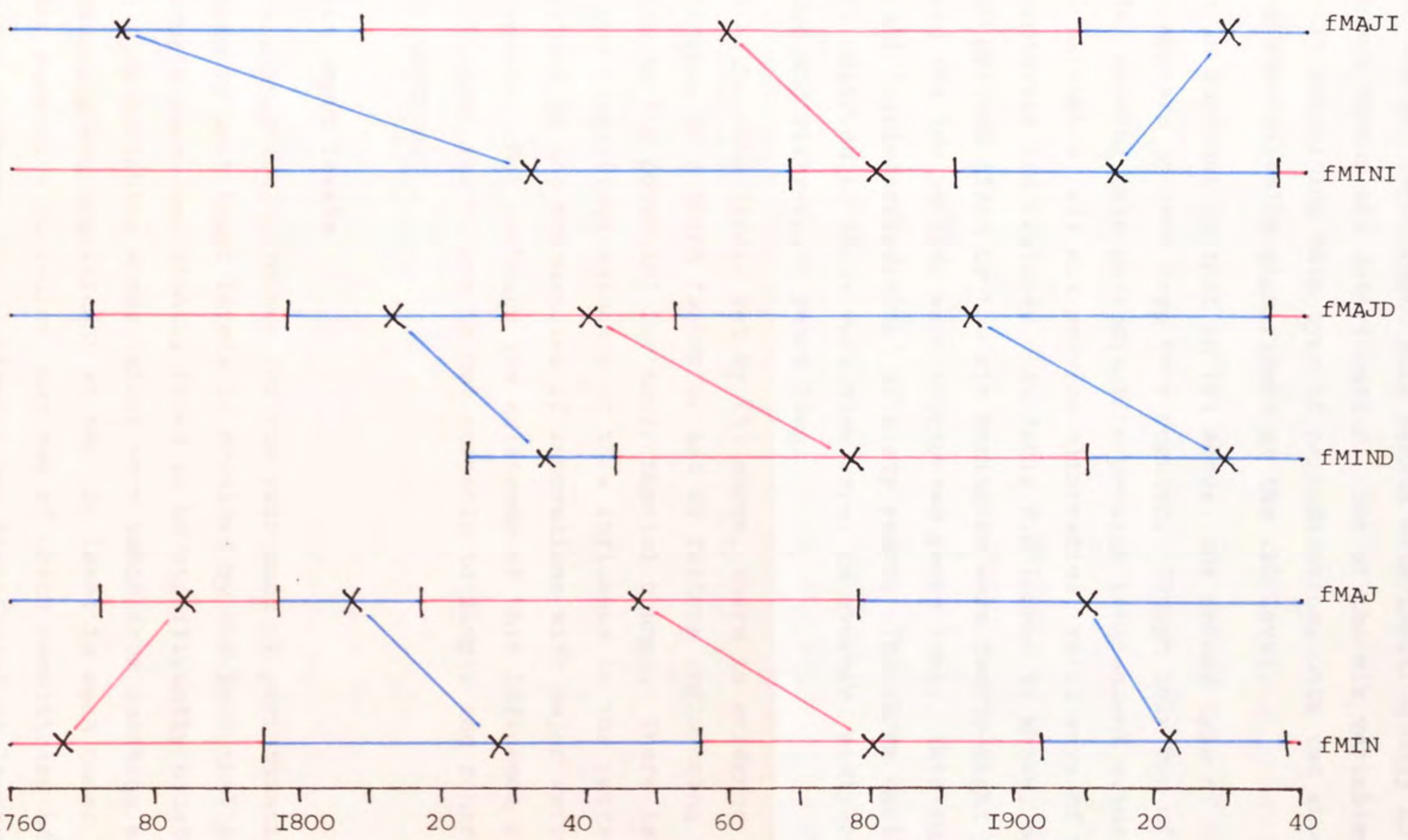
In view of this lack of coherence, it is probably better not to interpret these results as providing evidence for a third, distinct type of periodization. It may be that this does exist, and that it is only being picked out partially and imperfectly by the variables used. But it may also be that the variables are picking up and reflecting a number of different factors that, although they have some influence on patterns of variation over time, do not result in a distinctive periodization. Perhaps the best interpretation is that theses variables are picking up influences on variation over time other than the two distinctive types of periodization noted, and that, at this stage, it is not clear whether these influences themselves constitute a third and distinctive type of periodization.

In summarising these impact potential results, we can make the following points:

1) We have visual evidence that the potential for environmental change in general is periodized, as shown by the periodization of the frequency of all innovations with environmental impacts (though this does not register as statistically significant).

2) Within the overall limits set by (1), we have two independent pieces of evidence that a second, distinctive type of periodization

Figure 2.7 - Leads/lags between innovations with major or minor impacts



X = mid years of periods of high (red) and low (blue) frequencies exists. This is illustrated visually by the periodization of the frequencies of innovations associated with qualitative versus quantitative change, improvement only versus deterioration only and all improvement versus all deterioration. But of the six variables apparently exhibiting this type of periodization, only two show it as being statistically significant at the .10 level.

3) In contrast to that in (1) above, the second type of periodization appears to have been very regular. Though only two of the variables showing this periodization provide independent evidence for its existence, all six provide alternative, valid ways of trying to characterise its features. As table 2.8 (annex 1) shows, on average, the high periods given by the six variables were twenty-eight years long, and the low periods were thirty-two years long. This suggests an overall 'cycle periodicity' of sixty years. The three cycles actually observed in these variables were, on average, sixty-one, fifty-two and sixty-seven years long.

4) Within the limits set by (1) above, there is evidence for the existence of a third factor or set of factors influencing variations over time in the potential for environmental change. There is both visual and statistical evidence of this influence in the patterns of variation in the frequencies of innovations with major versus minor impacts. But although the existence of this influence can be established, its nature is not amenable to simple and coherent characterisation.

(C2) Unit input levels

The statistical evidence for the existence of periodization of changes in unit input levels is provided by the fact that sequences of residuals were consistently found to be significantly clustered. For the five variables whose values were taken from existing sources, the clustering was significant at the .01 level in each case. For the four remaining variables, any one of which constitutes additional, independent evidence, the clustering was significant at least at the .10 level.

In trying to characterise the nature of this periodization, all nine variables were used, the data being plotted in figures 2.19 to 2.27 (annex 2). Lying beneath the year to year variations, we can identify a periodization on the basis of the rate at which unit input levels changed. We can distinguish some periods of rapid change - either increase or decrease, and others where levels were basically stable, or changed only relatively slowly. As picked out by eye, the approximate dates of boundaries between such periods have been shown on the figures.

There are sufficient similarities between the inputs in each class so that we can abstract patterns of change that are characteristic of each class as a whole.

All three old inputs have a central period in which unit levels decreased rapidly, followed by one in which they were very stable. Each also has an initial period in which levels oscillated around stability (ore and BF solids) or slower decline (coke). As well as this basic pattern being held in common, the length of periods and the dates of the boundaries were similar in all three cases. The pattern for old inputs in general can therefore be abstracted as shown in figure 2.8 below.

Apart from the rapid decline in unit levels of scrap iron used from about 1968, the most important feature of variation in scrap usage is that they have basically been stable over the period of study.[1] There is evidence that variation around these constants was not random. As the plot for total scrap (figure 2.23) shows, there appears to have been a cyclical variation around the trend, with a periodicity of five or six years - clearly a different phenomenon to the periodization of the underlying rate of change observed for old inputs.

The plots for the new inputs provide evidence of a character-

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[1] The linear regression slope coefficients for steel scrap and total scrap are virtually identical to zero.

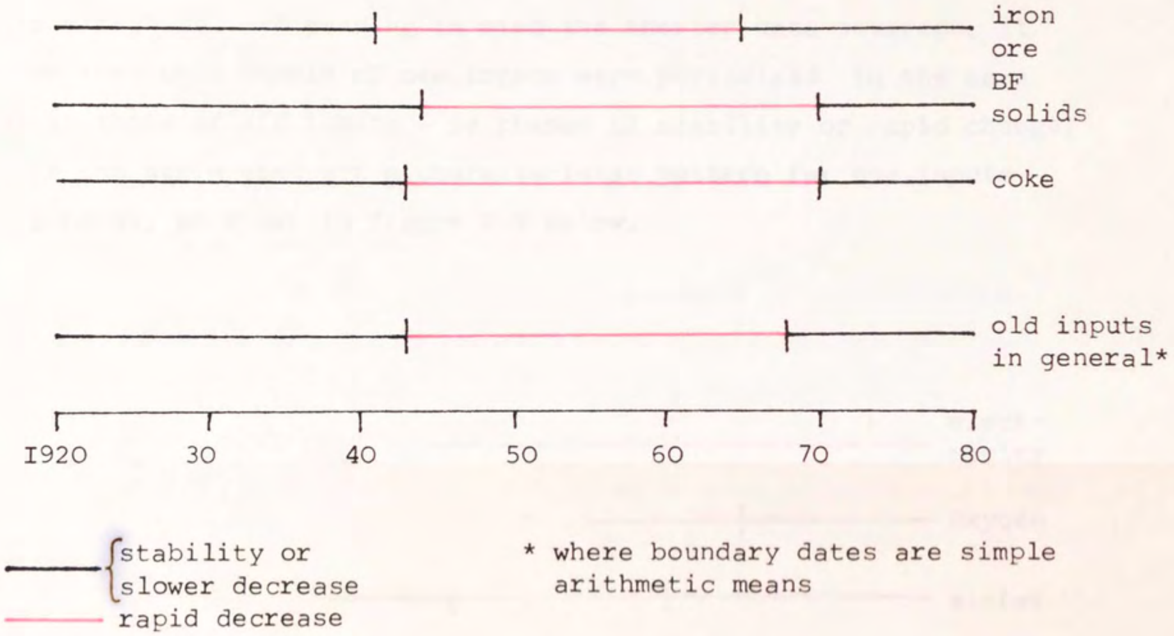

Figure 2.8 - Distinctive periods of change in unit input levels of old inputs

istic pattern similar to that in old inputs, though less clear cut. From about 1950 to 65, all three new inputs experienced very rapid increases. In the case of sinter, which has the longest data coverage of the three, this was preceded by a distinct period in which unit input levels were stable. For both sinter and oxygen, the rapid increase phase was also followed by one of stability, though rates of increase of electricity did not fall off in the same way. With this exception, and bearing in mind the shorter data coverage, it seems that unit levels of new inputs were periodized in the same way as those of old inputs - ie phases of stability or rapid change. So we can again abstract a characteristic pattern for new inputs in general, as shown in figure 2.9 below.

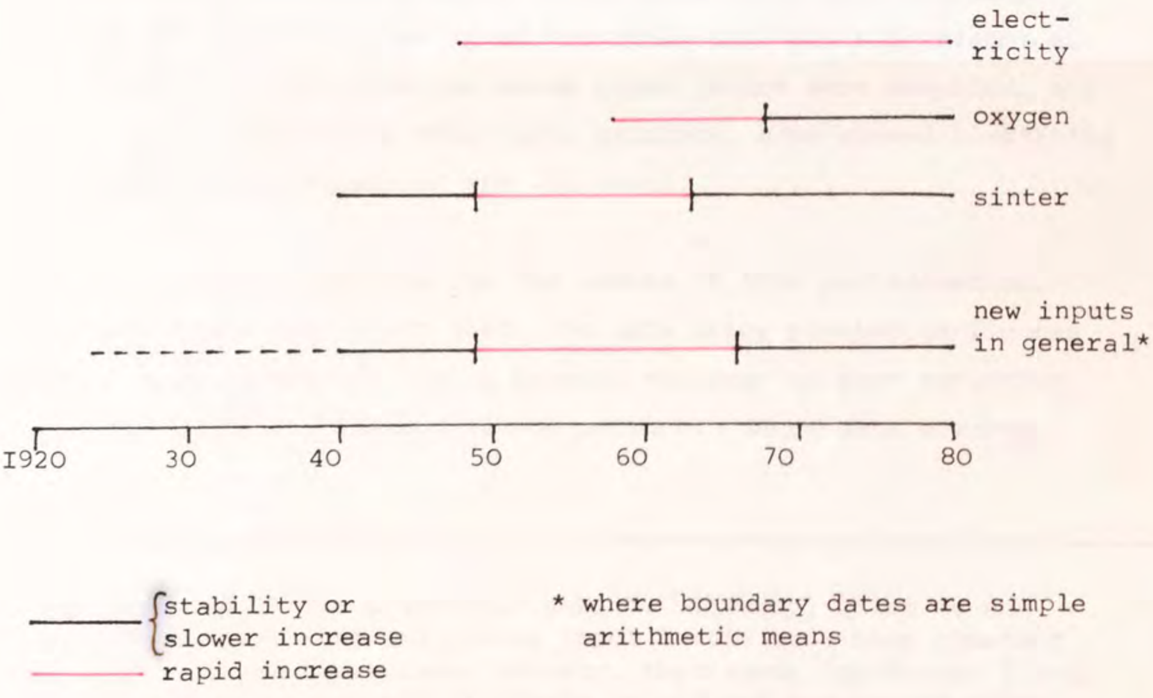

Figure 2.9 - Distinctive periods of change in unit input levels of new inputs

The generalised patterns for old and new input classes are not only similar in their basic form, but also as regards the length and timing of the periods. As shown in figure 2.10 below, we can, therefore, further abstract to a descriptive model of changes in unit input levels in general. Scrap levels are seen as being constant,[2,3] and all other inputs are seen as having a central period of rapid change surrounded by periods of stability. Figures 2.19 to 2.27 provide only two cases of deviation from this model (both in the period after 1969 - the decrease in unit scrap iron levels and the increase in unit electricity levels).

(C3) Gross consumption level

The statistical evidence for the existence of periodization of changes in gross consumption levels is also very strong. The six independent variables whose values were taken from existing sources all showed clustering of residuals that was significant at the .01 level. The three variables whose values were computed, any one of which constitutes additional evidence, also showed clustering of residuals significant at the .01 level.

In trying to characterise the nature of this periodization, all nine inputs were again used, the data being plotted in figures 2.28 to 2.36 (annex 2). Lying beneath the year to year variation there was a distinctive and common pattern. Where data coverage

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[2] Over this particular sixty year period. Clearly, there is no implication here that unit scrap input levels have been constant for ever. We can speculate, however, that scrap inputs are likely to conform to the pattern of change in old and new inputs after 1920. In this case, we would expect that changes in scrap input levels in the past were probably concentrated into fairly short periods when other input classes were also undergoing rapid change.

[3] The assumption of constant levels of unit scrap inputs does not sit very easily with the fact that the scrap variables also showed significant clustering of residuals. But the visual evidence clearly showed that the periodization was of a different type to that in old and new inputs. And this also shows up in a detailed look at the statistical analysis. Of the three input classes, the scrap input variables had the shortest average 'run length' and the lowest average Z score. Both features are indicators of a periodization which, if regular, would have a shorter 'cycle length'.

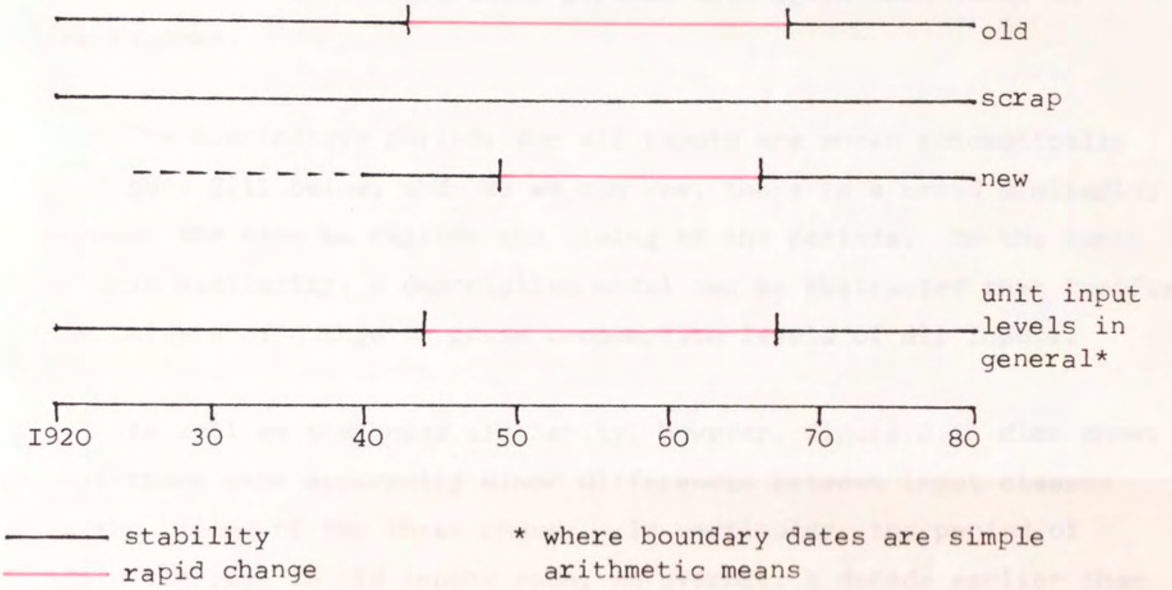


Figure 2.10 - Distinctive periods of change in unit input levels in general

was long enough, all variables showed an initial period in which gross consumption levels were stable or falling slowly. All variables indicated a central period where levels increased rapidly. And for all inputs except one, the final period was one of rapid decrease in consumption. The exception was electricity, the consumption of which remained stable over the final period. The approximate dates of the boundaries between these periods have again been shown on the figures.

The distinctive periods for all inputs are shown schematically in figure 2.11 below, and, as we can see, there is a broad similarity between the nine as regards the timing of the periods. On the basis of this similarity, a descriptive model can be abstracted that typifies the pattern of change in gross consumption levels of all inputs.

As well as the broad similarity, however, figure 2.11 also shows that there were apparently minor differences between input classes in the timing of the three phases. In particular, the period of rapid increase in old inputs ends, on average, a decade earlier than that in new or scrap inputs. Also, it may be that the period of rapid increase in new inputs starts later than in old or scrap inputs (though this is based on only a single observation).

Before going on to summarise all the results of Section C, there is one further point concerning data dependency that needs to be discussed. There are only two inputs for which the data at unit and gross consumption levels were independent (coke and sinter). For the remaining seven inputs, there were mathematical links between the variables used to measure changes at the two descriptive levels. There is, therefore, a question about the extent to which the patterns described at the two levels can be seen as being separate. The problem is that the periodization observed in a computed variable at one level may just be a reflection of, or an alternative way of illustrating that which already exists in the independent data at the other level. This would be a serious problem if all the estimations were in the same direction. For example, if the seven variables with computed

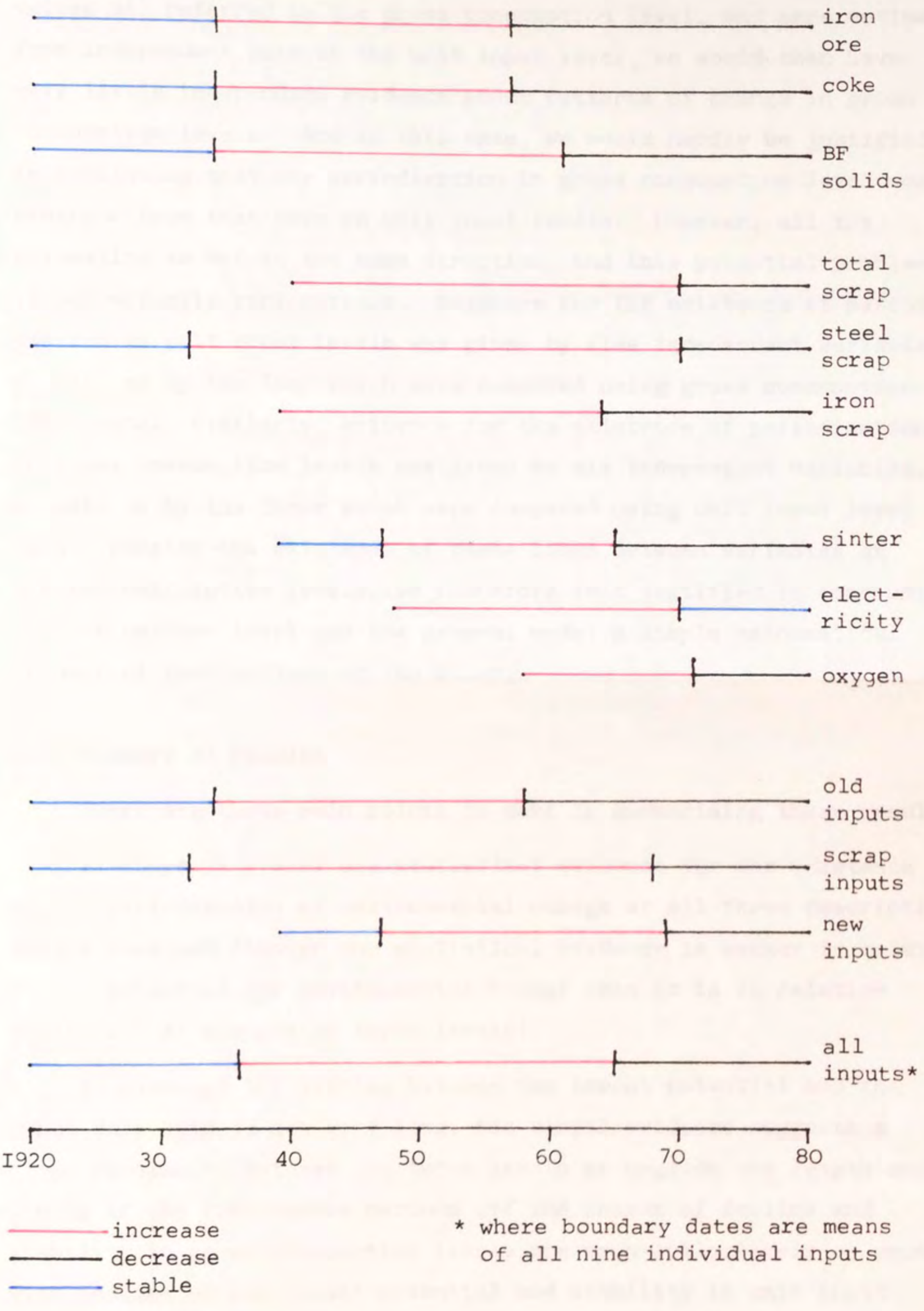


Figure 2.11 - Distinctive periods of change in gross consumption levels

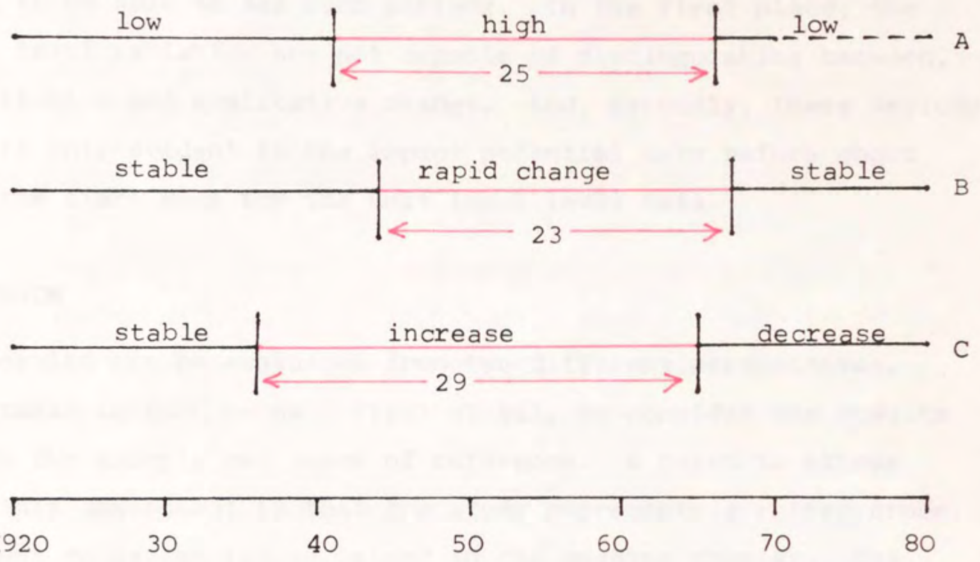
values all referred to the gross consumption level, and were estimated from independent data at the unit input level, we would then have very little independent evidence about patterns of change in gross consumption levels. And in this case, we would hardly be justified in concluding that any periodization in gross consumption level was separate from that seen in unit input levels. However, all the estimation is not in the same direction, and this potential problem is not actually very serious. Evidence for the existence of periodization in unit input levels was given by five independent variables, as well as by the four which were computed using gross consumption level data. Similarly, evidence for the existence of periodization in gross consumption levels was given by six independent variables, as well as by the three which were computed using unit input level data. Despite the existence of these links between variables at the two descriptive levels, we therefore felt justified in concluding that at neither level was the general model a simple mathematical product of that evolved at the other.

(C4) Summary of results

There are three main points to make in summarising these results:

1) There is visual and statistical evidence for the existence of the periodization of environmental change at all three descriptive levels examined (though the statistical evidence is weaker in relation to the potential for environmental change than it is in relation to the actual changes in input levels).

2) Although the overlap between the impact potential and the input data sets is not very long, the visual evidence suggests a close similarity between the three levels as regards the length and timing of the distinctive periods (if the phases of decline and stability in gross consumption levels are seen collectively as equating with periods of low impact potential and stability in unit input levels). The comparison is shown in figure 2.12 below.



A - potential for environmental change (boundary dates from table 2.9)
B - unit input levels (boundary dates from figure 2.IO)
C - gross consumption levels (boundary dates from figure 2.II)

Figure 2.12 - Distinctive periods of environmental change at the three levels of description

3) There is no evidence in the unit input data that we can recognise periods of bias, towards either improvement or deterioration, or towards either quantitative or qualitative changes. But we would not expect to be able to see such periods. In the first place, the unit input level variables are not capable of distinguishing between, say, quantitative and qualitative change. And, secondly, these periods of bias were only evident in the impact potential data before about 1920 - ie the start date for the unit input level data.

2D DISCUSSION

The results can be evaluated from two different perspectives, which are taken in turn below. First of all, we consider the results from within the study's own terms of reference. A point to stress in making this assessment is that the study represents a rather crude, first attempt to get at issues raised in the opening chapter. The central question, of whether or not environmental change has been periodized, was not precisely formulated beforehand. No particular guidelines were set out as to what would or would not constitute periodization, in terms of length, regularity or distinctiveness. And although the broad types of data sought were guided by theoretical considerations, the actual data used was rather an ad hoc mixture - one experimental set of soft indicators, and the harder data dictated by what happened to be available. Consequently, the statistics used had to be adaptable and robust. The use of more sophisticated techniques was neither possible nor justified.

Given this context, there are two features of the results that were particularly gratifying. First of all, the study did provide a very clear affirmative answer to the central question about the existence of periodization. And, furthermore, it was generally possible to draw up simple and clear descriptions of the patterns, descriptions that were deviated from considerably less than might have been expected (given, for example, the relatively small number of inputs examined).

The second pleasing feature of the results is the fact that the impact potential data proved to be quite a good indicator for the broad outline of periodization in the harder, input data. This suggests that innovation-based indicators may be a very useful approach to historical, environmental research.[4]

However, there were also problems arising from the rough-and-ready nature of the project. First of all, the impact potential data rather fell between two stools. It was more than adequate for giving an answer to the basic question, in the sense that it suggested at least two, and possibly three separate periodizing influences. However, it was not sufficiently sophisticated to really separate out and characterise these influences. They were compounded in the variables used, and not much other than their existence could be deduced. The results therefore served as a hint of the possibilities that the innovation-based approach to environmental change contains. But to further explore and develop these possibilities, we would need finer data than was used in this study. In this context, it would probably be a useful exercise to take a shorter time period, such as just the nineteenth century, and study the patterns of innovations and their environmental implications in greater depth, perhaps using a number of particular iron and steelmaking locations as case studies, rather than taking in the whole national industry.

The second problem is highlighted by the generally low significance levels attached to the periodization in the impact potential data. The contrast between this and the often compelling visual

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[4] Where they would be a welcome addition to the very small collection of softer indicators that have already been tried. For example, T Baines (ref: 5) used state regulatory action on the environment as the basis for a long term historical indicator (also, incidentally, finding evidence of periodization). This is a 'response' type of indicator, measuring concern, and, because of its data sources, is inherently an indicator relevant to the national level. In contrast, and as a complementary tool, the innovation-based indicators used in this study are industry-specific and look at causes of environmental change, rather than responses to it.

evidence pointed to a problem of method. The Z scores obtained from the runs test, and their significance levels depend on two factors. The first is the periodicity of any cyclical variation that may exist in the real world. The second is the way we aggregate the point-in-time events (innovations). In this case, aggregating into frequencies per decade, and assuming a perfectly regular cyclical variation of sixty years periodicity, each 'run' of positive or negative residuals would cover only three observations. On average, over the two hundred and seventy years, we would expect ten runs, giving a Z score of about -1.8, significant at the .05 level. And, as table 2.7 shows, even two or three extra runs in the data yield Z scores with very low significance levels. Although adequate in relation to the input data, it might have been better, in retrospect, to have used some other method of assessing the significance of apparent periodization in the impact potential data.

The second perspective from which the results were assessed is given by putting them in a broader context. The general question is to what extent are the results likely to apply outside the immediate scope of the study? And several particular questions follow from this. First of all, the data was very much biassed towards the resources side of 'environmental change'. The impact potential data did take into account the pollution changes associated with innovations, and therefore provided evidence that the potential for changes in pollution was periodized. But all the materials balance data related to inputs, and the study therefore provided no evidence that changes in actual unit or gross pollutant levels were periodized. The question, therefore, is whether or not the patterns of change in pollutant levels actually were similar to those observed in input levels. We can speculate that this is likely. First of all, the unit input level patterns were almost exactly what we would expect from those in the impact potential data - ie rapid changes in input levels coinciding with high frequencies of innovations with environmental impacts, and stable input levels coinciding with low frequencies. And there is no obvious reason to think that the relationship between innovation frequency and rate of change in unit pollutant levels should be any different. Secondly, changes in unit input levels are themselves one of the main sources of variation in unit pollutant levels. Other things being equal, we would therefore expect patterns of change in unit input levels to be transmitted to, and reflected in changes in unit pollutant levels. However, technical change may also affect the ratio between amounts of inputs and wastes per unit of output, and the study provides no evidence about the stability or otherwise of this ratio. So, although we can speculate, with reason, that similar patterns of change are likely to have characterised pollution levels, without some further work the case cannot be proven either way, and conclusions about the periodization of 'environmental' change must remain qualified.

Secondly, the input data was quite short, and there is clearly a question as to whether the distinctive periodization observed after 1920 was actually present beforehand. This is not a question that can be given a certain answer, since the data does not exist. But further work would make it possible to give a likely answer. In the period after 1920, the impact potential data appears to give a reasonably good 'prediction' of the broad patterns of change in unit and gross consumption levels. And, of course, if it provides the same accuracy of prediction over the whole study period, we would then expect to find that input levels were indeed periodized before 1920. To find out whether the impact potential data is likely to have the same predictive use before 1920 would involve two stages. First of all, we would have to establish the source of this accuracy over the last sixty years of the study. And this would involve looking at patterns of change in the factors other than innovation that influence input levels. If innovation creates the potential for change, the main factor that determines whether and how rapidly that potential is fulfilled is the rate of diffusion of relevant innovations. Over the last sixty years of the study, it is therefore likely to have been a particular pattern of diffusion that has 'allowed' the periodization of the potential to be straightforwardly transformed into an observable periodization of actual change in unit input levels. And, similarly, a particular pattern of change in output levels is responsible for the link between the patterns observed after 1920 in unit and gross consumption levels. The first stage would therefore be to map out the patterns of diffusion and output growth since 1920. And the second stage would be to establish whether these patterns extended back into the period before 1920. If the relationships between innovation, diffusion and output were the same before 1920 as they were afterwards, we would then be in a strong position to argue that relationships between innovation, unit and gross consumption levels would also be the same. And, conversely, such an analysis could, of course, also serve to suggest that the impact potential data would provide a less accurate indicator of actual patterns of change in input levels before 1920.

The third respect in which the study data is restricted is that it only measures environmental change at levels within what we might call the 'production' sub-system. We have no data relating to the objective, 'ecological' levels - such as changes in ambient carriers or in impacts on targets. Nor do we have any data relevant to the levels of 'social' recognition, concern or response to environmental problems. And the question therefore arises as to whether or not the periodization observed at the level of the production sub-system was also present at the ecological and social levels of description. The fact that changes at the materials balance levels may have no impact at ecological or social levels is well put by N Haigh, in relation to the possible policy responses to pollution problems:

> "(It follows from this definition that) if the pollutant reaches no target in damaging quantities because it has been rendered harmless either by being transformed into another substance or into a form where it cannot affect the target because it has been diluted to harmless levels, then there has been no pollution. It also follows that the mere emission of a potential pollutant to the environment does not necessarily constitute pollution (and that to eliminate pollution, one does not have to restrict emissions to zero)."
>
> N Haigh (ref: 19, p 27).

There are problems with this definition. In particular, it seems to exclude from the definition of pollution those emissions that raise the concentrations of 'potential' pollutants in ambient carriers towards, but not beyond some threshold that is critical for given targets. (For example, do radioactive discharges into the Irish Sea constitute pollution or not?) But, even if we accept the general validity of the point being made, there is ample evidence that, in the iron and steel industry at least, changes at the production levels have led fairly directly to pollution problems at these other levels of description, problems that have long been of concern to the industry, the public and the state. And, indeed, the industry was chosen partly because it would minimise the extent to which the study could be charged with dealing in 'potential' rather than 'actual' environmental problems.

But even if it is undeniable that production level changes have had their impacts at these other levels of description, the question still remains as to whether or not there was any periodization. In trying to answer this question, the first point to make is that if we had the relevant empirical data, it would no longer be industry specific. For example, the iron and steel industry is a producer of sulphur oxide pollution, but so are many other industries. Whether or not there has been any periodization in the concentrations of sulphur oxides in the atmosphere therefore depends on patterns of variation in the amounts emitted by these other industries as well as on the activities of the iron and steel industry. Carrying on with the example of sulphur oxides, we don't know whether, and how directly any periodization of gross amounts emitted might be reflected in the periodization of ambient concentrations.[5] But, for there to be any similarity between the periodization of changes at the gross materials balance level in the iron and steel industry and patterns of change in ambient conditions or impacts on targets, it would clearly be a prerequisite that emissions from the other industries relevant to a given pollution problem followed the same sort of pattern of change as did those in the iron and steel industry (otherwise the

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[5] And to take things a stage further, whether, and to what extent it might show up as periodization of the impact on targets such as trees, fresh water crustacea or masonry.

patterns of emission from the individual industries would tend to conflict, rather than reinforcing each other, so that no periodization of ambient conditions would occur).

So, we cannot adequately address the question of whether periodization of environmental change is likely at ecological and/or social levels of description without reference to the question of whether the patterns of change observed in the iron and steel industry are likely to have been present in other industries as well. And this is the fourth aspect of the restricted nature of the study that we need to consider when evaluating its results. The first point to note, in this context, is that the environmental changes described in the study are outcomes, whose causes, at this stage, are not known. It is hypothesised that they result from periodization in aspects of profitability and technical change that are assumed to be causally linked with environmental change. But, so far, we have no evidence to this effect.

And given that this is the case, there are three interpretations we can make of the results. First of all, it may be that all the causal factors are tied together in a single, systematic and periodized relationship that explains all the observed results. Second, it may be that the results can be explained by the factors assumed to be causally important, but in terms of a series of basically separate events that are not a part of a single dynamic process operating over time. Thirdly, it may be that, despite their apparently clear-cut nature, the periodizations observed cannot be accounted for by reference to those factors assumed to be causal. In this last case, we might conclude that, despite the evidence to the contrary, the results had actually arisen by chance, and that there was therefore no reason to expect to find the same patterns of change in other industries. Under both the other interpretations, the implications for other industries would depend on how widespread in the economy were the processes or events held to be responsible for the observed patterns of change in the iron and steel industry.

At one extreme, the explanations might invoke processes or events that were specific to iron and steel, in which case we would not necessarily expect the pattern of outcomes to be the same in other industries. At the other extreme, explanations may involve processes or events relevant nationally or even internationally. In this case we would expect to find that environmental change had in some way been similarly periodized in many other industries. And in this last case, of course, we would then have the condition stated as a prerequisite for expecting that there might be periodization of environmental change, as measured at ecological and/or social levels of description.

2E CONCLUSIONS

We can conclude that, in the UK iron and steel industry between 1700 and 1980, there were significant patterns in the distribution over time of the variability in environmental outcomes. In particular, at all descriptive levels examined, we could identify distinct periods, contrasted in terms of types and/or rates of environmental change.

The study therefore provides some evidence of the utility of the focus on questions of distribution. It helps us to progress beyond the apparent impasse created by the traditional approaches to relationships between profits, technical and environmental change. In particular, it provides an empirical input to the meso level of analysis that offers hope of bringing micro and macro levels of analysis together without an irreconcileable conflict. In the traditional micro level analyses, the conditions governing environmental outcomes are taken as given, so that we have no way of predicting outcomes without reference to those conditions. By showing that outcomes are periodized, the study suggests a periodization in those conditions which govern the sort of outcomes resulting from profit-maximisation. And, in turn, this draws us away from the ideas about the 'universal nature' of capitalism that are at the source of the conflict between the neoclassical and neomarxist macro levels of analysis. Perhaps, with regard to environmental change, the important thing is not those aspects that are universal (whatever we believe them to be), but rather, is those aspects, those conditions that appear to change periodically. Any proposed, but unproveable, fundamental bias towards improvement or deterioration, say, is less important an influence on actual outcomes than the apparent periodization of conditions that are not the universal, defining features of capitalism. For practical purposes, the case study results suggest that neither macro level proposition has any validity in general, though both have in particular and different periods.[6] The meso level of analysis therefore gives us a way of partially reconciling the conflict present in traditional macro level approaches, as well as grounds for seeing the variability in conditions governing particular outcomes as being other than randomly distributed over time.

A glimpse of the possible utility of this approach is therefore provided, despite the fact that this study represents rather a crude first attempt to get at these issues. But, as the discussion above demonstrates, the implications we can draw from the results are limited by the nature and scope of the study. And three areas of further work are seen as being particularly important in this context. First, in order to further explore the utility of innovation-based indicators of environmental change, and in order to more clearly understand the role of innovation itself, it would be useful to study in greater depth and detail the patterns of innovation over time, and their environmental implications. Second, some sort of work on the pollution side is really needed before we are justified in talking about the periodization of environmental change, even in the restricted sense of changes at levels within the production subsystem. And third, it would be of great value to try to account

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[6] At impact potential and gross consumption levels, at least, where there was evidence of improvement and deterioration being concentrated into different periods. At the unit input level, the breakdown was into periods of no improvement or deterioration and periods of both.

for these case study results in terms of those aspects of profitability and technical change assumed to have a causal influence. In the absence of data that is either difficult or impossible to get hold of, this should allow us to make reasoned arguments about the broader applicability of the results as regards materials balance changes before 1920, as regards other industries and as regards the ecological and social levels of description of environmental change.

2F Annex 1: Data Tables

Table 2.1 - Innovations in the UK iron and steel industry

Code	Date[2]	Description	Sources[1]
*1		Bloomery wrought iron process	
*2	1500	Early blast furnace cast iron	(15:20-23, 70)
*3		Thick walled cast iron	
*4	1590	Water powered slitting mill (wrought iron strips)	(15:26-28)
*5		Cementation process (blister and shear steel)	
6	1709	Coke-fired blast furnace	(15:31-33)
7	1740	Crucible steel process (mild carbon)	(15:35-36)
8	1775	Reciprocating blowing engine (Watt)	(15:38,39)
9	1762	Rotative blast furnace blowing engine (Boulton and Watt)	(15:42)
10	1785	Reverberatory furnaces for wrought iron production (dry puddling)	(15:43-45, 62,65)
11	1784	Grooved rolling mills to conslidate wrought iron bloom	(15:47) (24:88)
12	1795	Cupola for remelting iron	(15:51)
13	1829	Hot blast	(15:55-58)
14	1835	Water-cooled tuyeres in blast furnaces	(15:58)
15	1832	Round hearths in blast furnaces	(15:59)
16	1838	Pressurised blast	(15:59)
17	1820	Recycling of cinders to blast furnace input charge	(15:59,60)
18	1816	Use of iron oxide linings in wrought iron furnaces (wet puddling)	(15:62-65, 70)
19	1839	Fettling	(15:64)
20	1827	Use of waste heat from puddling furnaces in boilers	(15:66)
21	1846	Heat extracted from blast furnace waste gases and recycled	(15:67)
22	1850	Single bell and hopper (reduces blast furnace gas escapes to charging phase)	(15:68,69)
23	1840	Steam hammer for shingling bloom	(15:74,75)

Code	Date	Description	Sources
24	1856	Acidic Bessemer process (flawed)	(15:90-96, 103,111)
25	1857	Use of phosphorous-free pig iron in acid Bessemer process	(15:95)
26	1857	Use of magnesite in acid Bessemer process (reduces oxygen content of steel)	(15:95)
27	1868	'Self-hardening' tungsten steel	(15:96,97)
28	1864	First book on scientific analysis of iron	(15:98)
29	1866	Open hearth steel process	(15:98-102)
30	1879	Basic Bessemer process (use of dolomite allows phosphoric pig iron input)	(15:107,108)
31	1855	Cast steel	(15:113)
32	1876	Sheet steel (first rolled)	(15:114)
33	1857	Cowper regenerative hot-blast stove	(15:115)
34	1861	Copper/gunmetal tuyeres	(15:115)
35	1868	Closed forepart to blast furnace	(15:116) (28:2)
36	1898	Pig casting machines	(15:119)
37	1900	Taphole clay gun	(15:119) (8:209)
38	1905	Mechanical blast furnace charging	(15:119,121)
39	1902	Double bell and hopper	(15:120) (8:209)
40	1883	Electricity used for light steel rolling	(15:121)
41	1878	Universal steel plate mill	(15:122)
42	1905	Universal steel beam mill	(15:123)
43	1948	Meehanite cast iron	(15:125)
44	1948	Spheroidal graphite cast iron	(15:125)
45	1890	Nickel/iron alloy (cast iron)	(15:125)
46	1892	Chromium/iron alloy (cast iron)	(15:125) (25:1892)
47	1894	Cupronickel/iron alloy (cast iron)	(15:125)
48	1887	Manganese alloy steel	(15:127) (13:Vol 17:642)
49	1902	Silicon alloy steel	(15:128) (13:Vol 17:642)

Code	Date	Description	Sources
50	1893	Chromium alloy steel	(15:128-146)
51	1908	Electric reverse-rolling mill	(15-146)
52	1903	Standards set for iron and steel beams and sections	(15:147)
53	1908	Electric arc furnace (steel)	(15:147,148) (8:219) (6:185)
54	1938	Continuous wide strip rolling mill	(15:149,150)
55	1944	Electrolytic tin plating of sheet steel	(15:151) (13:Vol 17:642)
56	1938	Fully automatic blast furnace charging	(15:155) (8:552)
57		Partial sintering of blast furnace charge	
58	1960	Bulk oxygen steelmaking (L D process)	(15:156-158) (9:64)
59	1939	In-furnace spectrographic steel analysis	(15:158) (25:1939)
60	1946	Continuous steel casting	(15:159,160)
61	1788	Steam lifts for blast furnace charging	(15:119)
62	1785	Steam power used to haul blast furnace charging waggons	(15:161)
63	1785	Refining of pig iron before dry puddling	(15:46)
64	1965	Improved continuous steel casting	(15:161)
65	1954	Automatic gauge and tension control in sheet steel milling	(15:161)
66		Flying micrometer gauge controls	
67	1922	Electric induction furnace for alloy steels	(15:163) (8:219)
68	1955	Vacuum melting of special steels	(15:164) (30:13)
69	1962	Vacuum degassing in bulk steel production	(15:165) (30:13)
70		Aston Byers process (wrought iron)	
71		Water powered tilt hammer for wrought iron processing	
72	1782	Helve hammer	(15:24,75,76) (49:472)
73		Wrought iron grades, established	
74	1852	Wrought iron joints (first rolled)	(15:79)

Code	Date	Description	Sources
75	1863	Microscope analysis of iron and steel	(15:98)
76	1952	Fully sintered blast furnace charge	(15:155)
77	1961	Automatic steel billet cutting	(15:167,168)
78	1862	Continuous rolling of wrought iron	(15:105)
79		Two-high rolling mills (wrought iron)	
80	1815	Three-high rolling mills	(15:83)
81		Rolling mill guide passes	
82	1850	Hot-saw billet cutting	(15:86)
83	1884	Gauge standards for wrought iron sheet	(15:87)
84	1862	Mechanical manipulation in rolling mills	(15:103)
85	1866	Reversing mill	(15:103)
86	1864	Looping mill	(15:104)
87	1888	Nickel steel	(32:54-56)
88	1903	Molybdenum steel	(32:54-56) (13: Vol 17: 642)
89	1903	Vanadium steel	(32:54-56)
90	1903	Titanium steel	(32:54-56)
91	1937	Chemical production of refractory magnesia	(32:57)
92	1941	Improvements to hydraulic forging presses	(32:68)
93	1905	Heat-resisting steel alloys ('high speed')	(32:71) (8:221)
94	1840	(Zinc) galvanised sheet steel	(32:71) (49:625)
95	1887	Seamless steel tubes	(32:73,74) (49:629)
96	1897	Ferro-concrete	(32:92) (49:490)
97	1955	Four-high steel plate rolling mills	(32:109)
98	1869	Use of fuel oil in blast furnace charge	(32:113)
99	1868	Iron and Steel Institute (cooperative research and development)	(32:116)
100	1890	Active mixers (prerefining of molten pig for open hearth steel)	(32:117) (8:217)
101	1948	Oxygen use in electric arc furnaces	(32:117) (9:117)
102	1947	Oil-firing of open hearth furnaces	(32:121) (3:197)

Code	Date	Description	Sources
103	1720	Hot-dip tinplating	(15:46)
104	1830	Pickling (acid cleaning of steel sheet)	(15:150) (49:616)
105	1708	Thin-walled iron casting	(24:40)
106	1742	Newcomen engine (steam assistance in blast furnace blowing)	(24:70)
107	1735	Use of coal as coal in wrought iron chafery	(24:82,83)
108	1762	Coal-fired potting process (wrought iron)	(24:83)
109	1772	Coke-fired potting process	(24:84)
110	1790	Cast iron tops to dry puddling furnaces (replaces clay)	(24:100)
111	1790	Sea sand floors to dry puddling furnaces	(24:100)
112	1818	Cast iron floors to puddling furnaces	(24:142)
113	1823	Use of molten pig iron in wrought iron puddling	(24:143)
114	1837	Use of anthracite in blast furnaces	(24:159)
115	1942	Hot-blast cupolas in steel foundry sector	(13:Vol 17:643)
116		Stainless steel electrostatic precipitation in crude steel production	
117		'First stage' particulate matter arrestors used in blast furnaces	
118		'Second stage' PM arrestors	
119		'Third stage' PM arrestors	
120	1891	Tropenas furnaces in steel foundries	(8:214)
121	1964	Fume arrestors fitted to tropenas furnaces	(2:1973)
122		Cold-blast cupolas in foundry sector	
123*	1970	PM arrestors in open hearth furnaces using light oxygen	(2:1973)
124	1956	Use of light oxygen in open hearth furnaces	(3:143)
125	1959	Bulk use of oxygen in open hearth furnaces	(3:143)
126		Iron ore calcination	
127	1955	Use of cyclone arrestors in hot-blast cupolas	(2:1960)
128		Use of electrostatic precipitation for PM reduction in steel making	

Code	Date	Description	Sources
129	1893	Nickel/chrome steel	(13:Vol 17:642)
130	1942	Boron steel	(13:Vol 17:642)
131	1947	Continuous galvanising	(13:Vol 17:642)
132		Aluminium steel coating	
133		'Organic' steel coating	
134	1881	Use of fluorspar as flux in basic steelmaking	(13:Vol 17: 642)
135	1947	Oxygen enrichment of basic Bessemer blast	(3:129) (3:181)
136	1958	Oxygen/steam enrichment of basic Bessemer blast	(3:129) (3:191)
137		Oxygen/carbon dioxide enrichment of basic Bessemer blast	
138	1963	LD/AC process (bulk oxygen steel)	(3:136) (3:206)
139	1965	Kaldo process	(3:138) (3:141)
140	1961	Rotor process	(3:140) (27:52)
141	1836	Mechanical puddling furnaces	(8:56)
142	1786	Steam-powered slitting and rolling mill	(8:57)
143	1845	Corrugated iron sheet	(8:58)
144	1866	Hydraulic forging press	(8:61) (49:616)
145	1882	By-product coke oven (for tar and oils)	(8:153)
146	1892	Flying shear (billet cutting)	(8:162)
147	1907	Gayley's dry air blast (blast furnaces)	(8:210)
148	1903	Stock converter (steel foundries)	(8:215)
149	1902	Tilting open hearth furnaces (continuous production)	(8:215)
150	1913	Ferro-uranium	(8:222)
151	1913	Ferro-tantalum	(8:222)
152	1935	Blast furnace slag granulated for building blocks	(8:551)
153		Steel/plastic laminates	
154	1880	Steel tinplate	(8:114)
155	1759	Beehive coke ovens	(8:54)
156	1872	Retort coke ovens (non-recovery)	(8:54)

Code	Date	Description	Sources
157	1951	Use of oxygen for prerefining molten pig iron (in ladles or mixers)	(9:20)(9:33)
158	1947	Use of oxygen in tropenas furnaces	(9:74)
159	1949	Oxygen enriched blast (blast furnaces)	(9:159)
160	1954	Pelletising (blast furnace charge preparation)	(9:160)(13: Vol 9:895)
161	1948	Oxygen enrichment of cupola blast	(9:204)
162	1881	Blast furnace gas washing, to reclaim ammonium sulphate	(28:3)
163	1884	Carvés process (removes sulphur from sulphur oxides in coke oven gases)	(28:133)
164	1950	Scarfing (oxygen billett cleaning)	(9:162)
165		Coke oven gas washing	
166		Activated sludge process to deal with coke oven liquors	
167	1947	British Iron and Steel Research Association	(3:184)
168	1918	National Federation of Iron and Steel Manufacturers	(3:155)
169	1969	Regenerative process to reclaim acids from pickling liquors	(38:133)
170*	1972	Ion exchange process to deal with tinplating electrolytes	(28:242)
171	1894	Electric drives for heavy steel mills	(49:594)
172	1949	Automatic combustion control in open hearth furnaces	(27:2)
173		Reduction of sulphur oxide content of waste gases from open hearth and electric arc steelmaking	
174		Carbonate process for pickling liquor acids (neutralises them)	
175		Oxide process (uses iron oxide to remove hydrogen sulphide from coke oven gases)	
176		Electrostatic precipitators used to clean scarfing fumes	
177		Mechanical extractors and tall chimneys used to control fume from electric arc furnaces	
178	1960	Fume arrestors applied to oxygen converter steelmaking processes	(29:80)
179	1962	Electrostatic precipitators used in open hearth furnaces using bulk oxygen	(29:65)

Code	Date[2]	Description	Sources[1]
180	1959	Bag filters in electric arc furnaces using bulk oxygen	(29:144)
181	1953	Wet washers in electric arc furnaces using bulk oxygen	(29:150)

[1] In addition to sources cited in relation to innovation dates, further works were used to gather information on other technical and environmental aspects of the innovations (see references 79 to 85).

[2] In most cases, the exact date of the innovation is known (where innovation was defined as first commercial use in the UK). In the remainder, innovation dates were estimated to within two or three years. For example, references to innovations in the 'early', '*mid*' or 'late' 1880s would be recorded as 1882, 85 and 88 respectively.

*Innovations not used when calculating period frequency data which runs from 1700 to 1969 inclusive.

Table 2.2 - Environmental impacts of innovations

Notes

(1) When trying to detail the environmental impacts of innovations, there was a boundary question to be addressed, particularly with reference to inputs, but also as regards the wastes produced in their collection and use. Considering iron and steel production as a linear process chain, the question was how far back along the chain should we go? For example, iron ore is the essential ingredient in pig iron, and since 1700 the unit amount needed has been substantially reduced by technical change. But the mining and transport of the ore also requies inputs and produces pollution, and these operations have also been altered by technical change. Clearly, we cannot include all these inputs or wastes. For instance, one of the inputs is human labour power, but the reproduction of the labour force involves environmental withdrawals and additions way beyond the scope of this study. It was necessary to draw the boundary line somewhere, and certain 'basic' inputs were taken as given. Those occurring most often included iron ore, coal, wood, oil, oxygen and human labour power. Others occurred less frequently, and these included dolomite, animal power, sulphuric acid, tin and gravity.

(2) Where known, all impacts were recorded, as far back along the relevant process chain as possible. For example, there were several innovations resulting in a reduction in the amount of pig iron needed to produce a unit amount of crude steel. Since less pig iron was needed, there was also a reduction in the amount of blast furnace wastes per unit of crude steel. Similarly, there were reductions in amounts of blast furnace inputs needed, such as coke and prepared ore. But these inputs are 'intermediate' rather than basic. The reduction in coke, for example, implies a reduction in the amount of coal needed per unit of crude steel. It also implies a reduction in the amount of coking wastes per unit of crude steel. In the table below, the intermediate inputs are shown in brackets because any increases or decreases they experienced are not additional to, or separate from those in the associated basic input.

(3) There are two ways in which the detail in the descriptions varies. First of all, we can contrast those cases where changes were recorded for quite specific inputs or wastes (eg sodium dichromate) with those cases where we had to refer to a broader group or class (such as coal combustion wastes).

Some of these broader classes recurred frequently, and their individual members have not been itemised each time in the table below. Rather, they are given in the list at the end of the table. The list demonstrates the second way in which the descriptions vary as regards detail. In some classes, such as coking wastes, we were able to break these down quite finely. But in other cases, such as producer gas combustion wastes, we had no information with which to break the class down into separate pollutants.

(4) According to the nature of the innovation and of the source material, there are also variations in the terms used to describe impacts. First, some changes are recorded as start/stop, whilst others are recorded as increase/decrease. Secondly, some changes are recorded in relation to units of given outputs, such as coal per ton of pig iron, and other changes are recorded in relation to particular operations within the industry, such as casting, milling or blast furnace charging.

Innovation Code	Description of impacts	Number of separate impacts
6	In blast furnace (BF) pig iron production: start - coal input (as coke) - coking wastes - coke BF wastes stop - wood input (as charcoal) - charcoal production wastes - charcoal BF wastes increase - slag produced/ton pig - power input/ton pig, since coke is not as combustible as charcoal, and needs stronger blast for furnace to reach operating temperature (water power at first)	26
7	In steel production: start - coal input - coal combustion wastes stop - wood input (as charcoal) - charcoal production wastes - charcoal combustion wastes decrease - slag produced/ton steel	(17)
8	Per ton pig iron: increase - coal input - coal combustion wastes decrease - water power input	9
9	Per ton pig iron: Decrease - coal input - coal combustion wastes	8

Innovation code	Description of impacts	Number of separate impacts
10	In wrought iron (WI) production: increase - acidity of slag stop/decrease - wood input (as charcoal) - charcoal production wastes - charcoal consumption wastes start/increase - coal input - coal combustion wastes - both in the furnace and in the prerefining necessary for dry puddling which could only use 'white' pigs (iron low in carbon and silicon)	(15)
11	In 'consolidating' WI blooms: start/increase - milling wastes - oil, millscale - coal input - coal combustion wastes stop/decrease - water power input	10
13	Per ton of pig, blast heating requires: increase - coal input - coal combustion wastes But resulting increases in BF efficiency mean that, per ton of pig: decrease - coke BF wastes - coal (as coke) - ore (as prepared) - coking wastes - ore preparation wastes	32
16	Per ton of pig iron, stronger blast requires: increase - coal input - coal combustion wastes	

	But resulting increases in BF efficiency mean that, per ton of pig: decrease - coke BF wastes - coal (as coke) - ore (as prepared) - coking wastes - ore preparation wastes	32
17	Per ton of puddled WI: decrease - cinder waste Use of puddling cinder as part of BF charge means, per ton of pig iron: decrease - ore input (as prepared) - ore preparation wastes	5
18	Wet puddling WI production: stops - acid slag problem of dry puddling - input of virgin sand as furnace lining starts - use of iron oxide as furnace lining, recycled from its own cinder waste, and therefore decrease - amount of cinder waste/ton WI Process removes the need to prerefine pigs, and therefore, in this operation: stops - wood input (as charcoal) - charcoal production wastes - charcoal combustion wastes Process substantially reduces amount of pig iron needed, and therefore, per ton of wrought iron: decrease - coke BF wastes - coal (as coke) - ore (as prepared) - coking wastes - charcoal combustion wastes	(36)

19	Roasting of puddling furnace slag (fettling) in order to stop it attacking cast iron (CI) furnace linings means that, per ton of wrought iron start - fettling wastes increase - coal input - coal combustion wastes	(11)
20	Rastrick's waste heat boiler helps power rolling mills etc so that, per ton of processed bar iron: decrease - coal input - coal combustion wastes	8
21	Use of BF gas wastes for blast heating means, per ton of pig iron: decrease - coal input - coal combustion wastes	8
22	Restriction of BF gas escapes to charging period means that, per ton of pig iron: decrease - coke BF gas wastes and reduced heat loss means that less blast heating needed, and therefore, per ton of pig: decrease - coal input - coal combustion wastes	13
23	In shingling wrought iron bloom: start/increase - coal input - coal combustion wastes stop/decrease - water power input	9
24	Acid Bessemer process for crude steel production needed phosphorous-free inputs. Blast furnaces could no longer use recycled puddling furnace slag as part of their charge, since it was phosphorous-rich. For steel produced by this process, this therefore meant, per ton of steel: increase - ore (as prepared) - ore preparation wastes	

24	But process used pig iron directly, rather than wrought iron, so that, per ton of steel: stops - puddling wastes (wet) - puddling inputs (other than pig iron) In contrast to crucible process, Bessemer could use molten pig iron directly from blast furnace. No reheating was needed, and therefore, per ton of steel: decrease - coal input - coal combustion wastes	22
26	To reduce the oxygen content of Bessemer steel, and improve its quality, furnaces were lined with magnesite bricks, resulting in: start - input of spiegeleisen (manganese source) - production of very acidic slags (hence 'acid Bessemer' process)	2
29	Open hearth process could use greater proportions of scrap as input than other steel processes, and a wider variety of scrap types, so that less pig iron was needed and, per average ton of crude steel: decrease - coke BF wastes - coal input (as BF coke) - ore input (as prepared) - coking wastes - ore preparation wastes Regenerative heating allowed substantial fuel savings: decrease - coal/ton steel Immediate fuel input was producer gas (LPG), so that substitution of steel production wastes was as follows: start - LPG combustion wastes - LPG production wastes stop - coal combustion wastes	(40)

30	Basic Bessemer able to use phosphoric pig inputs. Blast furnaces supplying pig iron can again use puddling slag as input charge, and so, per ton of steel: decrease - BF ore input (as prepared) - ore production wastes Change in furnace lining means that, for Bessemer steel production: start - dolomite input decrease - spiegeleisen input - acidity of furnace slag and because basic slag could be sold as by-product, per ton of Bessemer steel: decrease - amount of slag waste but also: increase - dust/fume waste/ton steel	9
33	Cowper regenerative stove uses BF waste heat more efficiently, and in blast heating: decrease - coal input - coal combustion wastes Resulting increases in BF efficiency lead to reduction in coke rate, and therefore, per ton of pig iron: decrease - coal input (as coke) - coking wastes	19
35	Per ton pig iron: decrease - BF gas wastes	5
36	Mechanised casting means that, for finished pigs: stop - sand input (no longer needed in pig beds) - human labour input (no longer needed for breaking up and loading pigs) - gravity (no longer used to feed beds) start - coal input (as electricity) - electricity production wastes	(11)

37	In rebuilding BF tapholes: stop - human labour power input start - coal input (as electricity) - electricity production wastes	(9)
38	In BF charging: stop - human labour power input start - coal input (as electricity) - electricity production wastes	(9)
39	Per ton pig iron: decrease - BF gas wastes	5
40	For light steel rolling: stop - coal combustion wastes (in steam power) start - electricity production wastes	(14)
41	Per unit of steel plate: decrease - coal input decrease - coal combustion wastes	8
42	Per unit of steel beams: decrease - coal input decrease - coal combustion wastes	8
51	Per unit of steel sheet or billet: decrease - coal combustion wastes increase - electricity production wastes	(14)
53	Greater thermal efficiency of arc furnace means that, per ton of steel: decrease - coal input Furnace could also use light steel scrap, so that, on average, less pig iron needed, and therefore, per ton of steel:	29

	decrease - BF wastes - coal input (as coke) - coking wastes - ore input (as prepared) - ore preparation wastes - other BF inputs/wastes	
55	Per unit of sheet tinplate: decrease - tin input used - coal input (since no heating of hot dip) - coal combustion wastes start - electrolyte wastes (including chromates and phenolsulphonic acid)	11
56	Increased furnace efficiency means: decrease - BF wastes - coal input (as coke) - coking wastes - ore input (prepared) - ore preparation wastes - other BF inputs	29
57	Sintering allowed ore fines to be used for the first time, and therefore, per average ton of pig iron: decrease - ore fines waste - ore input (as prepared) Also, per ton pig iron: decrease - coal input (as coke) - coking wastes In ore preparation: starts - sintering wastes reduces - calcination wastes	19
58	Per ton of steel: new source - iron oxide fume - oxygen input	2

60	Continuous casting bypasses need for primary mill, and therefore, in steel casting: decrease - milling wastes - coal input (as electricity) - electricity production wastes	(17)
61	In BF charging: decrease - water/animal power input increase - coal input - coal combustion wastes	9
62	In BF charging: decrease - water/animal power input increase - coal input - coal combustion wastes	9
65	Better gauge and tension controls in sheet steel rolling means that, per unit of sheet steel, less crude steel needs to be produced, and therefore: decrease - steel furnace wastes - steel furnace inputs (other than pig iron) Reduced pig iron input means that, per unit of sheet steel: decrease - BF wastes - coal input (as coke) - coking wastes - ore input (as prepared) - ore preparation wastes - other BF inputs	38
66	As innovation 65	
72	In wrought iron forging: stop - water power input start - coal input - coal combustion wastes	9

74	In production of joints: stop - human labour power input start - coal input - coal combustion wastes	9
76	Per ton pig iron: decrease - ore fines wastes - ore input (as prepared) - coal input (as coke) - coking wastes - calcination wastes increase - sintering wastes	19
78	Bypassing the need to reheat means that, per unit of wrought iron sheet or bar: decrease - coal input - coal combustion wastes	8
80	Due to time saved, need for reheating is reduced, and impacts as innovation 78	8
81	Reduce weight of wrought iron per unit product, and therefore: - puddling wastes - ore input - ore preparation wastes - coal input (as coke) - coking wastes - puddling inputs - BF wastes	(35)
84	Per unit of wrought iron bar or sheet: decrease - human labour power input increase - coal input - coal combustion wastes	9
86	As innovation 80	8

94	Start - zinc input - zinc galvanising wastes - pickling wastes (needed to clean sheets before galvanising process)	(6)
98	Per ton pig iron: start - fuel oil input decrease - slag waste - coal input (as coke) - coking wastes	13
100	In active mixer: start - input of desulphurising agents (eg lime chloride) start - coal input (as LPG) - LPG production wastes - LPG combustion wastes But reduced heat time in open hearth furnace means that, per ton steel: decrease - coal (as LPG) - LPG production wastes - LPG combustion wastes	(19)
101	In electric arc steel: start - oxygen input - iron oxide fume waste increase - scrap input decrease - iron ore input (as pig iron) - ore preparation wastes - BF wastes - coal (as BF coke) - coking wastes - other BF inputs Reduced heat time in arc furnace means that per ton of steel: decrease - electricity input (basic input unknown) - electricity production wastes	(40)

102	In open hearth furnace steel stop - coal input (as LPG) - LPG production wastes - LPG combustion wastes start - oil input - oil combustion wastes	9
103	Per unit of wrought iron product: start - tin input - tinplating wastes (acids, oil and grease) And in heating the hot dip: increase - coal input - coal combustion wastes	12
104	In wrought iron processing start - input of sulphuric acid - pickling wastes	3
105	Per iron casting, less pig iron needed, and therefore: decrease - charcoal BF wastes - wood input (as charcoal) - charcoal production wastes decrease - ore input (as prepared) - ore preparation wastes - other charcoal BF inputs	21
106	In BF furnace blowing: start - coal input - coal combustion wastes decrease - water power input	9
107	In production of wrought iron: start - coal input - coal combustion wastes	(16)

	stop - wood input (as charcoal) - charcoal production wastes - charcoal combustion wastes	
108	In production of wrought iron: stop - wood input (as charcoal) - charcoal production wastes - charcoal combustion wastes increase - slag/ton WI start - coal input - coal combustion wastes - limestone input (as flux in pots) Process uses more pig iron than finery/chafery process, so, per ton wrought iron: increase - BF wastes - ore input (as prepared) - ore preparation wastes - wood input (as charcoal) - charcoal production wastes - other charcoal BF inputs/wastes	(40)
109	Flux no longer needed, so in WI production: stop - limestone input decrease - slag waste stop - coal combustion wastes start - coking wastes	19
112	Per ton of puddled wrought iron decrease - slag waste - iron ore input (as pig iron) - coke BF wastes - ore preparation wastes - coal input (as coke) - coking wastes - other BF inputs	30

113	Use of molten pig bypasses need for reheating, and therefore, per ton of puddled wrought iron: decrease - coal input - coal combustion wastes	8
114	Per ton of pig iron: decrease - coal input increase - BF fume waste	2
115	Per ton of cast steel: decrease - coal input (as coke) - coking wastes - coke combustion wastes	(15)
117	Per ton of pig iron: decrease - BF particulate matter wastes	1
118	As innovation 117	1
119	As innovation 117, especially fine fume	1
120	Per average ton of cast steel: increase - fume wastes	1
121	Per average ton of cast steel: decrease - fume wastes	1
123	Per ton of crude steel: decrease - fume wastes	1
124	Per ton of crude steel: increase - oxygen input - iron oxide fume waste But reduces furnace melt time, and therefore, per ton of crude steel: decrease - oil input	3

125	As innovation 124	3
126	In ore preparation: start - calcination wastes	3
127	Per ton of cast steel: decrease - particulate matter waste (especially coarse)	1
128	Per ton of crude steel: decrease - fine fume waste	1
135	Per ton of Bessemer steel: start - oxygen input - iron oxide fume waste increase - scrap input Increased scrap use and increased converter efficiency means that, per ton of steel: decrease - iron ore (as pig iron) - ore preparation wastes - coke BF wastes - coal input (as coke) decrease - coking wastes - other BF inputs	32
136	Per ton of Bessemer steel: decrease - iron oxide fume waste	1
138	In order to allow high phosphorous pigs to be used, per ton Bessemer steel: start - input of lime flux increase - iron oxide fume waste	2
139	Per ton of pneumatic (oxygen) steel: decrease - carbon monoxide waste	1

141	In puddled wrought iron: decrease - human labour power input increase - coal input - coal combustion wastes	9
142	In wrought iron rolling: decrease - water power input increase - coal input - coal combustion wastes	9
145	Per ton of coke: decrease - wastes of oil and tar and because heat was also recycled: decrease - coal input/ton coke	3
147	Refrigeration used to dry air blast, so that, per ton of pig iron: increase - electricity input (basic input unknown) - electricity production wastes But resulted in improved coke rate, so that, per ton of pig iron: decrease - coal input (as coke) - coking wastes	(19)
152	Per ton pig iron: decrease - slag waste	1
155	Greater thermal efficiency than open coking means that, per ton of coke: decrease - coal input - coking wastes	11
156	As innovation 155	11

157	In prerefining open hearth pig input: start - oxygen input - iron oxide fume waste But decreases open hearth melt time, and per ton of crude steel: decrease - furnace wastes, especially slag - oil input	10
158	Per average ton of cast steel: increase - oxygen input - iron oxide fume waste	2
159	Per ton of pig iron: start - oxygen input increase - BF carbon monoxide waste - BF dust waste But reductions in coke rate mean that, per ton of pig iron: decrease - coal input (as coke) - coking wastes	14
161	Per ton of cast steel: increase - oxygen input - wastes of iron oxide fume, carbon monoxide and other fume decrease - coal input (as coke) - coking wastes	14
162	Per ton of pig iron: decrease - sulphur oxide wastes increase - liquid BF wastes, especially suspended solids, ammonia and cyanides	4
163	Per ton of coke: decrease - sulphur oxide wastes	1

164	In steel billet cleaning: start - oxygen input increase - fume wastes	2
165	Per ton of coke: decrease - gaseous wastes increase - liquid wastes, especially phenols, suspended solids, cyanides, ammonia	10
166	Per ton of coke: decrease - waste phenols	1
169	Per unit of steel product: decrease - sulphuric acid waste	1
170	In tinplating: decrease - sodium dichromate waste	1
171	In sheet steel rolling: decrease - coal combustion wastes increase - electricity production wastes	(14)
172	Increases in furnace efficiency means that, per ton of crude steel: decrease - open hearth furnace wastes - oil input - iron ore input (as pig iron) - BF wastes - ore preparation wastes - coal input (as BF coke) - coking wastes - other BF inputs	36
173	Per ton of crude steel: decrease - sulphur oxide waste	1

174	Per unit of steel product: decrease - acidity of pickling wastes	1
175	Per ton of coke: start - input of iron oxide decrease - hydrogen sulphide waste	2
176	Per unit of steel billet: decrease - fume wastes	1
178	Per ton of pneumatic steel: decrease - fume wastes	1
179	Per ton of open hearth steel: decrease - fine fume wastes, especially iron oxide	1
180	As innovation 179, for electric arc steel	1
181	Per ton of electric arc steel: decrease - particulate matter wastes increase - liquid wastes	(4)

Those broader classes of wastes or inputs used above are described in greater detail below. Given in brackets are the known or estimated numbers of separate inputs or wastes in the class.

(1) Ore preparation wastes (3). Either calcination (dust, smoke, fluorine) or sintering (fume, dust, sulphur oxides).

(2) Pickling wastes (2). Dissolved metals and acids.

(3) Coking wastes (10). Composed of (a) gaseous (sulphur oxides, smoke, hydrogen sulphide, particulate matter), (b) liquids (phenols, oil, tar, suspended solids, ammonia, cyanides).

(4) Blast furnace wastes (9). Composed of (a) slag, (b) gaseous (smoke, carbon monoxide, sulphur oxides, particulate matter, nitrogen oxides), (c) liquids (suspended solids, cyanides, ammonia).

(5) Coal combustion wastes, where used as source of direct heat or steam power (7), smoke, carbon monoxide, particulate matter, sulphur oxides, tar, ash, nitrogen oxides.

(6) Charcoal production wastes (3), smoke, carbon monoxide, nitrogen oxides.

(7) Charcoal combustion wastes (4) estimate, includes ash.

(8) Producer gas production wastes (4) estimate.

(9) Producer gas combustion wastes (4) estimate.

(10) Electricity production wastes, will vary according to basic input used as source (7) estimate.

(11) Milling wastes (9). composed of (a) fuel combustion (7), and (b) processing wastes - oil, millscale (2).

(12) Crude steel furnace wastes (11). composed of (a) slag, (b) liquids (3) estimate, (c) fuel combustion wastes (7).

(13) Other blast furnace inputs (apart from ore and coke in charge). For operations such as charging, blowing, blast heating, tapping and casting (5). Combinations of different basic inputs including gravity, water power, animal power, human labour power, coal, oil, natural gas.

(14) Puddling wastes (8) slag plus coal combustion.

(15) Tinplating wastes (10) fuel combustion (7) plus acids, chromates, oil.

(16) Fettling wastes (3) estimate.

(17) Galvanising wastes (3) estimate.

(18) Steel furnace inputs (5). Pig iron, steel scrap, flux, basic power source, additions such as oxygen, steam etc.

(19) Oil combustion wastes (3) sulphur oxides, nitrogen oxides, carbon monoxide.

(20) Puddling inputs (3) coal, pig iron, human labour power.

In the right hand column of table 2.2, an attempt has been made to identify roughly the number of separate impacts associated with each innovation. Where total impact frequencies are shown in brackets, the innovations affected broad classes of inputs or wastes where numbers of separate, individual inputs or wastes are estimated rather than known.

Table 2.3 – Classification of innovations according to aspects of environmental change

Industry sector – BF blast furnace and input preparation
– CI cast iron
– WIP wrought iron production
– WIT wrought iron products and processing (treatment)
– SP steel production
– ST steel products and processing (treatment)

Environmental change
– QL qualitative } A
– QT quantitative } A
– IO improvement only } B
– DO deterioration only } B
– B both } B
– MAJI major improvement } C
– MINI minor improvement } C
– MAJD major deterioration } D
– MIND minor deterioration } D

Innovation code	Industry sector	Environmental change			
		A	B	C	D
006	BF	QL	B	MINI	MAJD
007	SP	QL	B	MINI	MAJD
008	BF	QL	DO		MAJD
009	BF	QT	IO	MAJI	
010	WIP	QT	B	MAJI	MAJD
011	WIT	QL	DO		MAJD
012	CI	QL	B	MINI	MAJD
013	BF	QT	IO	MAJI	
014	BF				
015	BF				
016	BF	QT	IO	MAJI	
017	BF,WIP	QT	IO	MAJI	
018	WIP	QT	IO	MINI	
019	WIP	QL	DO		MAJD

020	WIP,WIT	QT	IO	MAJI	
021	BF	QT	IO	MAJI	
022	BF	QT	B	MAJI	MIND
023	WIT	QL	B	MINI	MAJD
024	SP	QT	B	MAJI	MIND
025	SP				
026	SP	QL	DO		MIND
027	ST				
028	*				
029	SP	QL	B	MAJI	MAJD
030	SP	QT	B	MINI	MIND
031	ST				
032	ST	QT	IO	MINI	
033	BF	QT	IO	MAJI	
034	BF				
035	BF	QL	IO	MINI	
036	BF	QL	B	MAJI	MIND
037	BF	QL	B	MAJI	MIND
038	BF	QL	B	MAJI	MIND
039	BF	QL	IO	MINI	
040	ST	QL	B	MINI	MIND
041	ST	QT	IO	MINI	
042	ST	QT	IO	MINI	
043	CI				
044	CI				
045	CI				
046	CI				
047	CI				
048	ST				
049	ST				
050	ST				
051	ST	QL	B	MAJI	MIND
052	*				
053	SP	QL	B	MAJI	MIND
054	ST				
055	ST	QL	B	MAJI	MAJD
056	BF	QT	IO	MINI	

057	BF	QL	B	MAJI	MAJD
058	SP	QL	B	MINI	MAJD
059	SP				
060	ST	QT	IO	MAJI	
061	BF	QL	B	MINI	MAJD
062	BF	QL	B	MINI	MAJD
063	WIP				
064	ST				
065	ST	QT	IO	MINI	
066	ST	QT	IO	MINI	
067	SP				
068	SP				
069	SP				
070	WIP				
071	WIT				
072	WIT	QL	DO		MAJD
073	*				
074	WIT	QL	DO		MAJD
075	*				
076	BF	QT	B	MAJI	MAJD
077	ST				
078	WIT	QT	IO	MAJI	
079	WIT				
080	WIT	QT	IO	MAJI	
081	WIT	QT	IO	MINI	
082	WIT				
083	*				
084	WIT	QL	B	MAJI	MIND
085	WIT				
086	WIT	QT	IO	MAJI	
087	ST				
088	ST				
089	ST				
090	ST				
091	SP				
092	ST				
093	ST				

094	ST	QL	DO		MAJD
095	ST				
096	ST				
097	ST				
098	BF	QL	B	MAJI	MIND
099	*				
100	SP	QT	B	MINI	MAJD
101	SP	QL	B	MINI	MAJD
102	SP	QL	B	MINI	MIND
103	WIT	QL	DO		MAJD
104	WIT,ST	QL	DO		MAJD
105	CI	QL	B	MAJI	MAJD
106	BF	QL	DO		MAJD
107	WIP	QL	B	MAJI	MAJD
108	WIP	QL	B	MINI	MAJD
109	WIP	QL	IO	MINI	
110	WIP				
111	WIP				
112	WIP	QT	IO	MAJI	
113	WIP	QT	IO	MAJI	
114	BF	QT	IO	MINI	
115	SP	QT	B	MINI	MIND
116	SP				
117	BF	QT	IO	MINI	
118	BF	QT	IO	MINI	
119	BF	QT	IO	MAJI	
120	SP	QT	DO		MIND
121	SP	QT	IO	MAJI	
122	SP				
123	SP	QT	IO	MAJI	
124	SP	QL	B	MINI	MIND
125	SP	QL	B	MINI	MAJD
126	BF	QL	DO		MAJD
127	SP	QT	IO	MINI	
128	SP	QT	IO	MAJI	
129	ST				
130	ST				

131	ST				
132	ST				
133	ST				
134	SP				
135	SP	QT	DO		MAJD
136	SP	QT	B	MINI	MIND
137	SP				
138	SP	QT	DO		MIND
139	SP	QT	B	MINI	MIND
140	SP	QT	DO		MIND
141	WIP	QL	B	MAJI	MIND
142	WIT	QL	DO		MAJD
143	WIT				
144	WIT	QT	B	MAJI	MIND
145	BF	QT	IO	MAJI	
146	ST				
147	BF	QT	IO	MAJI	
148	SP				
149	SP				
150	ST				
151	ST				
152	BF	QT	IO	MINI	
153	ST				
154	ST				
155	BF	QT	IO	MINI	
156	BF	QT	IO	MAJI	
157	SP	QL	B	MINI	MIND
158	SP	QL	DO		MIND
159	BF	QL	B	MINI	MAJD
160	BF				
161	SP	QL	B	MINI	MAJD
162	BF	QT	B	MAJI	MIND
163	BF	QT	IO	MAJI	
164	ST	QL	B	MINI	MAJD
165	BF	QT	B	MAJI	MAJD
166	BF	QT	IO	MAJI	

167	*				
168	*				
169	ST	QT	IO	MAJI	
170	ST	QT	IO	MAJI	
171	ST	QL	B	MAJI	MIND
172	SP	QT	IO	MINI	
173	SP	QT	IO	MINI	
174	ST	QL	IO	MAJI	
175	BF	QL	IO	MAJI	
176	ST	QT	IO	MAJI	
177	SP				
178	SP	QT	IO	MAJI	
179	SP	QT	IO	MAJI	
180	SP	QT	IO	MAJI	
181	SP	QT	IO	MAJI	

*innovations not fitting into six main categories

Table 2.4 - Unit input levels

	OLD INPUTS			NEW INPUTS			SCRAP INPUTS		
	Cwts iron ore/ ton pig iron	Cwts coke /ton pig iron	Cwts solids /ton pig iron	m^3 oxygen/ million tons iron & steel	Cwts sinter /ton pig iron	Gwh elec- tricity/ million tons iron & steel	Cwts iron scrap /ton pig iron	Cwts total scrap /ton iron & steel	Cwts steel scrap /ton crude steel
1920	47.6	28.1	60.6						8.8
21	42.9	26.5	56.4						11.4
22	41.8	26.1	55.3						12.2
23	44.3	26.0	56.4						11.0
24	46.2	25.8	57.5						10.2
25	47.3	25.5	58.8						10.4
26	46.5	25.4	57.8						11.2
27	45.8	24.9	57.5						10.8
28	46.7	24.8	58.3						11.0
29	47.4	24.9	58.9						10.4
30	48.7	24.8	59.8						11.2
31	50.1	24.7	60.9						12.0
32	50.0	24.1	60.6						12.8
33	47.1	23.2	57.4						12.8
34	47.5	23.0	55.6						12.2
35	46.6	22.3	56.3						12.0
36	45.9	22.4	55.9						11.6
37	46.6	22.9	56.7						11.6
38	47.6	22.6	57.2						11.8
39	42.0	22.0	55.0		4.8		0.96		11.2
40	43.5	23.4	59.1		5.9		0.93	9.6	11.0
41	46.3	24.7	62.9		6.5		1.28	9.4	11.2
42	46.0	24.8	62.8		6.3		1.68	10.6	11.8
43	44.8	24.4	61.9		6.5		1.99	10.8	12.4
44	43.8	23.0	60.9		6.7		1.80	9.6	12.2
45	41.2	22.1	56.9		6.5		1.54	9.0	12.2
46	38.2	22.0	53.4		5.9		1.46	9.4	12.2
47	37.3	21.5	51.8		5.6		1.44	9.6	12.2

1948	36.7	21.0	51.2		6.0	152	1.42	11.0	12.2
49	35.5	20.6	50.6		6.4	153	1.67	11.2	12.6
50	34.6	21.3	50.2		6.9	160	1.89	11.2	12.6
51	35.9	21.4	51.8		7.3	168	1.69	9.8	11.6
52	35.9	21.2	52.6		8.1	176	1.41	9.4	11.0
53	35.4	20.0	52.7		8.5	172	1.39	9.2	11.2
54	32.4	19.7	50.7		9.9	177	1.46	9.6	11.2
55	29.3	19.7	49.9		12.4	193	1.34	10.0	11.2
56	30.0	19.0	50.1		11.7	193	1.32	9.4	10.8
57	28.2	17.9	49.3		12.9	199	1.34	9.4	10.6
58	25.2	16.8	47.6	3.8	14.3	196	1.71	9.0	11.4
59	20.9	16.5	46.3	5.5	18.0	204	1.76	8.8	10.6
60	19.1	16.4	45.5	7.5	18.8	230	1.85	10.0	10.4
61	17.9	15.5	45.1	8.2	19.8	222	1.87	9.0	10.4
62	14.0	14.4	43.8	12.7	22.9	223	2.07	8.2	10.2
63	11.3	14.0	41.7	17.2	24.2	249	2.09	8.8	10.4
64	10.8	13.3	40.8	20.7	24.3	272	1.93	9.8	10.2
65	9.8	12.8	39.5	24.5	24.4	282	1.87	9.6	10.2
66	9.3	12.5	38.3	23.6	24.4	259	1.87	9.0	10.4
67	8.4	12.5	37.6	25.2	24.8	253	1.92	8.8	10.6
68	8.9	12.4	37.2	27.6	24.4	271	1.61	9.2	10.6
69	8.9	11.9	36.5	25.8	22.8	288	1.39	9.6	10.6
70	9.0	11.2	36.2	28.1	22.7	306	1.32	10.2	10.8
71	8.5	11.2	35.9	31.0	23.3	266	1.34	9.0	10.6
72	9.3	11.7	35.5	30.6	22.3	262	1.12	9.4	10.8
73	10.6	11.7	35.0	29.2	20.5	308	0.72	9.6	10.4
74	10.4	11.7	34.5	28.2	19.7	293	0.79	9.0	10.4
75	9.0	11.7	35.3	25.8	22.1	295	0.98	8.8	11.2
76	9.9	11.6	35.1	26.6	21.3	353	0.72	10.0	11.0
77	10.0	11.4	35.0	26.4	21.2	360	0.70	9.8	11.6
78	6.6	11.3	34.4	26.3	25.4	378	0.15	11.2	11.6
79	6.4	11.4	34.0	28.0	25.6	378	0.08	11.8	11.0
80	8.8	11.2	32.5	26.1	22.0		0.10		
81	11.0				19.9				

Table 2.5 - Gross consumption levels

	OLD INPUTS			NEW INPUTS			SCRAP INPUTS		
	Million tons iron ore	Million tons BF coke	Million tons BF solids	Million cubic metres oxygen	Million tons BF sinter	Thousand Gwh elec-tricity	Million tons iron scrap	Million tons total scrap	Million tons steel scrap
1920	19.8	11.3	25.1						4.0
21	5.6	3.5	7.3						2.1
22	10.2	6.4	13.6						3.6
23	16.4	9.7	20.9						4.7
24	16.9	9.4	21.0						4.2
25	14.9	8.0	18.5						3.8
26	5.8	3.1	7.2						2.0
27	16.7	9.1	21.0						4.9
28	15.4	8.2	19.3						4.7
29	18.0	9.5	22.4						5.0
30	15.1	7.7	18.5						4.1
31	9.5	4.7	11.6						3.1
32	9.0	4.3	10.9						3.4
33	9.7	4.8	11.8						4.5
34	14.3	6.8	16.7						5.4
35	14.9	7.2	18.0						5.9
36	17.7	8.7	21.6						6.9
37	19.8	9.7	24.1						7.5
38	16.2	7.8	19.4						6.1
39	16.8	9.0	22.0		1.9		0.38		7.4
40	17.9	9.9	24.3		2.4		0.38	9.7	7.2
41	17.2	9.3	23.3		2.4		0.47	9.4	6.9
42	17.7	9.7	26.5		2.4		0.65	10.5	7.6
43	16.1	8.8	22.3		2.4		0.72	10.9	8.0
44	14.7	8.2	20.4		2.3		0.60	9.9	7.4
45	14.6	8.2	20.2		2.3		0.55	9.4	7.2
46	14.9	8.6	20.8		2.3		0.57	10.1	7.7
47	14.6	8.4	20.2		2.2		0.56	10.6	7.7

1948	17.1	10.0	23.8		2.8	3.5	0.66	12.5	9.1
49	16.9	10.0	24.0		3.0	3.7	0.79	13.4	9.8
50	16.6	9.9	24.1		3.3	4.1	0.91	14.1	10.3
51	17.5	10.3	25.1		3.5	4.5	0.82	13.0	9.1
52	19.3	11.3	28.1		4.4	4.9	0.75	13.2	9.1
53	19.8	11.9	29.6		4.7	5.1	0.78	13.6	9.8
54	19.3	11.9	30.2		5.9	5.4	0.87	14.4	10.3
55	18.4	12.3	31.3		7.7	6.0	0.84	15.4	11.1
56	19.8	13.1	33.1		7.7	6.3	0.87	15.5	11.2
57	20.2	13.6	35.3		9.3	6.7	0.96	15.8	11.5
58	16.4	11.4	30.9	132	9.3	6.7	1.11	15.6	11.1
59	13.2	10.5	29.2	194	11.4	7.2	1.11	15.4	10.8
60	14.2	13.0	36.0	274	14.8	8.4	1.46	18.1	12.7
61	13.3	12.1	37.9	309	14.7	8.3	1.38	16.7	11.5
62	9.6	10.6	30.0	481	15.7	8.5	1.42	15.7	10.5
63	8.3	10.5	30.5	655	17.7	9.6	1.53	17.2	11.7
64	9.3	11.8	35.3	821	21.1	10.8	1.67	19.6	13.4
65	8.6	11.9	34.7	981	21.3	11.3	1.64	20.1	13.9
66	7.4	10.6	30.1	966	19.2	10.6	1.47	18.6	12.7
67	6.4	9.9	28.6	1044	20.1	10.5	1.46	18.3	12.6
68	7.4	10.8	30.5	1155	19.3	11.3	1.32	19.2	13.7
69	7.4	10.7	30.0	1079	20.4	12.0	1.14	20.1	14.4
70	7.8	10.6	31.5	1148	18.2	12.5	1.15	20.9	15.1
71	6.5	9.3	27.4	1238	17.4	10.6	1.02	17.8	12.5
72	7.1	8.8	26.9	1204	17.6	10.3	0.85	18.5	13.5
73	8.8	9.9	29.1	1122	14.1	11.8	0.60	18.6	13.6
74	7.1	8.3	23.7	1046	13.6	10.9	0.54	16.6	12.0
75	5.4	7.2	21.1	924	15.0	10.6	0.59	15.8	11.0
76	6.8	8.3	23.9	887	13.2	11.6	0.49	16.8	12.0
77	6.0	7.3	21.0	844	14.8	11.5	0.42	15.5	11.7
78	3.7	6.6	19.4	824	16.8	11.8	0.08	15.3	11.6
79	4.1	7.4	21.6	945	7.0	12.8	0.05	15.2	11.6
80			10.1	451		8.5			6.7
81				814		9.2			8.1
82				694		8.4			

Table 2.6 – Materials inputs variables: data sources and/or computations

	Unit input levels (UI)	Gross consumption level (GC)
Iron ore	Ref: 26, Ref: 8	UI x pig output
Coke	Ref: 26	ref: 4 (1921-80)
BF solids	Ref: 26	UI x pig output
Oxygen	GC/I&S output	Ref: 26
Sinter	Ref: 26, Ref: 8	Ref: 26
Electricity	GC/I&S output	Ref: 26
Iron scrap	Ref: 26	UI x pig output
Total scrap	GC/I&S output	Ref: 26
Steel scrap	GC/steel output	Ref: 26

As we can see, only three outputs were needed in computations – pig iron, crude steel and iron & steel. Annual output levels of pig iron were taken from ref: 8 (pp 346, 366, 429, 484, 596) and ref: 4 (1955, 61, 71, 81). Annual output levels for crude steel were taken from ref: 24 (p 193), ref: 8 (pp 366, 429, 484, 596) and ref: 4 (1971, 82). Where inputs were used in the production of both iron and steel, as well as for some processing operations, and all we have is total industry consumption (eg oxygen), we don't know how much was used in each sector, and so it is not clear what output to use in computing unit input levels. In these cases the aggregate of iron & steel output was used (calculated by simple addition of annual output levels of pig iron and crude steel). Clearly, since some pig iron is used in crude steel production, the output side of the ratio will be overstated in these cases. But we still have a consistent physical ratio with which to pick up any significant variations over time in unit input levels.

Table 2.7 - Analyses of residuals sequences

			Positive residuals	Negative residuals	Runs	Z[1]	Significance level[2]
fIM		Impact potential	11	16	13	-.43	
fQL			12	15	12	-.93	.20
fQT			15	12	9	-2.12	.02
fIO			12	15	10	-1.73	.05
fDO			11	16	14	-.02	
fAI			14	13	15	+.20	
fAD			12	15	13	-.53	
fMAJI			12	15	15	+.27	
fMINI			10	17	8	-2.36	.02
fMAJD			7	20	10	-.71	
fMIND			11	16	7	-2.86	.01
fMAJ			14	13	15	+.21	
fMIN			15	12	9	-2.12	.02
Ore	OLD	Unit input level	33	27	4	-7.02	.01
Coke			24	36	8	-5.92	.01
BF solids			32	28	5	-6.77	.01
Oxygen	NEW		11	11	3	-3.93	.01
Sinter			19	22	4	-5.54	.01
Electricity			16	16	11	-2.16	.05
Iron	SCRAP		19	22	7	-4.58	.01
Total			13	27	14	-1.67	.10
Steel			30	30	15	-4.17	.01

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[1] where negative Z scores indicate a tendency towards clustering and positive Z scores indicate a tendency towards dispersion

[2] blank if not significant at .20 level

Ore	OLD	Gross consumption	31	29	8	-5.98	.01
Coke			34	26	14	-4.37	.01
BF solids			34	26	14	-4.37	.01
Oxygen	NEW		12	10	3	-3.93	.01
Sinter			14	27	3	-5.79	.01
Electricity			12	20	5	-4.23	.01
Iron	SCRAP		18	23	5	-5.21	.01
Total			23	17	5	-5.10	.01
Steel			35	25	20	-2.73	.01

Table 2.8 - Period and cycle lengths in various aspects of the potential for environmental change

	High Periods			
	1	2	3	Mean
fAI	31	20	37	29
fAD	26	32	16	25
fIO	22	35	29	29
fDO	26	37	22	28
fQL	33	42	18	31
fQT	23	25	28	25
Mean	27	32	25	28
	Low Periods			
	1	2	3	Mean
fAI	36	17	51	35
fAD	36	22	35	31
fIO	35	13	58	35
fDO	31	17	32	27
fQL	30	22	27	26
fQT	36	31	50	39
Mean	34	20	42	32
Cycle Mean	61	52	67	60

Period lengths based on boundaries given in figures 2.13 to 2.15 in annex 2.

Table 2.9 - Dates of boundaries between periods of high and low impact potential

	A	B	C
fQL	1910	1937	61
fQT	1891	1941	71*
fIO	1884	1942	75*
fDO	1903	1937	70*
fAI	1890	1941	69*
fAD	1903	1938	63*
fMAJ	1902	1943	65*
fMIN	1904	1938	62*
fMAJI	1908	1951	70*
fMINI	1891	1936	65*
fMAJD	1852	1935	62*
fMIND	1910	1948	60
Mean	1896	1941	1966

*Estimated from plots

2G Annex 2: Plotted data

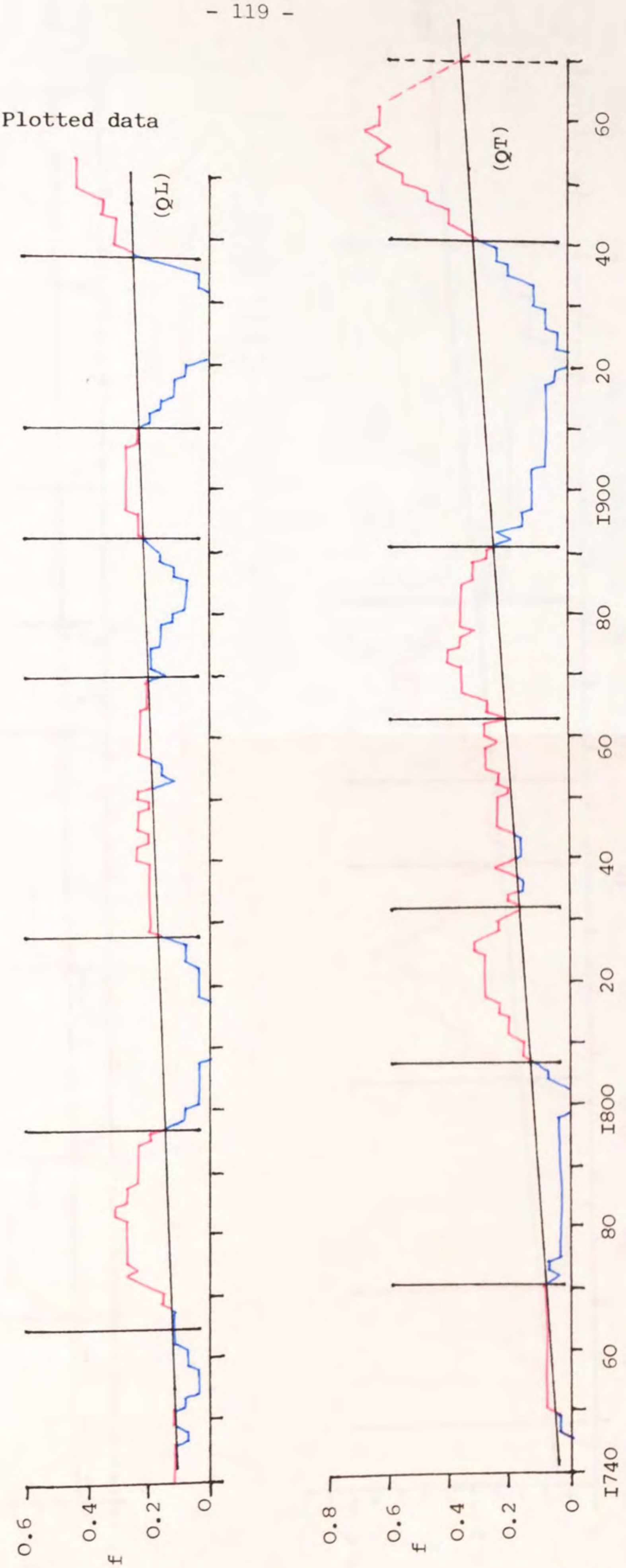


Figure 2.13 - Variations in the potentials for qualitative and quantitative change

Figure 2.14 - Variations in the potentials for improvement only and deterioration only

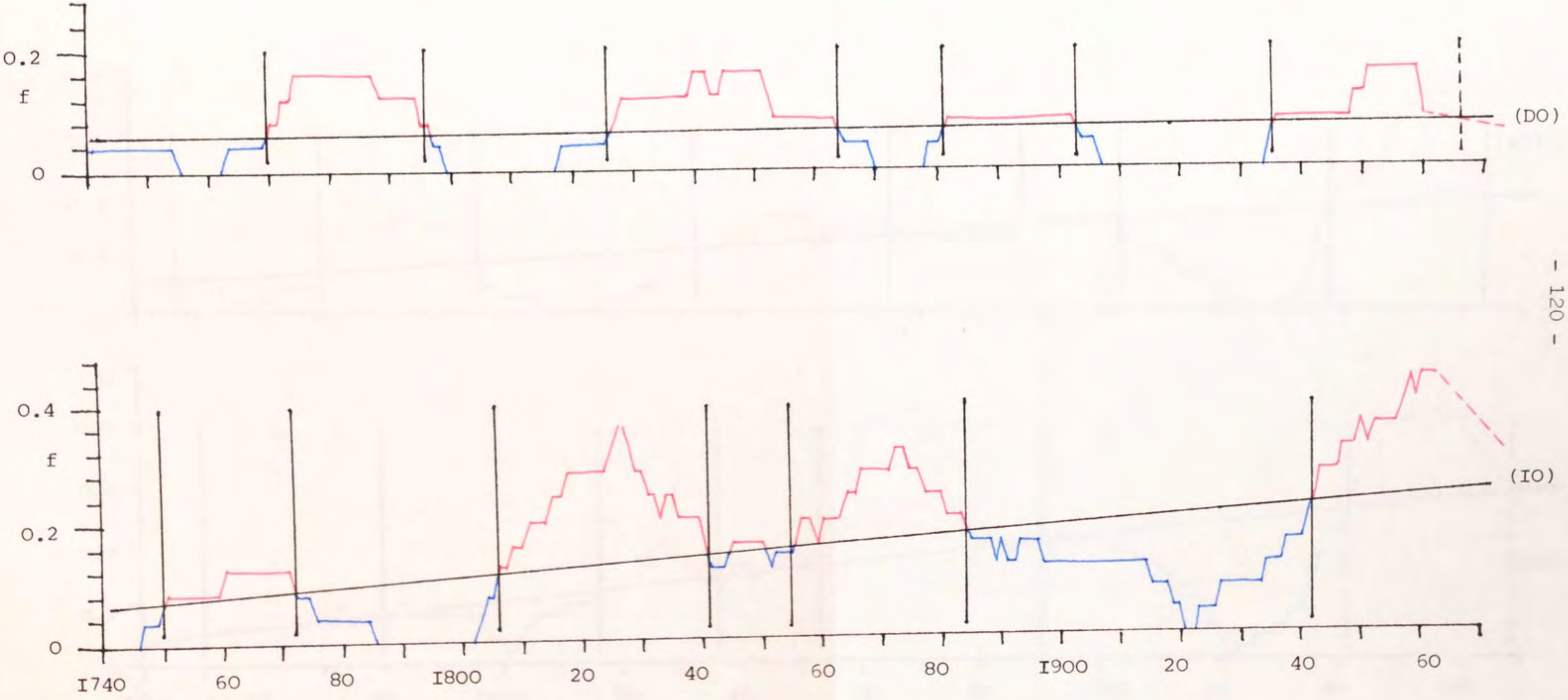


Figure 2.15 - Variations in the potentials for any improvement and any deterioration

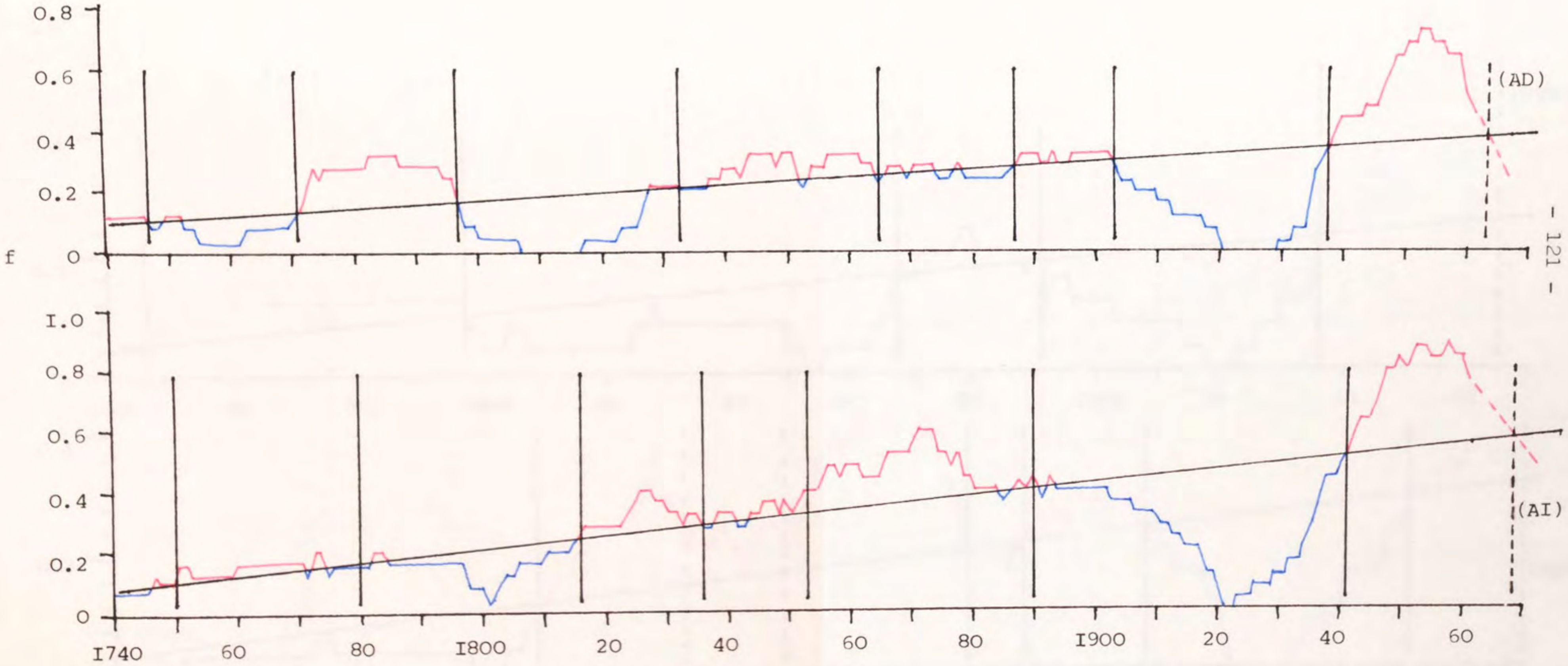


Figure 2.16 - Varations in the potentials for major improvements and minor improvements

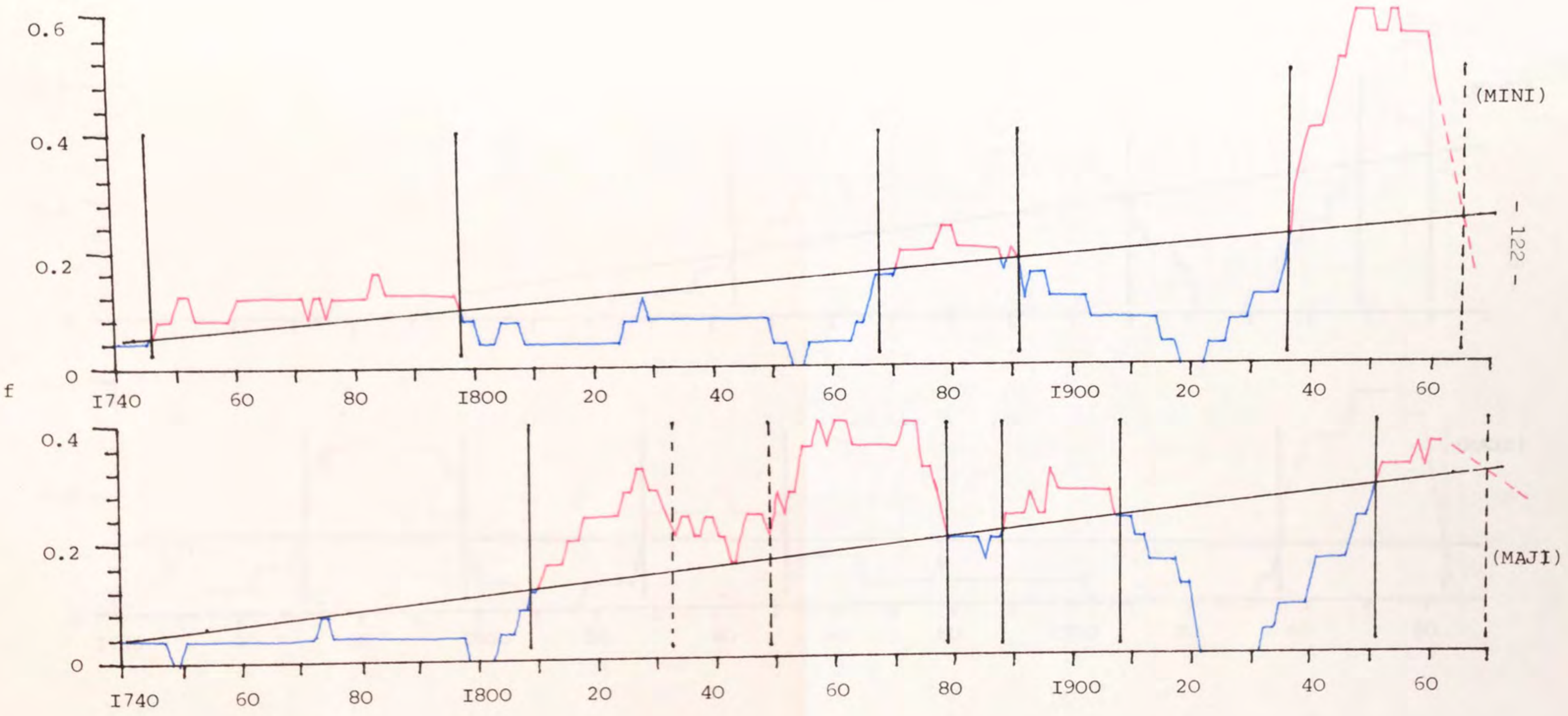


Figure 2.17 - Variations in the potentials for major deterioration and minor deterioration

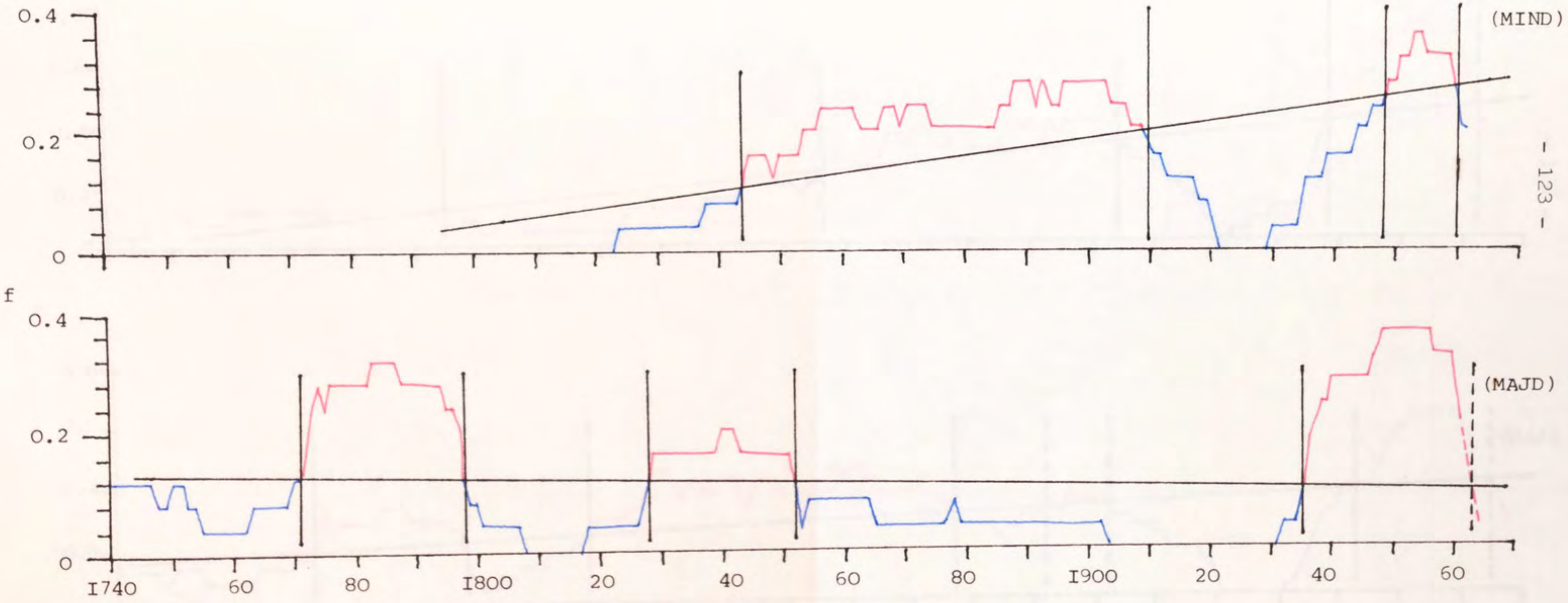
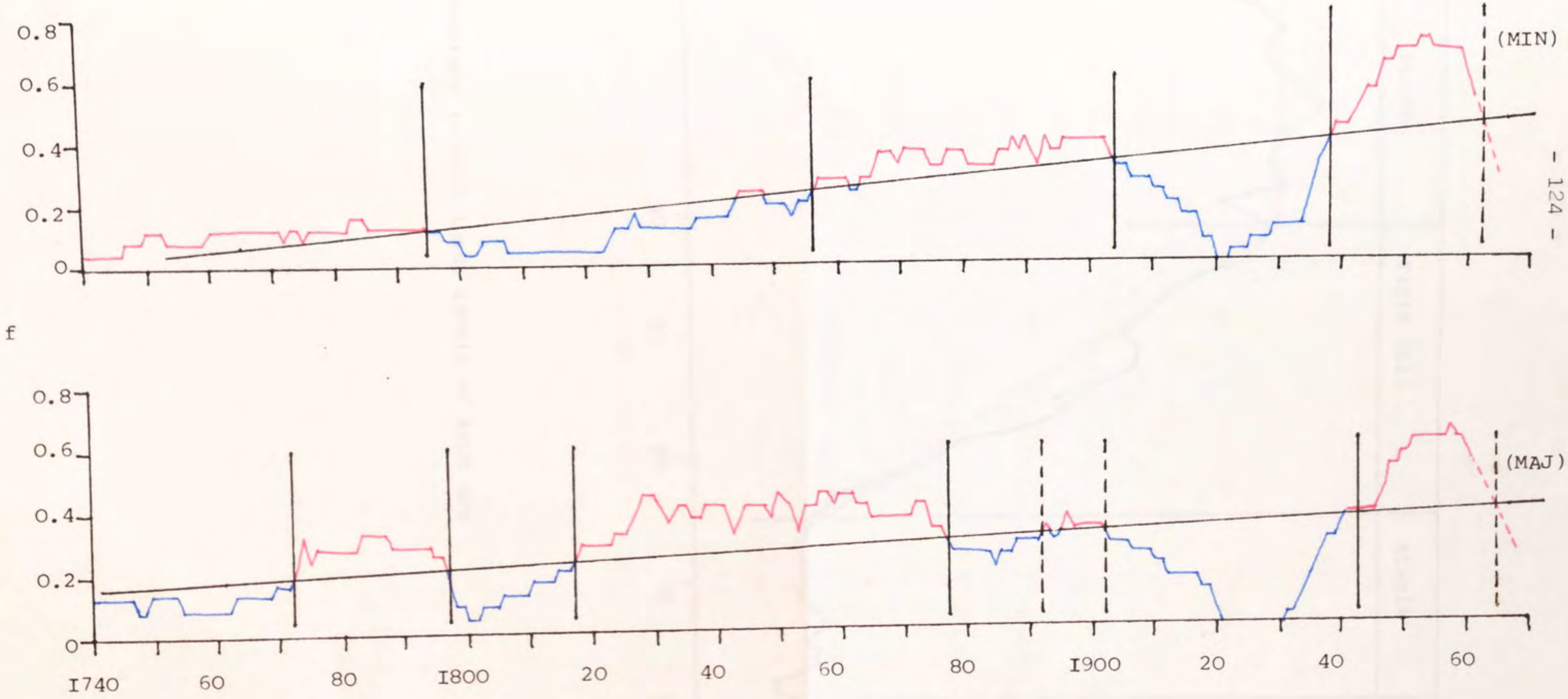


Figure 2.18 - Variations in the potentials for all major and all minor environmental changes



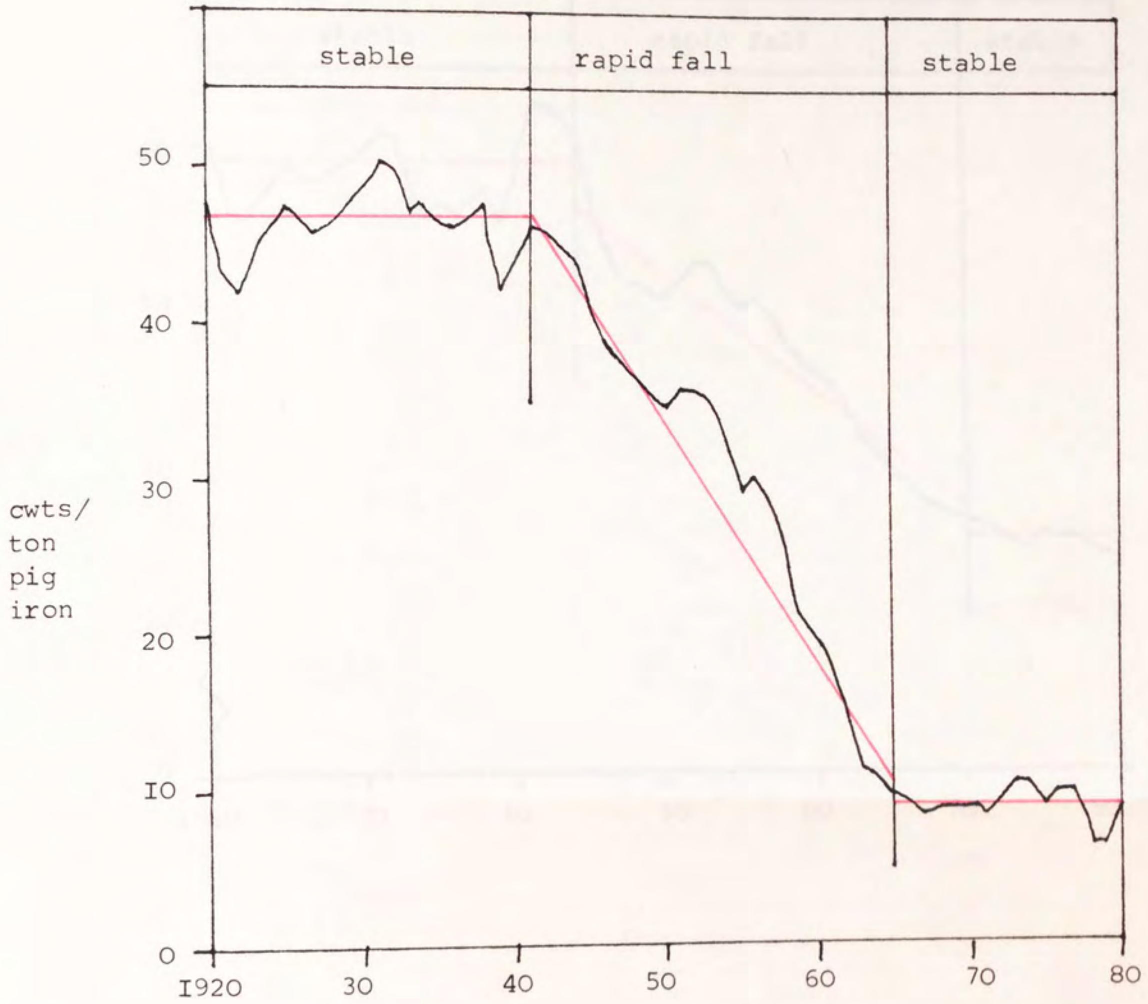


Figure 2.19 - Variations in unit input levels of iron ore

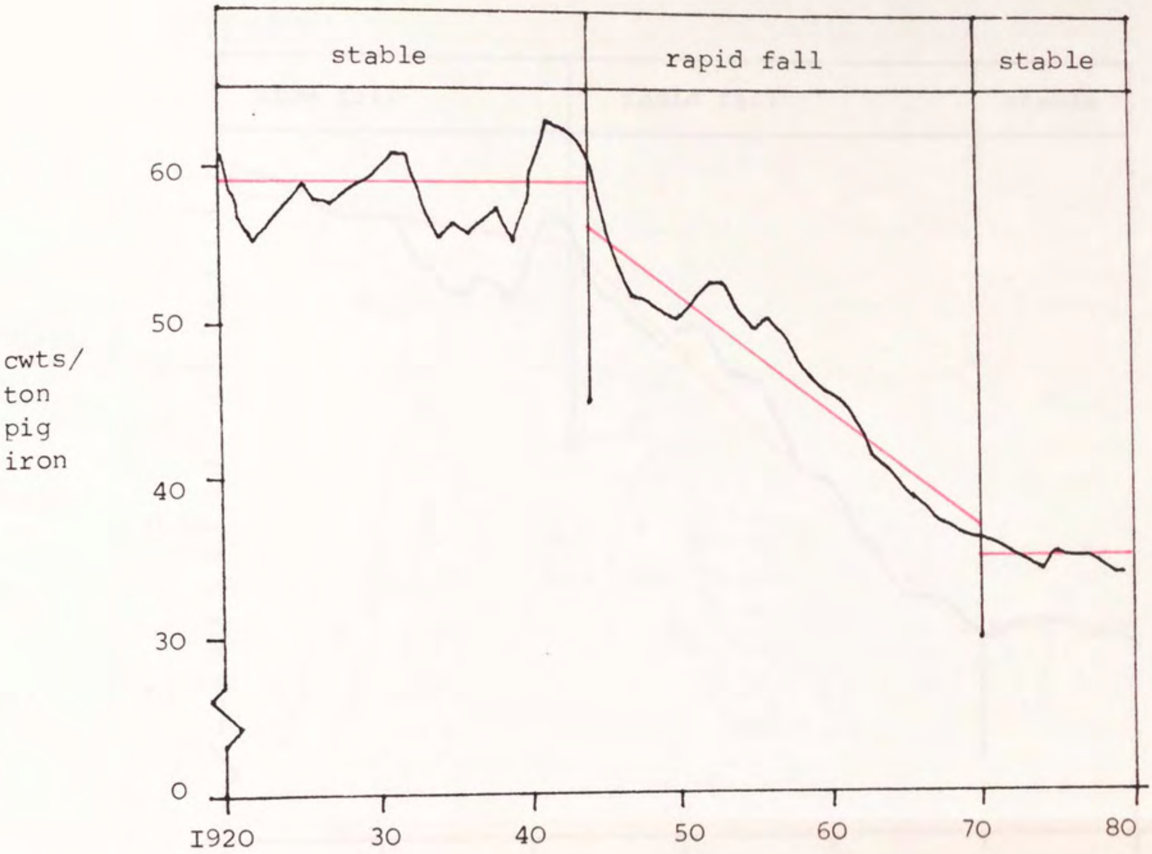


Figure 2.20 - Variations in unit input levels of blast furnace solids

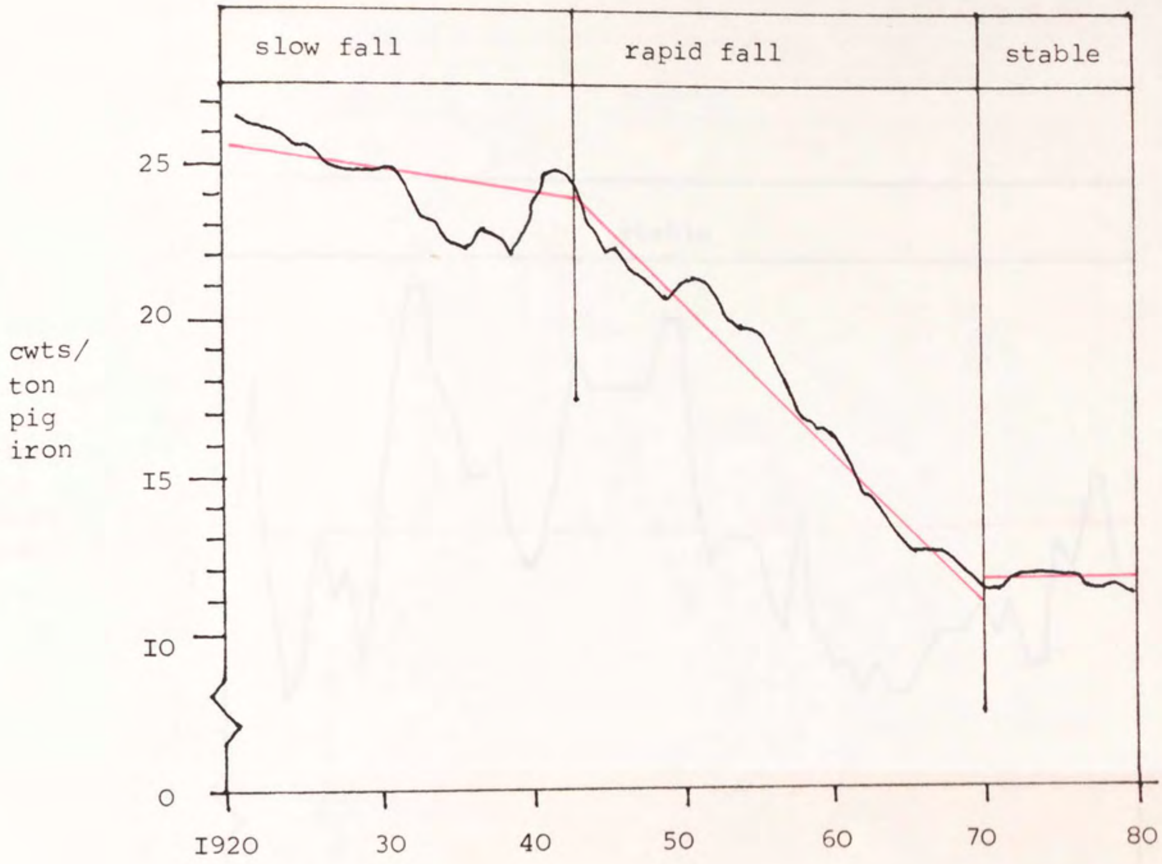


Figure 2.21 - Variations in unit input levels of coke

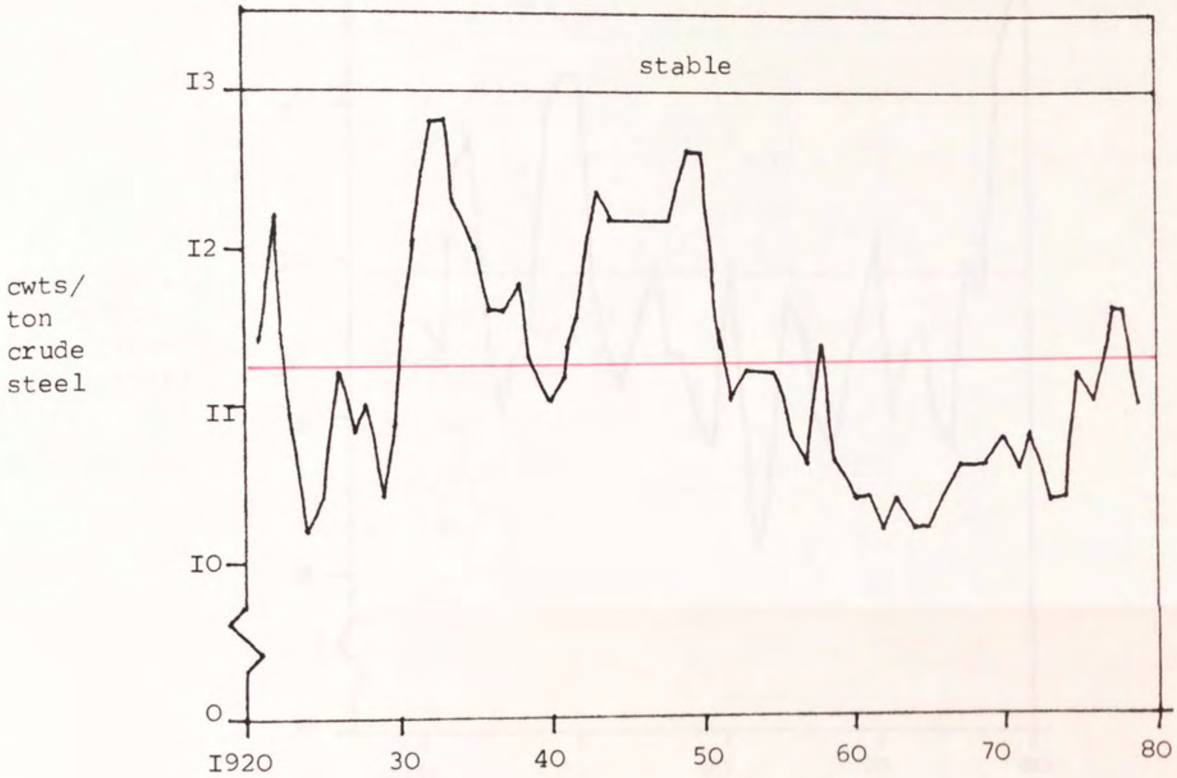


Figure 2.22 - Variations in unit input levels of steel scrap

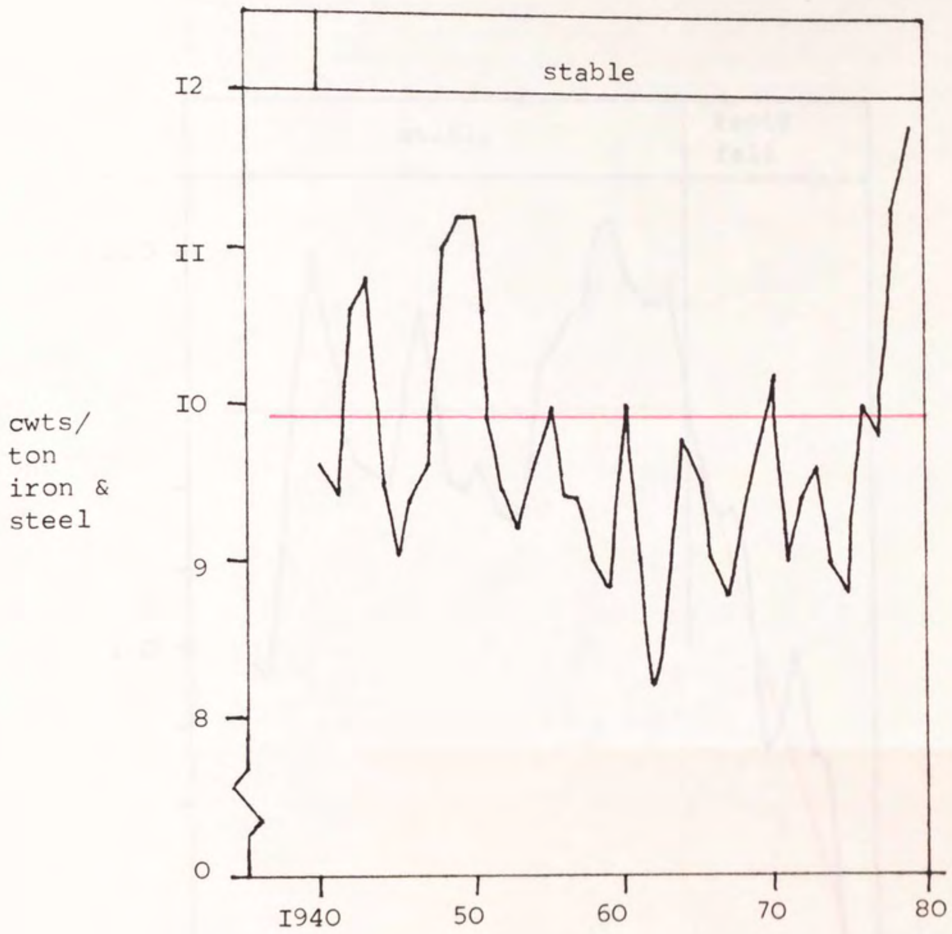


Figure 2.23 - Variations in unit input levels of total scrap

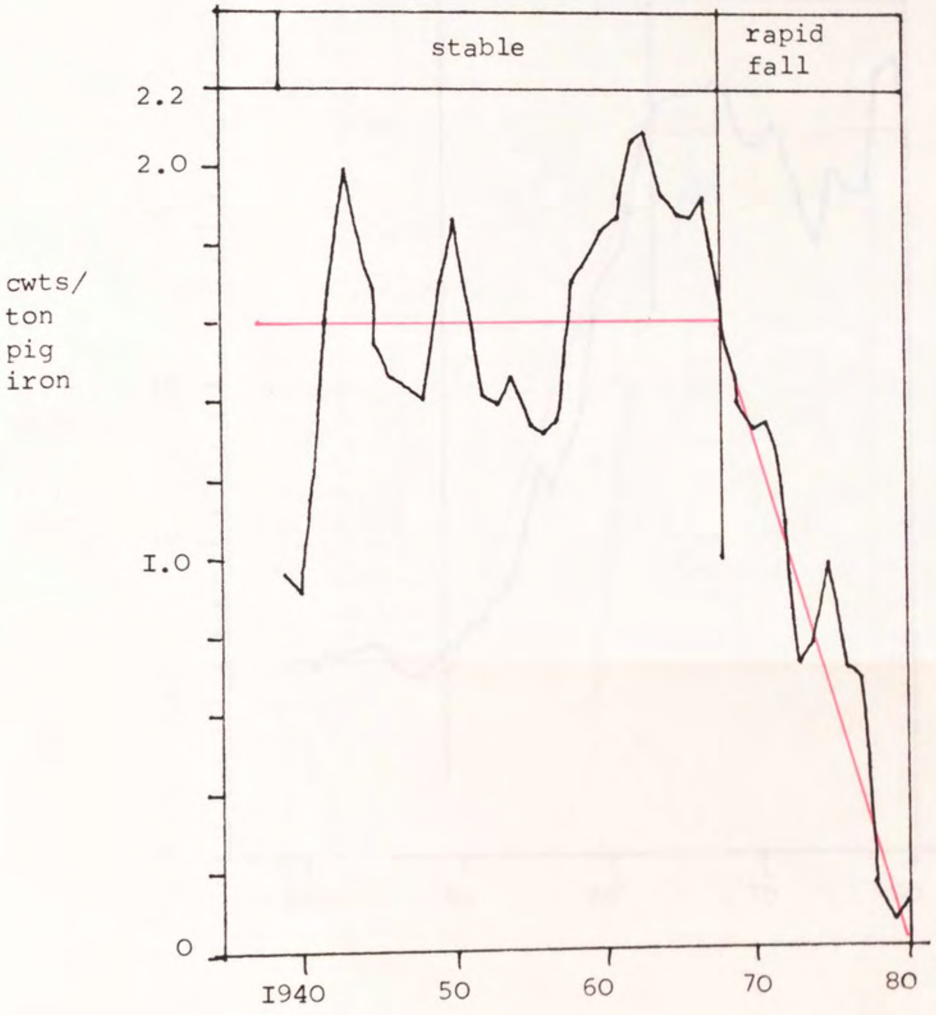


Figure 2.24 – Variations in unit input levels of iron scrap

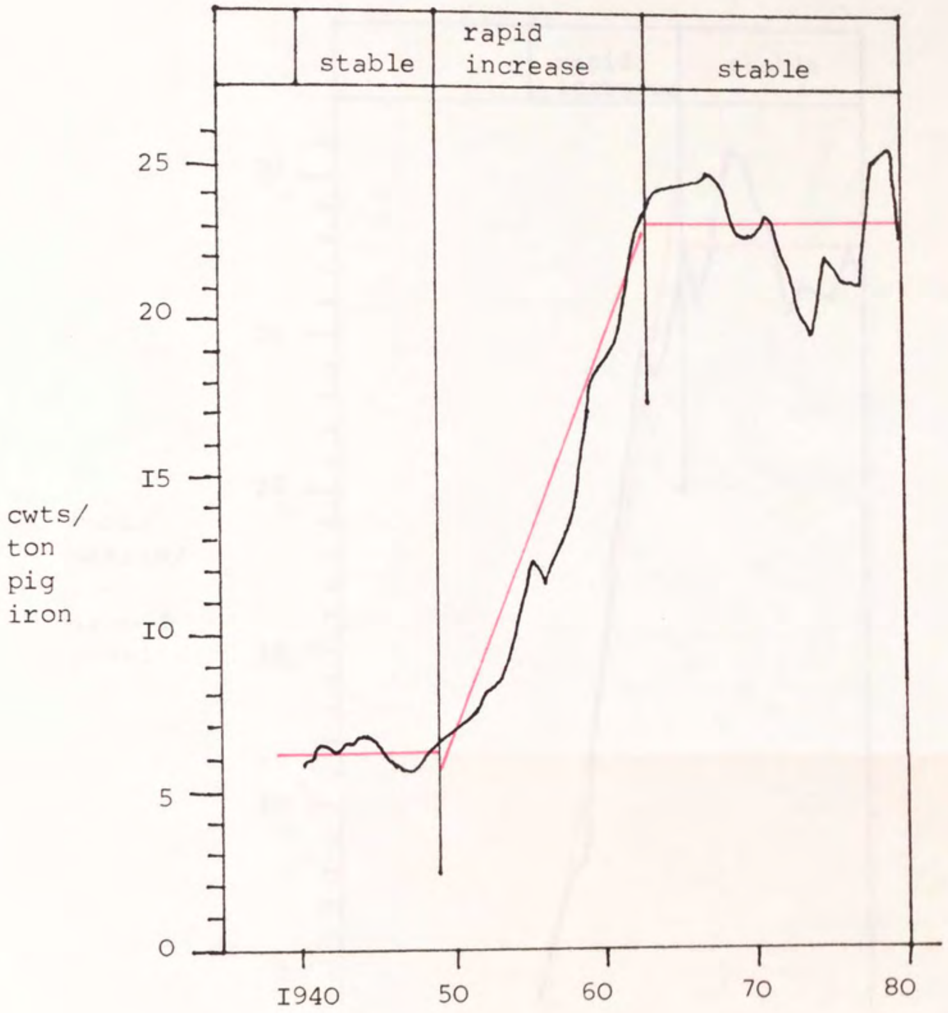


Figure 2.25 - Variations in unit input levels of sinter

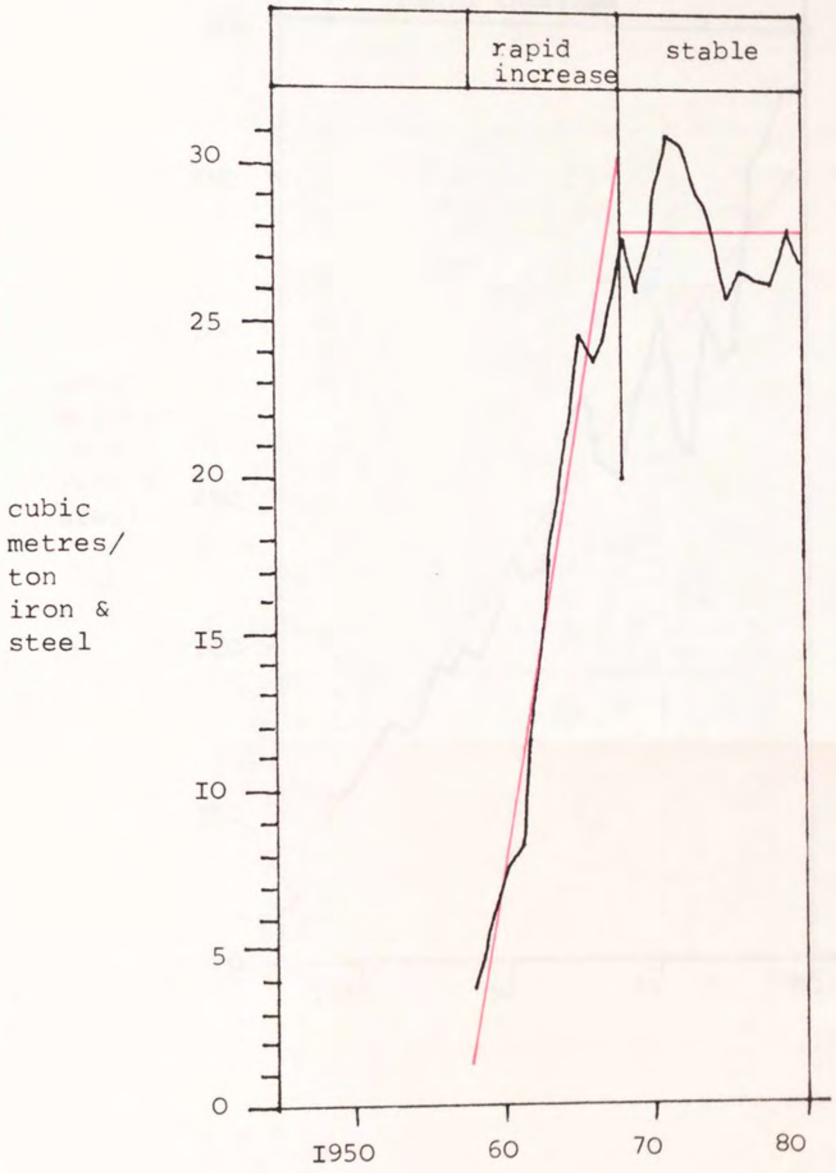


Figure 2.26 - Variations in unit input levels of oxygen

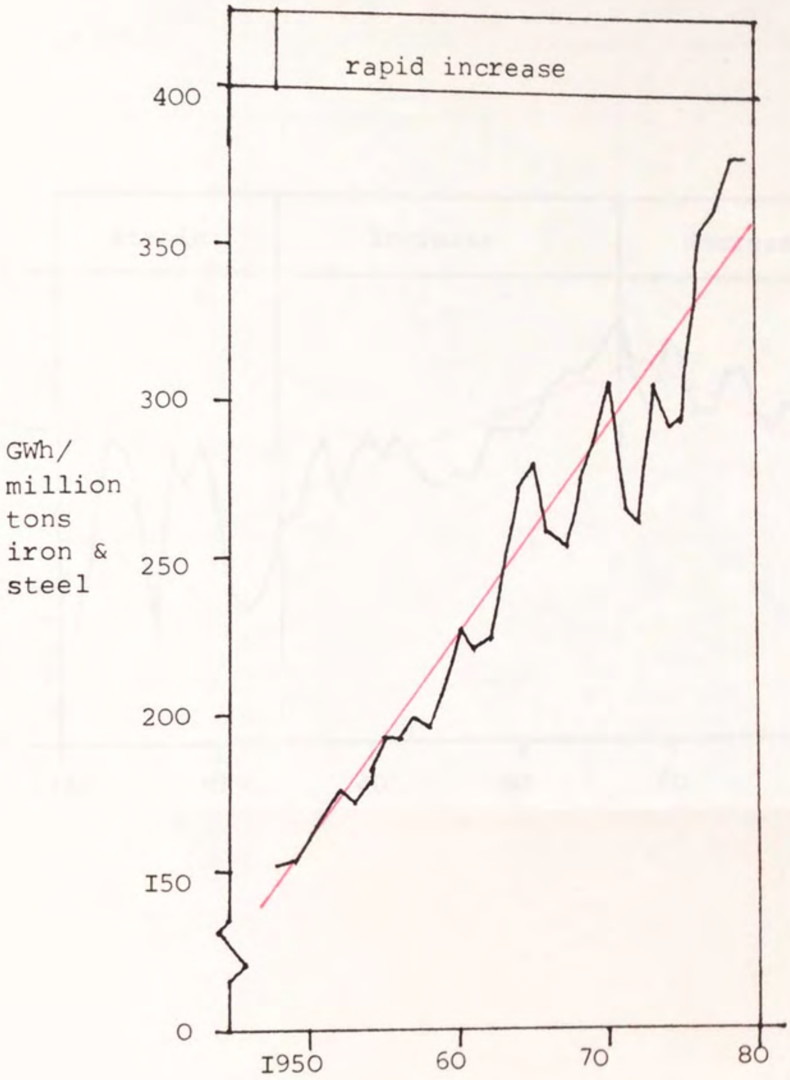


Figure 2.27 - Variations in unit input levels of electricity

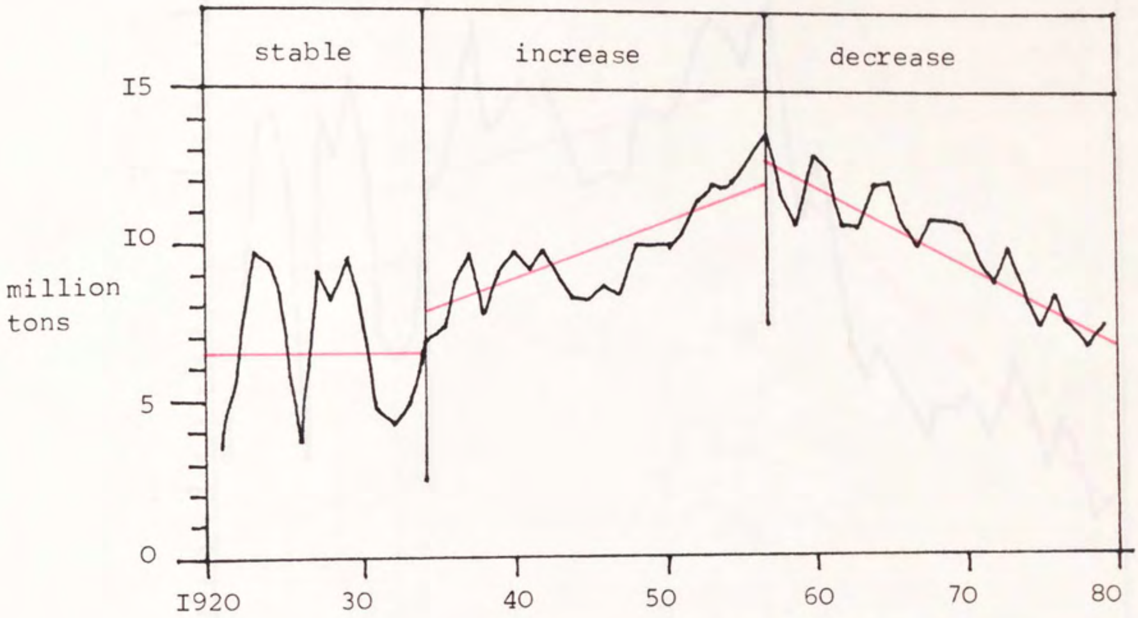


Figure 2.28 - Variations in gross consumption levels of coke

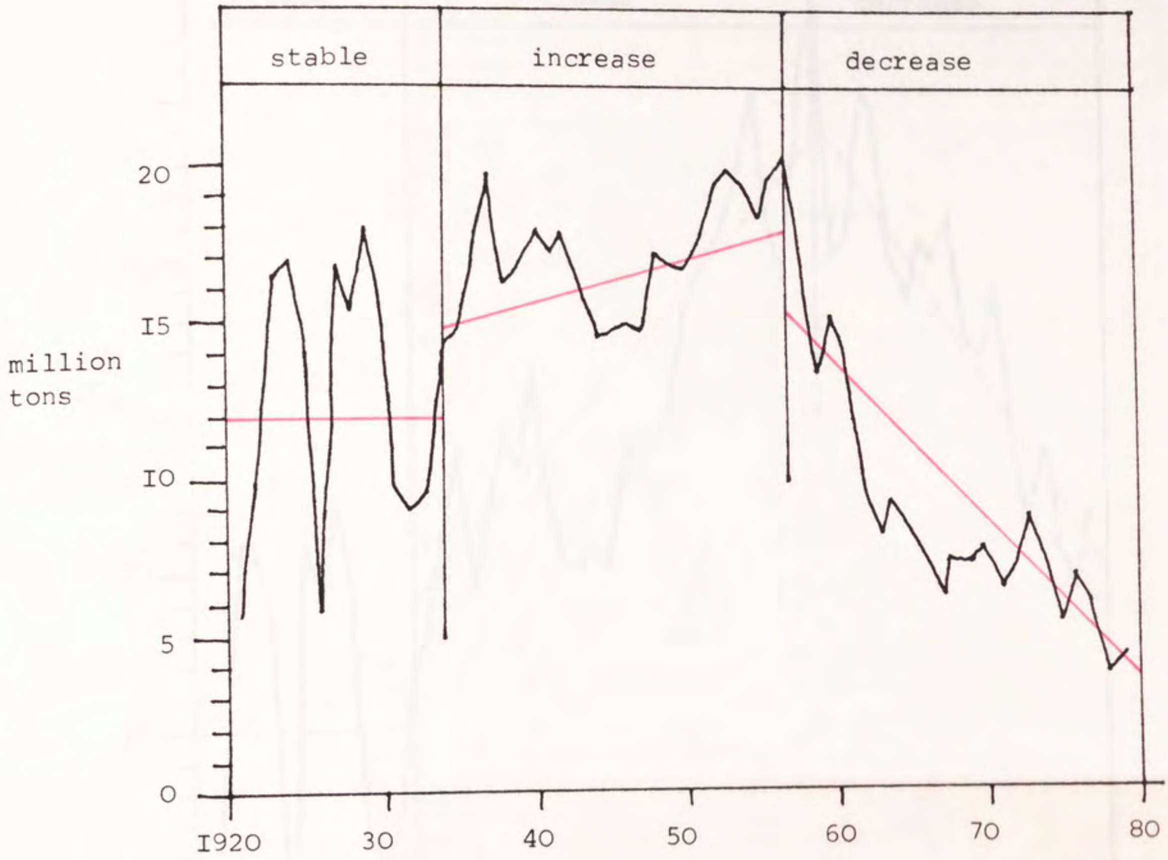


Figure 2.29 - Variations in gross consumption levels of iron ore

Figure 2.30 - Variations in gross consumption levels of blast furnace solids

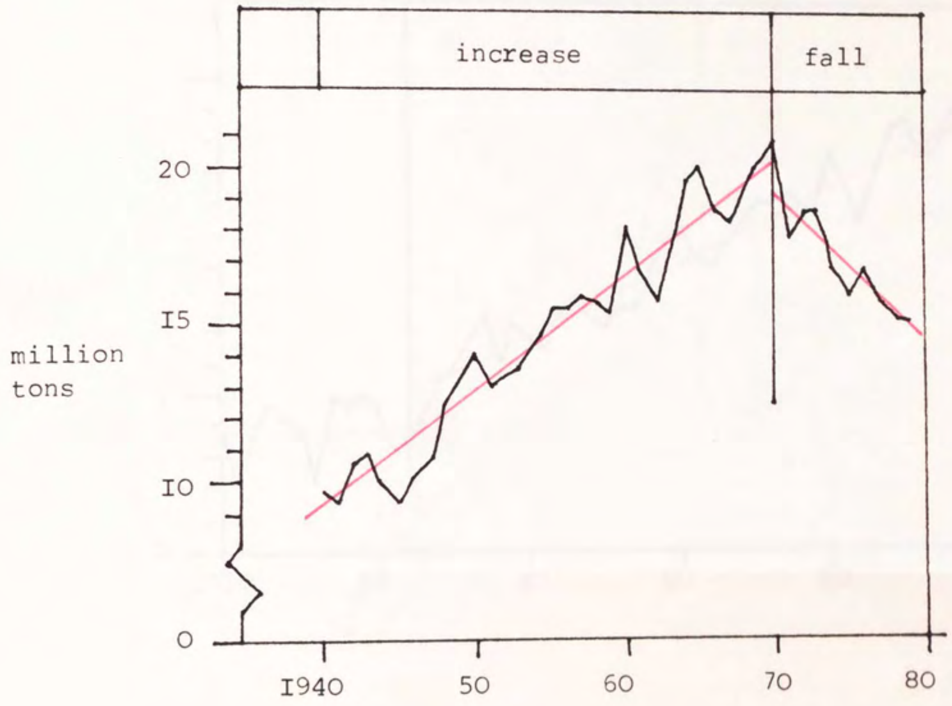


Figure 2.31 - Variations in gross consumption levels of total scrap

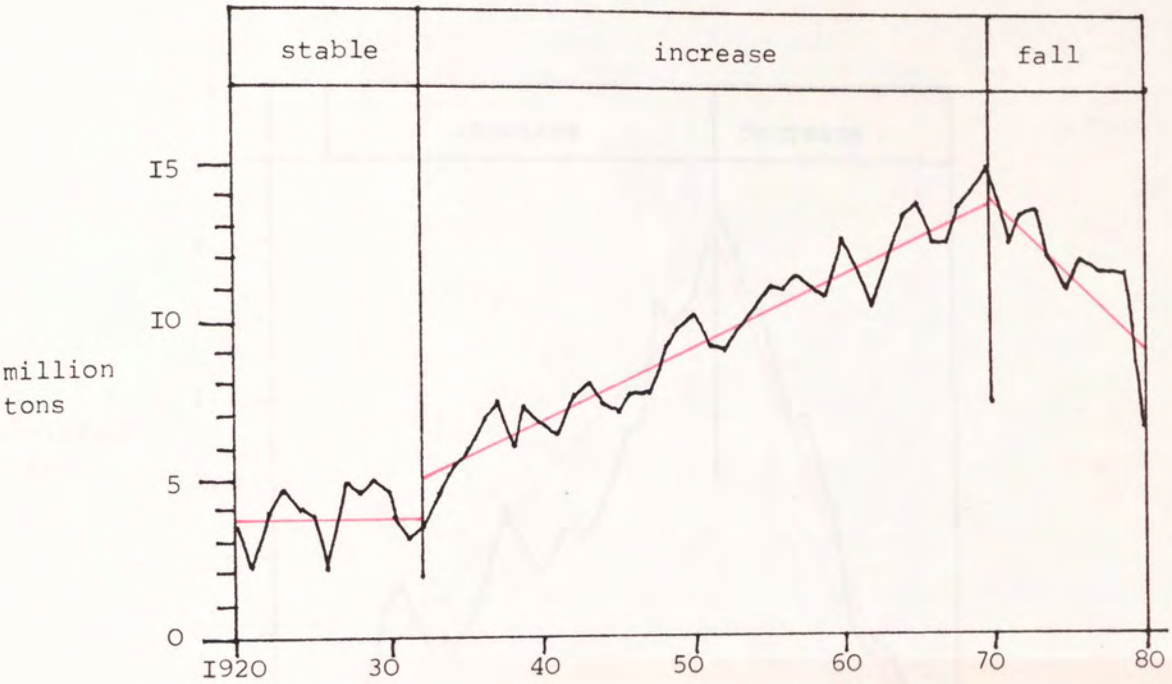


Figure 2.32 - Variations in gross consumption levels of steel scrap

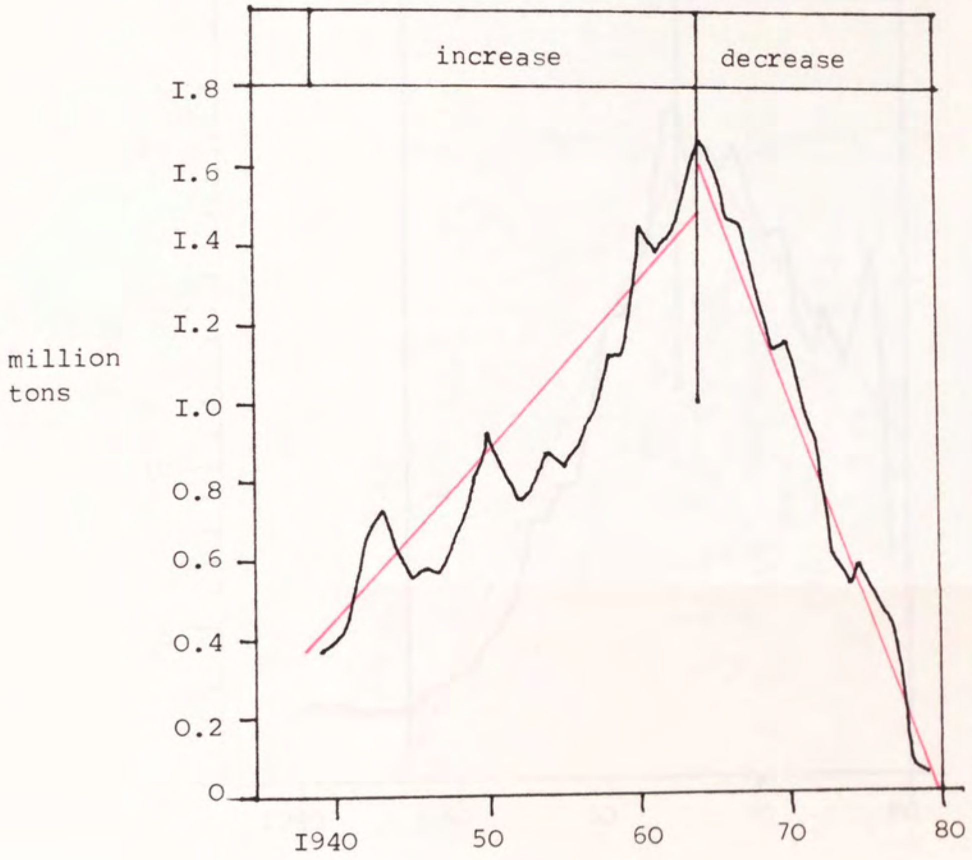


Figure 2.33 - Variations in gross consumption levels of iron scrap

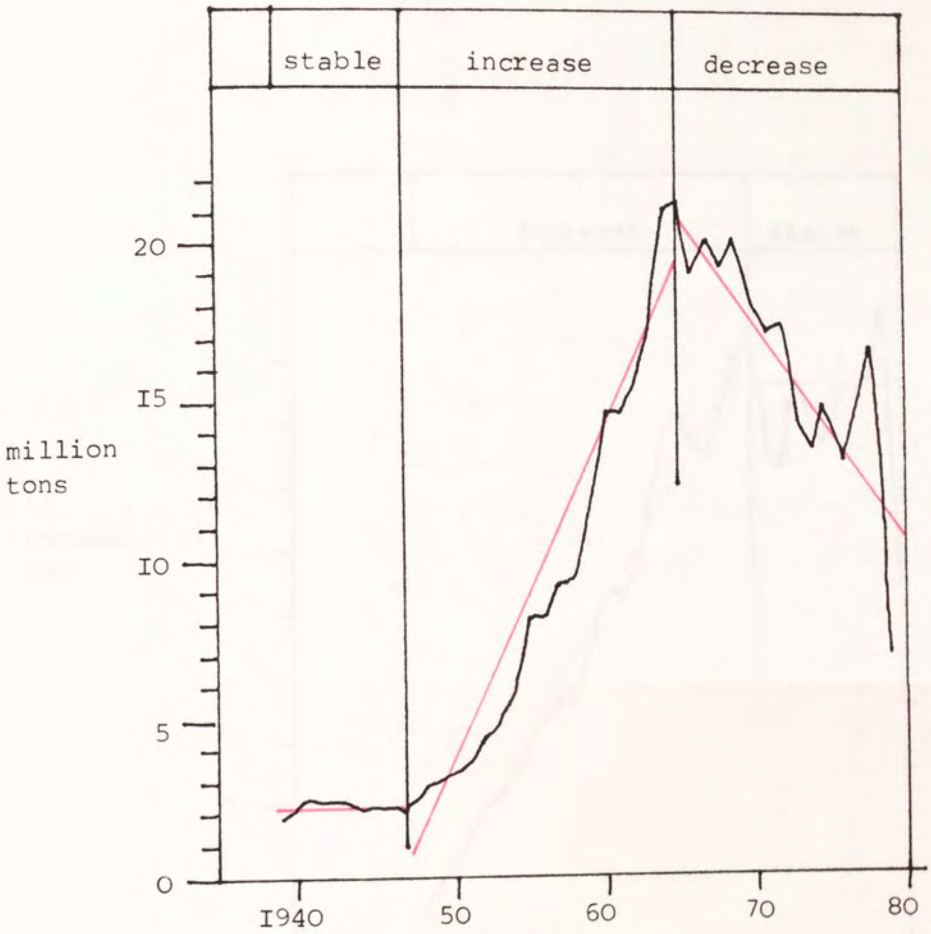


Figure 2.34 - Variations in gross consumption levels of sinter

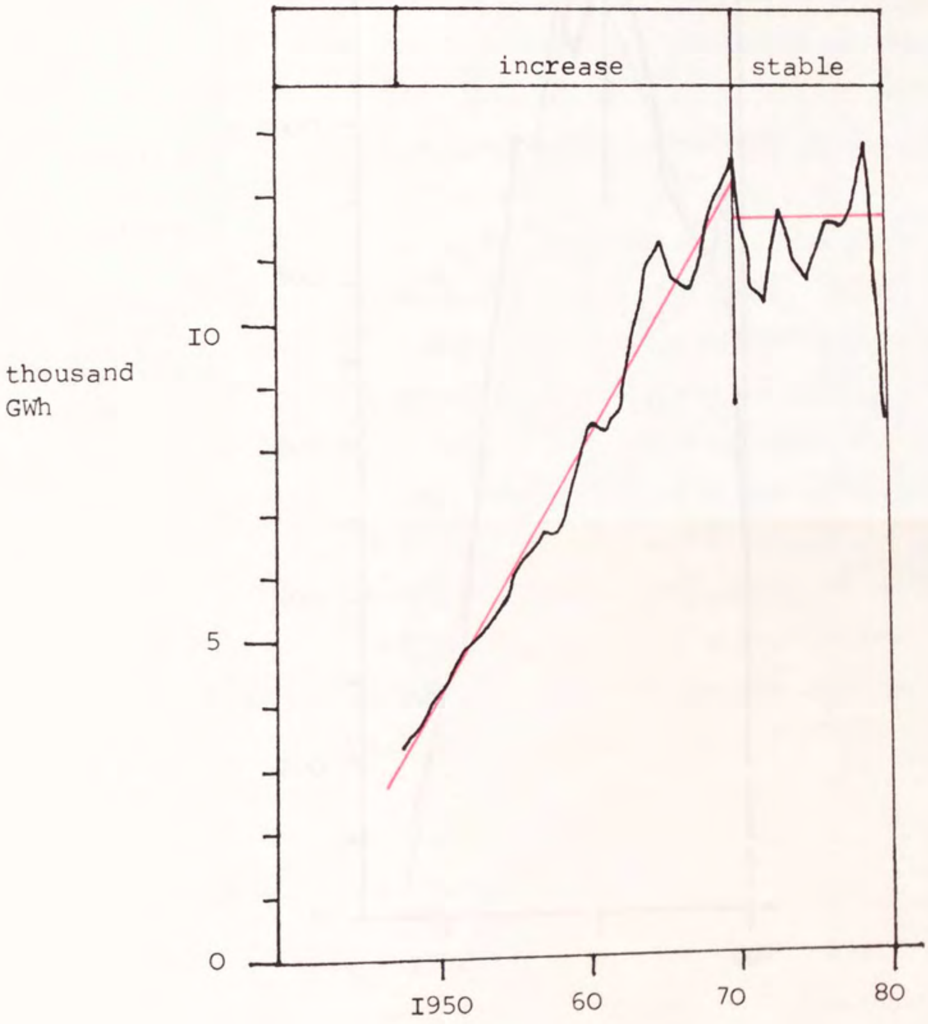


Figure 2.35 - Variations in gross consumption levels of electricity

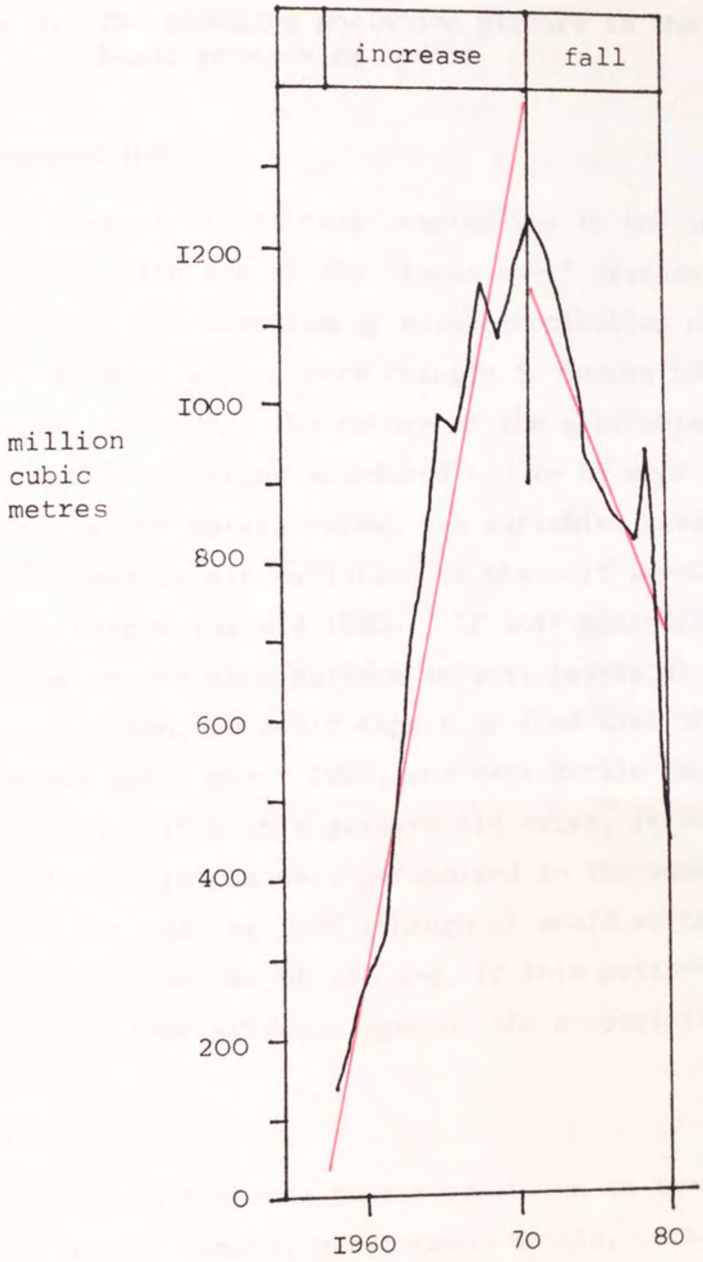


Figure 2.36 – Variations in gross consumption levels of oxygen

Chapter 3: The changing pollution picture in the United Kingdom basic processing sector

3A INTRODUCTION

The general aim of this chapter was to try and deal, as far as possible, with one of the 'loose ends' discussed at the end of Chapter Two - the question of whether pollution changes were periodized in the same way as were changes in inputs to iron and steel production. However, the nature of the available data meant that the particular question addressed had to be more limited. As outlined in greater detail below, the variables used were indicators of improvement in air pollution at the unit level, and no data was available before the mid 1950s. If unit pollution levels were periodized on the same pattern as unit levels of inputs to iron and steel production, we would expect to find that there was rapid improvement until about 1967, and very little change thereafter (see figure 2.10). If such a pattern did exist, it would not prove that unit pollution levels were periodized in the same way as unit input levels as far back as 1920 (though it would be consistent with this proposition). On the other hand, if this pattern did not occur, it would be clear evidence against the proposition.

3B DATA

The data all refers to air pollution in five UK industries - iron and steel, cement, non-ferrous metals, ceramics and electric power generation. The sources for raw data were the annual reports of the Alkali Inspectorate (ref: 2) and the government's 'Digest of Environmental Pollution Statistics' (ref: 11). The Alkali Inspectorate was the statutory body charged with overseeing air pollution in these industries, a responsibility taken over by the Health and Safety Executive in 1976, after which raw data comes from 'Industrial Air Pollution' (ref: 22). Thirty-seven variables were generated from the raw data, all being indicators for change in the rate of pollution improvement. Five different types of variable were used, as outlined in turn below.

1) The least direct of the variables measured changes in the volume of regulatory activity by the Inspectorate. Its claim to be an indicator of improvement lies in the nature of the regulatory 'actions' considered, which were of two types. The first consisted of the initial drawing up, and subsequent tightening of various 'standards'. These included maximum allowed concentrations in discharged air of particular pollutants (such as acids, metals and particulate matter), maximum allowed densities of smoke emitted during different phases of operations (as coded on the 'Ringelmann' scale) and other standards on things such as chimney height and practices of operating plant. The second type of action related to the 'enforcement' of these standards, and consisted of the issuing of orders to the industries concerned, requiring them to comply with particular standards within given time periods or they would be liable to prosectuion. Prosecutions themselves are, of course, an important aspect of enforcement. However, the reports do not give a complete and consistent breakdown of offences and prosecutions by industry, so this aspect could not be pursued. The full, dated list of both types of action is given in table 3.1 (annex 1). This was used to calculate a five year moving average of the annual frequency of all actions, as a measure of the volume of activity (Var 1). Values of this, and all other variables are given in table 3.4 (annex 1).

2) The next variable (Var 2) is a direct measure of changing amounts of a given pollutant per unit of a given output (sulphur dioxide per unit of electricy generated by the CEGB). It was calculated from electric power output data (ref: 4) and estimates of gross sulphur dioxide emissions from power stations (ref: 11, p 5).

3) The third type of variable measured concentrations in discharged air of various pollutants. The data was taken directly from the Inspectorate annual reports, and consists of annual means of samples taken. Table 3.2 (annex 1) gives details of the ten variables of this type (Vars 3 to 12).

4) The next twenty-two variables measured rates of diffusion of aspects of technology especially relevant to air pollution. In most cases they referred to add-on collectors or arrestors, and therefore acted as indicators of changes in amounts and/or concentrations of pollutants emitted. Three variables measured the changing adequacy of chimneys from furnaces, and acted as indicators for improvements in pollution through changes in the degree of dispersal achieved. One variable measured change in process technology particularly relevant to the problem of dark smoke emissions. The raw data in the Inspectorate reports consisted of numbers of plants of given type that were or were not using particular technologies. In all cases except one, total plant numbers were also given, which meant that the better diffusion measure of annual proportions could be calculated and used. Table 3.3 (annex 1) gives details of these variables (Vars 13 to 34).

There are two further points to make about these variables. First of all, eleven of them measured the 'diffusion-in' of technologies seen as being particularly beneficial. In these cases, rapid improvement in pollution is therefore indicated by rapid increases in proportions of plants using those technologies (such as % cement kilns using electrostatic particulate matter arrestors). The other eleven variables measured the 'diffusion-out' of aspects of technology that were seen as positively harmful, or as less beneficial. In these cases, rapid improvement in pollution was therefore indicated by rapid decreases in proportions of plants with those aspects of technology (such as % cement kilns with no arrestment plant for particulate matter).

The second point, as illustrated by the cement kilns example, is that not all the diffusion variables were statistically independent. Other things being equal, % kilns with no arrestment plant will be negatively correlated with % kilns using electrostatic precipitation.[1]

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[1] The negative autocorrelation would only be perfect if the substitution involved only two types of technology. If three or more were involved, and our variables measured the diffusion-in of the 'best' and the diffusion-out of the 'worst', we would still expect a negative relationship, but have no basis for predicting its strength. And this is the situation as regards the linked variables used.

This sort of link exists between other pairs of variables as well, leaving fifteen that are fully mutually independent (and these are indicated in table 3.3). Those variables which were not independent could not provide additional evidence for or against the existence of any particular pattern, but as alternative illustrations, they were used to help in characterising the patterns observed.

5) The thirty-four variables were plotted over time to see whether or not there was any evidence for the proposed pattern of change in the rate of pollution improvement. In the cases of sulphur dioxide from power stations and the volume of regulatory activity, it was easy enough to characterise the patterns of variation since we were looking at single variables over relatively long periods. But for the emission concentration and diffusion variables, the pictures were less clear. The graphs included many variables, covering a variety of timespans, and with differing start and finish dates. Methods were therefore sought for giving simple representations of the pictures painted collectively by each set of variables. And to do this, three summary variables were calculated.

Two of these (Vars 35, 36) were meausres of 'average diffusion rates', calculated by taking simple arithmetic means, across the two sets of diffusion variables, of annual changes in proportions (ie of plants using or not using certain technologies).[2] The same procedure was used to generate the final variable - measuring the 'average change' in emission concentration per year (Var 37). However, the ten individual variables in the set referred to different pollutants. And there was therefore a problem, in that the same absolute change may represent very different degrees of improvement. For example, a reduction of 0.05g/m^3 over a decade would represent

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[2] The calculation of these means included only the independent variables in each set. Also, one of the diffusion-out variables had to be excluded because it had different units of measurement from all the others - absolute plant numbers rather than plant proportions (Var 34). This meant that average rates of diffusion-in and diffusion-out were both based on seven individual variables.

a considerable improvement as regards concentrations of cadmium or flourine, but would represent virtually no improvement in concentrations of dust or sulphur trioxide. To get round this problem, sampled concentrations were indexed before the individual annual changes and the overall mean were calculated.[3]

3C RESULTS

Figure 3.1 below shows the variation over time in the volume of regulatory activity by the Inspectorate, and, as indicated, there was apparently a change in about 1972. Beforehand, there was a slow but steady increase in the volume of activity. After 1972, however, it was pretty stable. The graph does not imply that there was no improvement after 1972. Rather, it suggests that the increase in the rate/degree of improvement was not maintained.

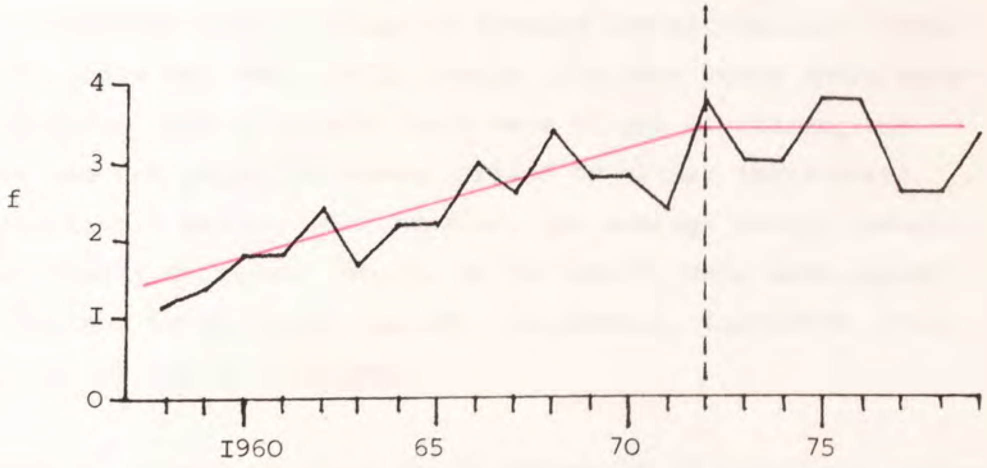

Figure 3.1 – Volume of regulatory activity by the Alkali Inspectorate

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[3] Because of the variation in the time periods covered, there was no base year for the indexing process that would allow the whole set of variables to be included. Whichever year was chosen, we had to lose two. Eight variables were indexed with a base of 1968=100, those excluded being variables 7 and 8.

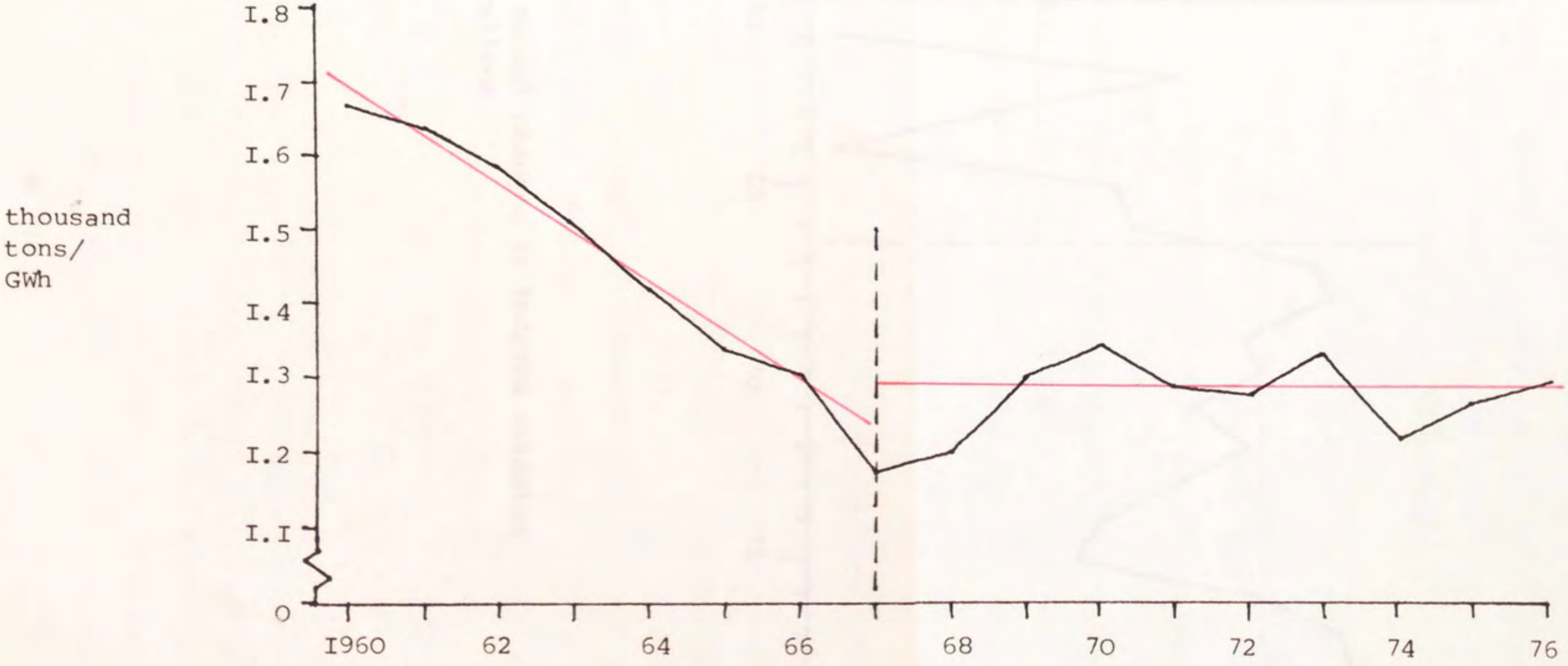
Figure 3.2 below shows the variation over time in sulphur dioxide emitted per unit of electric power generated. And, again, there was a clearly distinguishable change, this time in about 1967. Afterwards, there was very little change in the unit pollution level, whereas beforehand, there was a steady and quite rapid decrease.

Figure 3.6 (annex 2) shows the changes over time in sampled concentrations of pollutants in air discharged. The individual variables display a variety of patterns of change, but we can also make some generalisations. In the first decade or so, there are a few variables which showed little change (3, 6, 9), but most of them showed quite rapid improvements (especially 4, 5, 11, 12). During the rest of the period, some variables again showed little change (6, 7, 8), and some even indicated deterioration (3, 4). At some stage in the middle of the period studied, the balance therefore seems to have shifted - from stability or improvement to stability or deterioration.

Figure 3.3 below illustrates this shift in a different way, showing the average annual change in indexed concentrations. After about 1966, there was very little change. In some years there were slight increases, and in others there were slight decreases, but the period was not generally characterised by either improvement or deterioration. Before 1966, however, the average annual changes were consistently decreases, which, on the whole, were also larger than any changes in the later period. In general, therefore, this early period was one of improvement.

Figure 3.7 (annex 2) shows the diffusion-in of beneficial technologies, and the 1960s seems to have been a decade of quite marked improvement. The independent variables show the rapid diffusion-in of beneficial technologies (14, 16, 17, 18, 22), many being taken up by all plants to which they were potentially applicable (ie 100% diffusion). In the 1970s, the picture was more mixed. One of the independent variables indicates continued improvement (20), a trend

Figure 3.2 - Sulphur dioxide emitted per unit of electric power generated by the CEGB



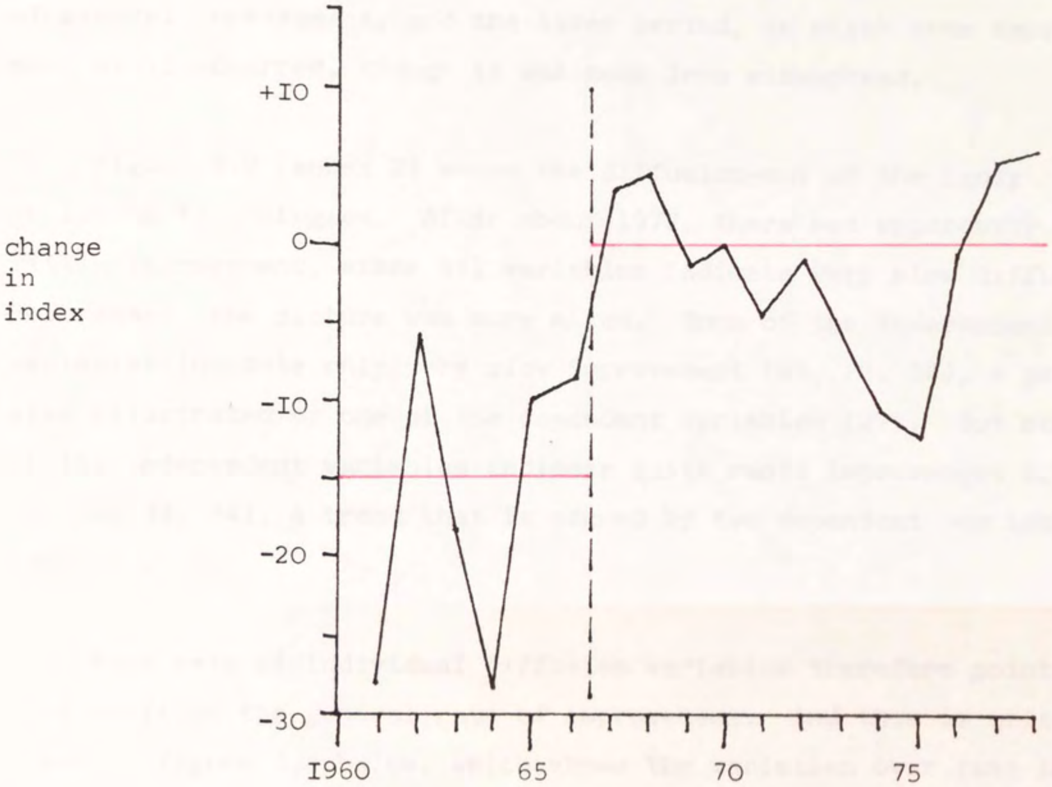


Figure 3.3 – Average annual changes in indexed emission concentrations

also shown by two of the dependent variables (19, 23). Two of the independent variables indicated very little change (15, 22), a trend again reflected by two of the dependent variables (13, 21). So we can apparently distinguish between the early period, which was one of general improvement, and the later period, in which some improvement still occurred, though it was much less widespread.

Figure 3.8 (annex 2) shows the diffusion-out of the badly polluting technologies. After about 1972, there was apparently very little improvement, since all variables indicate very slow diffusion. Beforehand, the picture was more mixed. Some of the independent variables indicate only very slow improvement (25, 28, 29), a pattern also illustrated by one of the dependent variables (27). But most of the independent variables indicate quite rapid improvement (24, 26, 32, 33, 34), a trend that is echoed by two dependent variables (30, 31).

Both sets of individual diffusion variables therefore point to a shift in the general rate of improvement. And this is quite clear in figure 3.4 below, which shows the variation over time in the average rates of diffusion - both in and out. As indicated, the change occurred in about 1973. Beforehand, the diffusion-in of beneficial technologies and the diffusion-out of badly polluting ones were both generally rapid, indicating rapid pollution improvement. Afterwards, average rates of diffusion-out were consistently low, indicating only very slow improvement. And average rates of diffusion-in fell quite sharply, indicating a decrease in the rate of improvement.

In summary, we note that all four types of indicator pointed to a decrease in the rate of pollution improvement at some time in the late 1960s or early 1970s. The similarity in the patterns revealed by these four types of measure allows us to abstract a description that would therefore be generally applicable to the air pollution problems in these industries. As illustrated schematically in

Figure 3.4 - Average annual rates of diffusion-in (35) and out (36)

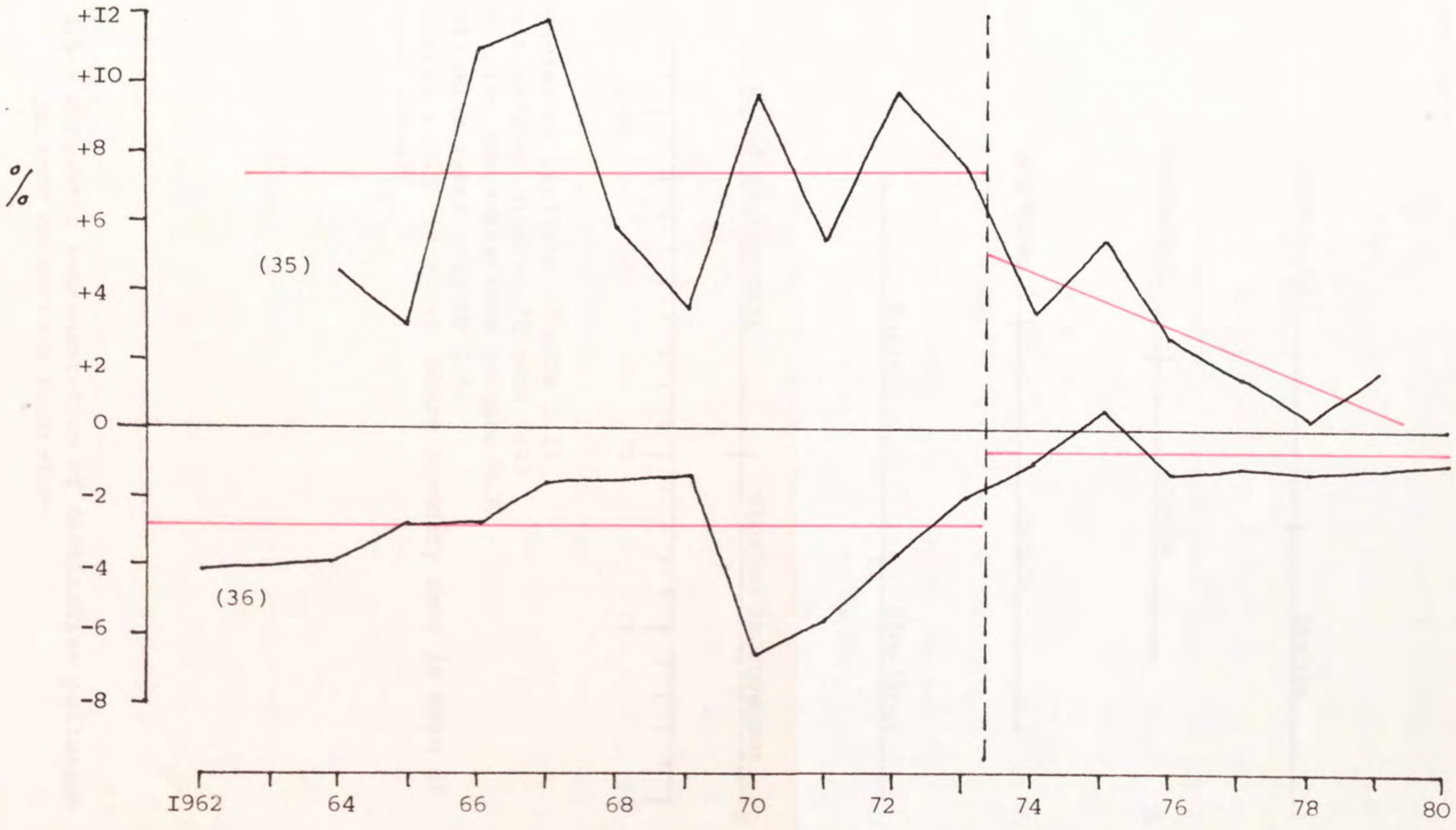
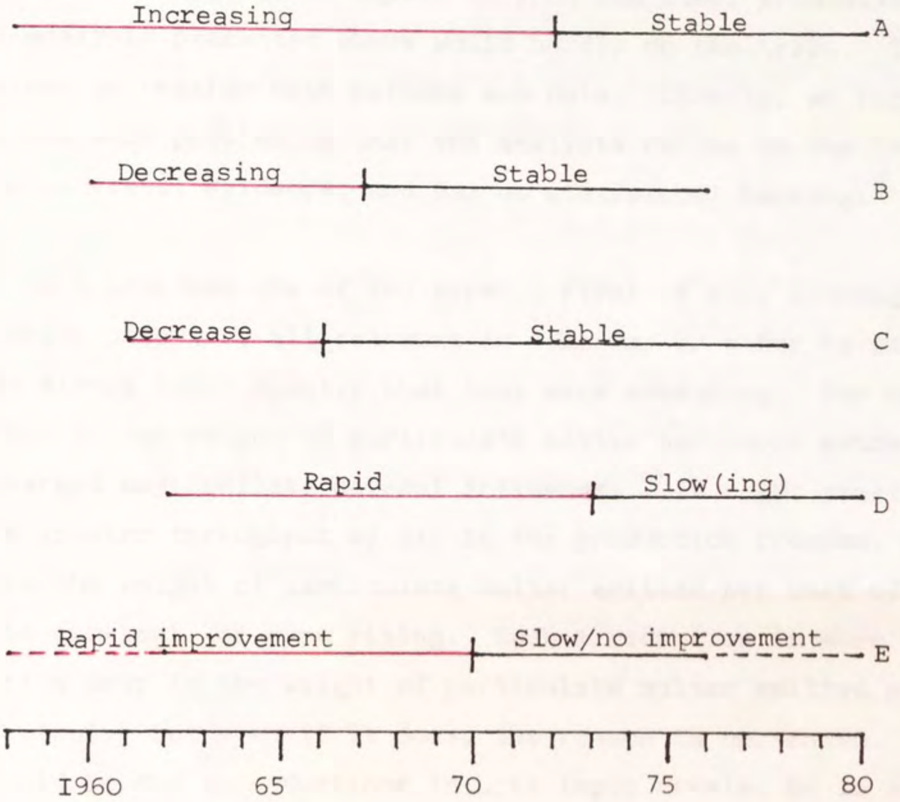


figure 3.5 below, the boundary between the two phases of this general model was 1970.



A - Regulatory activity (figure 3.I)
B - Unit sulphur dioxide (figure 3.2)
C - Emission concentrations (figure 3.3)
D - Diffusion rates (figure 3.4)
E - General pollution model (where boundary date is mean of those above)

Figure 3.5 - Schematic representation of distinctive pollution periods on various indicators

3D DISCUSSION AND CONCLUSION

If the objective of this chapter had been to try and 'prove' that unit pollution levels had the same pattern of change over this period as did unit levels of inputs to iron and steel production, then the analysis presented above would hardly do the trick. There are problems as regards both methods and data. Clearly, as regards methods, the main problem is that the analysis relies on the interpretation of visual evidence, and has no statistical backing.[4]

The data problems are of two types. First of all, although the variables used were all relevant in some way or other to pollution, it is not always clear exactly what they were measuring. For example, a reduction in the weight of particulate matter per cubic metre of air discharged may conflate several influences. It might possibly reflect a greater throughput of air in the production process, in which case the weight of particulate matter emitted per unit of output may be constant, or even rising. Such a reduction is more likely to reflect a drop in the weight of particulate matter emitted per unit of output. But even if it does, the reason is not known. Such a drop could be due to reductions in unit input levels, or to a change to the use of less 'dusty' inputs. It could be due to the introduction of 'cleaner' process technology, so that unit amounts of particulate matter actually evolved were reduced. But equally, unit amounts evolved in process may have been stable, and the drop in unit amounts emitted be due to the introduction of better add-on arrestors.

And this brings us to the second type of data problem - that of data omitted. Add-on cleaners feature prominently in the data, either as the object of diffusion variables, or implicitly, as possible sources of variation in sampled emission concentrations. And, as noted in chapter two, the problem is that we do not know the impact of all these technologies on water and land-based pollution problems.

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[4] The methods used to assess the significance of apparent periodization in the previous chapter would not have been appropriate here, because of the short timespans covered by the data.

The example serves to highlight the fact that the data is far from exhaustive, and there are large areas relevant to 'unit pollution levels' that are left unexplored due to lack of data. For example, until the Pollution Act of 1974, there was no right of access to the data on industrial water pollution held by the Water Authorities. In any such blank area, we can speculate that patterns of change may have been different from those described above.

However, despite these problems, the analysis presented would have been able to deal the proposition a severe blow (had it revealed the existence of other patterns of change). In this context, the fact that the data was not exhaustive is of relatively minor importance. Only a few counter examples would be needed to demonstrate that the proposition had, at best, limited validity. Similarly, it does not matter too much that some of the variables were ambiguous as regards exactly what they were measuring. Counter examples in any of the various senses of the term 'unit pollution levels' would, again, be sufficient to deal a blow to the general validity of the proposition.

The lack of statistical back-up for the visual evidence does remain a problem, but one that is also reduced, given the aim of disproving, rather than proving the proposition. It is one thing to say that the visual evidence supports the proposition although we cannot demonstrate this statistically. Clearly, it is quite another thing to claim that, merely because there is no statistical back-up, the visual evidence could be used to support the existence of some completely different pattern that had been proposed.

We can conclude, then, that although the data is not exhaustive, and some of it is ambiguous, none of it runs counter to the proposition. And, although the methods are imperfect, the visual evidence lends complete support to the proposition that patterns of change in pollution in these five industries were the same, from about 1960, as patterns of change in unit levels of inputs to iron and steel production. And again, although this conclusion does not constitute 'proof', it is consistent with the broader speculation that, since 1920, at least, variations in unit input and unit pollution levels have been periodized on the same pattern.

3E Annex 1: Data tables

Table 3.1 – Regulatory actions by the Alkali Inspectorate

Date	Action	Type[1]	Industry[2]
60	Pb from lead works: range .023 to .23 g/m^3	S	NF
61	Fume from copper works: max .115 g/m^3	S	NF
62	Pb from lead works: range .023 to .115 g/m^3	S	NF
64	Chimney standards for copper works	S	NF
66	Cd from cadmium works: max .04 g/m^3	S	NF
66	Dust from lead works: max .46 g/m^3	S	NF
66	Fume from lead works; max .115 g/m^3	S	NF
71	Total particulate matter (TPM) from secondary aluminium works: range .115 to .23 g/m^3	S	NF
74	Pb from lead works: range .012 to .115 g/m^3	S	NF
75	TPM from lead works: range .23 to .46 g/m^3	S	NF
77	Where PVC cables burnt in metal recovery, chimneys not to be less than 120 ft	S	NF
77	TPM from metal recovery: max .46 g/m^3	S	NF
77	HCL from metal recovery works: max .46 g/m^3	S	NF
77	No smoke to be darker than Ringelmann grade one (R1) at metal recovery works	S	NF
78	Zn from copper works: max .115 g/m^3	S	NF
78	Pb from copper works: range .012 to .115 g/m^3	S	NF
78	Cd from copper works: range .012 to .070 g/m^3	S	NF
81	95% arrestment of total fluoride required in primary aluminium works	S	NF
81	New standards for metal recovery works (not specified)	S	NF
81	TPM from secondary aluminium: max .115 g/m^3	S	NF
81	Max 10 ppm chlorine in discharges from all aluminium processes	S	NF
81	HCL from all aluminium processes: max .46 g/m^3	S	NF
48	TPM from all works: max .92 g/m^3	S	CT
62	TPM from all works: max .46 g/m^3	S	CT
68	TPM from all works: range .23 to .46 g/m^3	S	CT
68	Chimney regulations	S	CT
72	Notice sent to works with only cyclone arrestors that this no longer satisfactory	E	CT

Date	Action	Type[1]	Industry[2]
76	All new kilns, TPM: max .23 g/m^3	S	CT
79	All new kilns to have continuous pollution monitoring equipment	S	CT
59	Standards for bottle ovens (not specified)	S	CS
60	Provisional chimney standards agreed in salt glazing industry	S	CS
64	Salt glazing chimney standards confirmed	S	CS
64	Smoke standards (not specified)	S	CS
67	Salt glazing industry given till 1970 to conform with 1964 chimney standards	E	CS
66	All works given till 1970 to conform to 1964 smoke standards	E	CS
68	Standards on acid soot problems (not specified)	S	CS
72	New blue brick kilns not to emit smoke darker than R1 at any time	S	CS
77	All works, TPM: max .46 g/m^3	S	CS
77	No kilns in industry to emit smoke darker than R2 at any time	S	CS
79	New kilns, TPM: max .10 g/m^3	S	CT
79	New clinker coolers, TPM: max .15 g/m^3	S	CT
64	All boilers, TPM: provisional max .46 g/m^3	S	EY
69	All boilers, provisional chimney standards	S	EY
74	All boilers, chimneys to conform to 1969 standards	S	EY
74	All boilers, smoke and TPM to be monitored continuously	S	EY
74	Coal-fired plant designed before 1958, TPM: max .46 g/m^3	S	EY
74	Coal and oil-fired plant designed after 1958, TPM: range .115 to .46 g/m^3	S	EY
74	All new coal and oil-fired plant, TPM: max .115 g/m^3	S	EY
74	Smoke not normally to be darker than R1, and never darker than R2	S	EY
58	For all oxygen using processes, provisional TPM max .115 g/m^3	S	IS
60	For ore drying, crushing or sintering, TPM: max .46 g/m^3	S	IS
60	Provisional standards for hot-blast cupolas, chimney regulations and use of cyclones	S	IS

Date	Action	Type[1]	Industry[2]
63	Revised standards for hot-blast cupolas (not specified)	S	IS
67	All tropenas furnaces to have fume arrestors by end of year, or face prosectuion	E	IS
68	Further chimney standards for hot-blast cupolas	S	IS
68	Hot-blast cupolas, TPM: range .115 to .46 g/m^3	S	IS
69	Coke ovens, standards reviewed (not specified)	S	IS
70	New ore drying, crushing or sintering plant, TPM: max .115 g/m^3	S	IS
70	Blast furnace exit gases, TPM: max .115 g/m^3	S	IS
70	Non oxygen steelmaking, TPM: max .46 g/m^3	S	IS
70	Oxygen steelmaking, TPM: max confirmed at .115 g/m^3	S	IS
73	Further chimney standards for hot-blast cupolas	S	IS
73	Five year period for all hot-blast cupolas to have 'full' fume arrestment	E	IS
73	All new cupolas, TPM: max .115 g/m^3	S	IS
74	Notice sent to all open hearth steel works to fit fume arrestors	E	IS

1: S = standards, E = enforcement

2: NF = non-ferrous metals
CT = cement
CS = ceramics
EY = electricity
IS = iron and steel

3: Data from annual reports of the Alkali Inspectorate 1948 to 1975 (ref: 2), and 'Industrial Air Pollution' 1976 to 1983, annual reports of the Health and Safety Executive (ref: 22).

Table 3.2 - Emission concentration variables

Variable number	Description
3	g SO_3/m^3 from fletton brick works (5 year moving average)
4	g SO_3/m^3 from other ceramic works (5 year moving average)
5	gFL/m^3 from fletton brick works
6	g Pb/m^3 from lead works
7	g$\times10^{-1}$ Cd/m^3 from cadmium works
8	g particulate matter/m^3 from cement works
9	g dust/m^3 from 'Thameside' cement works
10	g SO_3/m^3 from oil-fired 'Bankside' power station
11	g SO_3/m^3 from ore-sintering works
12	g SO_3/m^3 from steel works

Data source as table 3.1 above

Table 3.3 - Diffusion variables

Variable number	Description
(13)	% of hot-blast cupolas with 'full' fume arrestment plant
14	% of tropenas furnaces with fume arrestment plant
15	% of iron blast furnaces with 'three-stage' arrestment plant
16	% of electric arc furnaces using bulk oxygen that have fume arrestors
17	% of electric arc furnaces using oxygen for light lancing that have fume arrestors
18	% of open hearth furnaces using oxygen for light lancing that have fume arrestors
(19)	% of CEGB boilers with electrostatic or combined particulate matter arrestors
20	% of CEGB boilers with continuous pollution monitoring
(21)	% of industrial boilers with electrostatic or combined particulate matter arrestors
22	% cement kilns with electrostatic dust arrestors
(23)	% of ceramics kilns that are oil-fired (reduces the dark smoke problems associated with coal-firing)
24	% of hot-blast cupolas with only 'provisional' best practical means of pollution control
25	% of CEGB boilers using only cyclone collectors
26	% of industrial boilers using only cyclone collectors
(27)	% of CEGB boilers using only scroll arrestors
28	% of CEGB boilers vented to 'unsatisfactory' chimneys
29	% of industrial boilers vented to 'unsatisfactory' chimneys
(30)	% of cement kilns using only cyclone collectors
(31)	% of cement kilns using no particulate matter arrestment plant
32	% of salt-glazing kilns vented to 'unsatisfactory' chimneys
33	% of ceramics kilns that are coal-fired by hand
34	number of furnaces vented to 'unsatisfactory' chimneys in the copper industry

Data source as table 3.1 above

( ): Variables not fully independent. Pattern of linkages as follows:

Independent variable	Linked variables
24	13
25	(19,27)
22	(30,31)
26	21
33	23

Table 3.4 - Pollution data

	Variable numbers								
	1	2	3	4	6	6	7	8	9
Units of measurement	f	thousand tons/GWh	g/m^3				g^{-1}/m^3	g/m^3	
1958	1.2								
59	1.4								
60	1.8	1.67							
61	1.8	1.64							
62	2.4	1.59		1.89		.044			
63	1.6	1.51		1.76	.029	.035			.916
64	2.2	1.42		1.59	.029	.046			.687
65	2.2	1.34	1.83	1.45	.016	.025			.687
66	3.0	1.31	1.86	1.39	.016	.025			.687
67	2.6	1.18	1.98	1.43	.011	.028			.687
68	3.4	1.20	2.00	1.39	.017	.032			.730
69	2.8	1.31	2.01	1.39	.014	.032			.782
70	2.8	1.35	2.10	1.48		.031			
71	2.4	1.30	2.08	1.43		.032			
72	3.8	1.29	2.00	1.43		.026			
73	3.0	1.34	1.97	1.55		.026	.027	.39	
74	3.0	1.22	2.03	1.67		.021	.064	.41	
75	3.8	1.27	2.00	1.74		.009	.046	.47	
76	3.8	1.30	2.09	1.86		.011	.046	.55	
77	2.6		2.21	2.00		.015	.014	.18	
78	2.6		2.33	2.11		.011	.053	.34	
79	3.4					.012	.022	.38	
80								.49	

( ): estimated where data coverage was not annual

	10	11	12	13	14	15	16	17	18	19
Measurement units	g/m³			%						
1958	.059									
59	.082									
60	.087	1.46	1.56							
61	.078	1.33	1.15							
62	.071	1.63	1.26							
63	.080	1.37	1.10		0					
64	.050	1.19	0.57		7.7					
65	.018	1.19	0.92		12.5					
66	.028	0.82	0.84	16.0	37.5	86.8	80.7	58.9		33.5
67	.044	1.21	0.80	18.0	57.1	86.6	89.3	78.6		34.0
68	.044	1.17	0.64	27.0	80.0	87.3	89.3	78.0		36.9
69	.057	1.03	0.62	30.2	87.0	87.3	89.3	87.8	0	39.9
70	.069	0.80	0.55	34.8	87.0	95.1	100	87.2	43.0	41.9
71	.082	0.73	0.39	38.7	100	98.0		87.2	50.0	44.8
72	.087	0.78	0.27	41.9		98.0		100	75.0	38.7
73	.096			50.7		97.9			100	39.9
74	.050			46.3		100				41.4
75	.025			47.7		100				46.8
76	.032			49.2		97.8				53.9
77	.037			55.2		97.6				54.9
78				54.0		97.1				55.4
79						96.6				58.1
80										60.7

	20	21	22	23	24	25	26	27	28	29
Measurement units	%									
1958										
59										
60										
61				9.5						
62				(13.2)						
63			63.0	16.9						
64			64.5	(21.0)						
65			65.9	25.1						
66		20.3	72.9	(29.2)	25.5	28.5	18.7	15.4	29.3	21.4
67		19.9	84.3	33.2	26.0	27.9	22.6	15.3	28.6	21.0
68		18.9	90.2	(38.2)	22.0	26.5	21.5	15.3	27.6	20.0
69		19.7	90.0	43.2	18.8	28.2	36.9	15.0	27.6	19.7
70		16.8	88.5	(54.4)	17.4	26.8	38.0	13.8	26.7	21.2
71	0	13.7	93.3	65.6	14.8	26.6	32.9	11.9	22.6	23.1
72	12.7	5.2	95.2	(71.5)	8.6	30.1	23.1	10.9	23.2	19.1
73	19.5	4.9	95.0	77.4	7.0	28.5	20.0	10.8	22.8	16.8
74	27.2	4.9	95.9	(79.8)	10.4	28.2	15.4	9.2	21.6	15.9
75	42.8	5.8	97.2	(82.2)	9.2	27.3	16.2	6.6	24.9	18.5
76	52.4	5.4	98.0	(84.6)	12.3	21.6	15.1	4.1	22.9	17.2
77	56.6	5.3	98.8	(87.0)	10.3	20.3	13.7	3.2	22.4	16.3
78	58.2	5.5	98.8	89.5	4.0	19.8	15.1	3.4	23.4	15.1
79	62.6	5.2	100	88.8		19.8	12.9	1.3	21.5	14.5
80	67.8	2.9		84.1		17.2	11.6	1.4	20.0	13.4

	30	31	32	33	34	35	36	37
Measurement units	%				f	annual change in... %		index
1958								
59								
60								
61				79.5				-28.0
62				(75.4)			-4.1	-5.3
63	18.7	17.9		71.3			-4.1	-18.5
64	18.2	14.0	82.0	(67.4)		+4.6	-3.9	-28.4
65	17.3	12.3	80.5	63.4		+3.1	-2.8	-10.0
66	15.8	11.3	79.0	(59.5)	132	+11.0	-2.7	-8.4
67	13.4	2.4	77.1	55.5	103	+11.8	-1.6	+3.5
68	7.3	2.4	76.8	(50.7)	91	+5.8	-1.4	+4.4
69	6.6	2.5	58.6	45.8	84	+3.5	-1.3	-1.4
70	8.7	2.9	27.2	(33.0)	54	+9.8	-6.5	-0.2
71	6.7	1.9	10.6	20.2	46	+5.5	-5.6	-4.6
72	6.8	0	6.5	(14.4)	37	+9.9	-3.7	-0.8
73	7.0		6.6	8.5	34	+7.9	-2.1	-5.8
74	4.1			(7.5)	27	+3.5	-0.8	-10.5
75	2.8			(6.5)		+5.6	+0.6	-12.0
76	2.0			(5.5)		+2.7	-1.3	-0.5
77	1.2			(4.5)		+1.6	-1.0	+5.3
78	1.2			3.5		+0.4	-1.1	+5.7
79	0			3.2		+1.7	-1.0	
80				4.0			-1.1	

THE ENVIRONMENTAL IMPACTS OF TECHNICAL CHANGE

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THE ENVIRONMENTAL IMPACTS OF TECHNICAL CHANGE

The thesis is concerned with relationships between profit, technology and environmental change. Existing work has concentrated on only a few questions, treated at either micro or macro levels of analysis. And there has been something of an impasse since the neoclassical and neomarxist approaches are either in direct conflict (macro level), or hardly interact (micro level). The aim of the thesis was to bypass this impasse by starting to develop a meso level of analysis that focusses on issues largely ignored in the traditional approaches - on questions about distribution.

The first questions looked at were descriptive - what were the patterns of distribution over time of the variability in types and rates of environmental change, and in particular, was there any evidence of periodization? Two case studies were used to examine these issues. The first looked at environmental change in the iron and steel industry since 1700, and the second studied pollution in five industries in the basic processing sector. It was established that environmental change has been markedly periodized, with an apparently fairly regular 'cycle length' of about fifty years.

The second questions considered were explanatory - whether and how this periodization could be accounted for by reference to variations in aspects of profitability and technical change. In the iron and steel industry, it was found that diffusion rates and the rate and nature of innovations were periodized on the same pattern as was environmental change. And the same sort of variation was also present in the realm of profits, as evidenced by cyclical changes in output growth. Simple theoretical accounts could be given for all the empirically demonstrable links, and it was suggested that the most useful models at this meso level of analysis are provided by structural change models of economic development.

ENVIRONMENT TECHNOLOGY PROFIT

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Chapter 1: Approaches to the role of technology in environmental change

1A INTRODUCTION

In general terms, this thesis is concerned with the role of technology in producing patterns of environmental change.[1] Relevant to this concern is a large body of literature dealing with relations between 'man' and nature - an interaction in which technology plays an important part. However, this literature is made up of several different strands, only one of which is particularly important to the thesis. The others are mentioned in order to provide a context, and so as to make explicit the main areas of thought that, although relevant, are not being considered.

The first distinction we can draw is between those works which see technological change itself as being causal, and those which see it as a factor that mediates the relationships.[2] The first position covers the 'autonomous technology' or 'technology-gone-wild' tradition, in which the development of science and technology is seen as responding to its own internal logic or teleology. Though much of this work concerns the influences of technological change on human social relations, there are some authors in this tradition who have also tried to draw out the systematic implications for the environment.[3]

The second position covers a number of separable strands. We can distinguish particularly between those works which locate the causal nexus in aspects of human nature and those which locate

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[1] Environmental change can be seen as being either essentially random, or as conforming to some sort of patterns. The latter view is a basic assumption of the thesis. The former would lead to no analysis at all.

[2] In practice, things are not this black and white. Rather, it is a question of degrees of causal primacy.

[3] For a review, see L Winner (ref: 52).

it in aspects of material reality.[4] Where human nature is seen as being the most important causal factor, we are usually referred to 'universal' aspects, such as 'instrumental rationality'. Under the compulsion of our own nature, we try to exert control over the laws and processes of nature in order to manipulate them for specific human purposes. Science and technology are seen as particular manifestations of this rationality, in contrast, say, to animistic religion. The argument generally continues to the effect that the sort of technological development engendered by this rationality tends to be antagonistic to the natural, self-regulation of ecosystems, and, on balance, is therefore environmentally harmful. Although found as an argument in a great deal of writing, the most detailed exposition is given by Critical Theory.[5]

Where causality is located in aspects of reality other than human consciousness, social structure and social relations are the key concepts. By far the majority of these works focus on capitalism or aspects of capitalism when looking for social structural forces which, when mediated by technological change, tend to produce systematic patterns in environmental outcomes. Within this literature, it is those focussing particularly on profits that are of special importance to the thesis, and which are discussed in greater detail in Section B below.

Before going on, however, we should also mention a second, and recently emerged strand of social structural analysis. This is feminist work, in which gender relations are seen as being of prime importance, rather than class relations, and in which the key causal concept is patriarchy, rather than capitalism.[6]

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[4] Again, the distinction really revolves around degrees of causal importance. Both traditions allow for the interplay between consciousness and material reality.

[5] See particularly W Leiss (ref: 34).

[6] See, for example, S Griffin (ref: 18).

1B TRADITIONAL APPROACHES

The underlying objective of the thesis is a response to what are seen as limitations of the traditional approaches to relations between profits, technology and environmental change. In this section, those approaches are characterised, their limitations are identified and the basic aim of the thesis is stated.

When looking at relationships between these three elements, the central empirical fact which acts as the starting point is variability in outcomes. Whether talking about pollution levels or rates of resource use, we can readily point to both increases and decreases. This observable variability gives rise to a number of theoretical issues, and the relevant literature focusses on two of these.

First of all, the immediate question to arise is how these contrasting outcomes result from technological change that is oriented towards maximising profits.[7] Why does this objective sometimes lead to increases in pollution, say, and sometimes to decreases?

The second issue concerns the social evaluation of these changes. Clearly, not all increases in resource use or pollution are 'bad', since they may result from the introduction of technologies which give rise to social benefits that more than compensate. Equally,

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[7] The idea that the main objective of the firm is to maximise profits is one which has received much criticism, but it is broadly accepted here. Many of the alternatives put forward can be seen either as specific profit-maximising strategies, or as more limited goals that can be subsumed within a broad, profit-maximising objective. Such goals include cost-minimisation, maximising the rate of turnover and maximising market share. And many of the other alternatives put forward can be seen as attempts to secure maximum profits in the long run, rather than, and possibly conflicting with short term profit-maximisation. These objectives include corporate growth, securing control over sources of material inputs and maintaining trouble-free relationships, with both the consumer and the labour force.

not all reductions are necessarily 'good'. Whatever definition of social welfare we use, all commentators accept that, in reality, technological change in the service of profit gives rise to a mixture of good and bad outcomes. And the question that has received particular attention is whether there is any general, underlying bias.

There are two main bodies of work that relate to these issues. They are referred to as neoclassical and neomarxist on the basis of their roots in more general political economic theory. The essences of these traditions are characterised in turn below.

(B1) Neoclassical Positions

Much of the work in this tradition was carried out in the late 1960s and early 1970s, and, in general, it can be seen as a response to the rising tide of environmental consciousness and concern, especially in the United States. More particularly, it represents an attempt to refute the criticism that mainstream economic theory was unable to deal with environmental issues. And, as such, the tradition developed a strong theoretical base, a base that can be seen as a specific application of the more general framework of neoclassical welfare economics.

Accordingly, the central explanatory model refers to individual 'actors' who try to maximise their own self-interest in conditions that are given from the outside. Under the assumptions of perfect competition, their behaviour can be accurately predicted.[8] To illustrate the use of the model, we consider changes in the level of pollution produced by a firm per unit of output. Figure 1.1 below demonstrates procedures used to determine whether pollution levels increase or decrease, and by how much.

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[8] For a full list of these assumptions, reference should be made to a general economics text (see, for example, B J McCormick, ref: 37, pp 320-322). Environmental economics texts often give a less than complete list (see, for example, A Kneese et al, ref: 33, p 66).

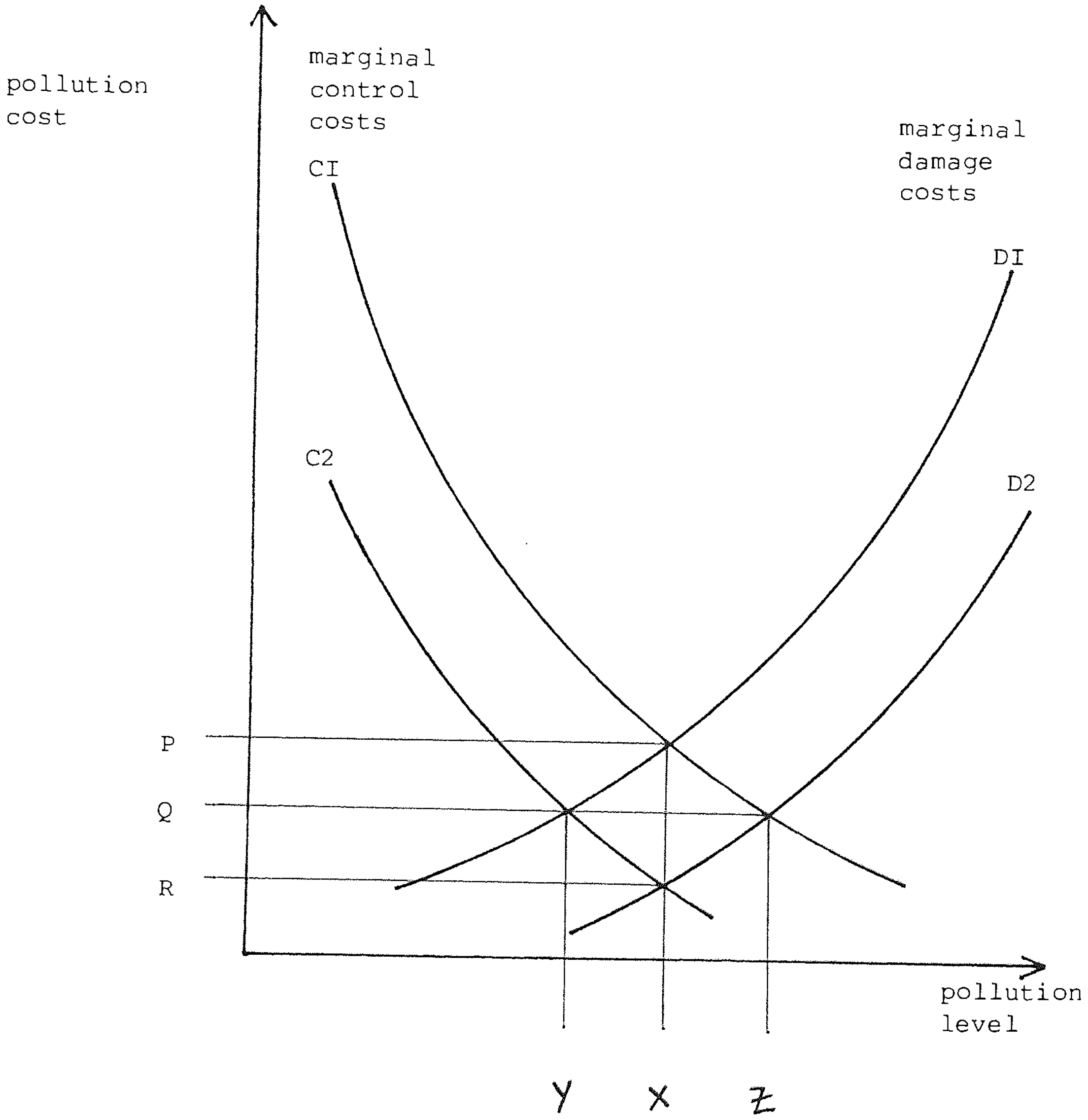

Figure 1.1 - Changing levels of pollution produced by the firm

For any given level of pollution, the total costs to the firm can be divided into damage and control costs. In both cases, the marginal cost curves are assumed to be positive[9] - ie each extra unit of pollution produced is assumed to result in more damage (and greater cost), and control costs are assumed to increase with successive unit reductions in pollution levels. Total pollution costs are least when marginal damage and marginal control costs are equal - at the intersection of the two cost curves.

In an initial equilibrium state, the cost curves facing the firm are given by C1 and D1. At the least cost point, the firm produces X amount of pollution per unit of output, at a total cost P(x2). For any reason, either or both of the cost curves facing the firm may change. If the control cost curve changes to C2, a new least-cost equilibrium point will emerge, where C2 intersects D1. In moving to this new position, the total pollution costs of the firm will fall from P to Q, and the level of pollution produced will fall from X to Y. If the damage cost curve changes to D2, but the control cost curve remains at C1, the least-cost equilibrium will also reduce total pollution costs from P to Q, but will increase levels of pollution from X to Z. If both cost curves change, the least-cost equilibrium point will be the intersection of the curves C2 and D2. At this point the total pollution costs facing the firm will be reduced still further to R, but the level of pollution produced will be the same as it was in the initial equilibrium - ie X.

Each of these three changes mean that the firm has to alter its production strategy in order to continue to make maximum profits. One of these profit-maximising moves results in decreasing pollution levels, one in increasing pollution levels and the third in no change

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[9] This is always the case in theory, though there is some debate about the shape of the curves in practice. See, for example, P Burrows (ref: 7, pp 34-40).

at all. Any particular outcome can be explained by reference to the model, and the observable variability in outcomes can therefore be accounted for.

In this illustration, the changes in the cost environment facing the firm are seen as being given from the outside. Any technical change that is necessary in order to move to the new profit-maximising position is therefore adaptive. But innovation is often part of an aggressive strategy to try and gain an advantage over competitors, rather than part of a responsive package. In the context of Figure 1.1, however, this would make no difference, either to the objectives of technical change - the reduction of damage costs, control costs or both, or to the pollution impacts that might result - increase, decrease or no change in unit pollution levels. The observable variability in outcomes can therefore be accounted for, irrespective of whether technical change is seen as part of an active strategy for gaining competitive advantage, or as a response to changing conditions that is necessary to firms simply in order to stay in business.

Figure 1.1 has been used to illustrate the basic nature of the neoclassical micro level models, but there are others, operating on similar principles, that are now reviewed here. First of all, in the 'cost/cost' formulation in Figure 1.1, the level of pollution by the firm is given by the 'Pareto' efficient position. But there are other criteria for efficiency, such as 'Potential Pareto', and there are other formulations such as 'cost/benefit' or 'benefit/benefit'.[10] Secondly, whilst Figure 1.1 relates to pollution levels, very similar models are used to theoretically determine the most efficient rates of resource use.[11] Thirdly, the individual actor considered in Figure 1.1 is the producer. Also relevant is the behaviour of consumers, which is predicted under the same assumptions, by the use of indifference curves rather than cost curves.

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[10] For a discussion of these alternatives, see D Pearce (ref: 39, Ch.1).

[11] See, for example, G Heal & P Dasgupta (ref: 21).

When we turn to consider the evaluation of environmental change, and, in particular, the balance between socially good and bad outcomes, we start by looking at a stable equilibrium under perfect competition assumptions. In this situation, the interests of producers trying to maximise profits and consumers trying to maximise utility will be perfectly balanced, and the total social welfare at maximum. The level of pollution produced by each individual firm will therefore be socially optimal as well as being the most profitable for the firm concerned. And, by aggregating over all producers, the mixture of different levels of the various pollutants produced will also be the optimum for society as a whole.

Disequilibrium may arise because of localised disruption in a single market, and the mix of environmental outcomes would then become sub-optimal. Adjustments by relevant producers and consumers to maximise their private profits/utility would, in these circumstances, lead to the restoration of an equilibrium that maximised total social welfare. The mix of environmental outcomes would again become socially optimal, and the changes resulting from private profit maximisation could be evaluated unequivocably as improvements from the social viewpoint.

In reality, of course, the conditions for perfect competition do not hold. Disruptions occur in many rather than single markets, and are widespread rather than localised. Under these circumstances, it is accepted that the mix of environmental outcomes produced is not the social optimum. And private profit-maximising changes no longer necessarily represent social improvements.[12] Those deviations from the conditions of perfect competition that are often cited as being responsible for a socially sub-optimal mix of environmental

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[12] And when the conditions of perfect competition do not hold, there is also a theoretical problem in trying to specify what is the 'second best' mix of environmental outcomes. In turn, this means that there is no single, simple yardstick against which particular outcomes can be measured to determine whether or not they are socially beneficial changes.

outcomes include the following:[13]

a) The existence and functioning of monopolies

b) Imperfect ownership/lack of market values for some environmental resources

c) Production indivisibilities

d) Uncertainty about the future -resource prices, the direction of technological change, government policy, etc

e) Unequal bargaining power between producers and consumers.

However, these deviations tend to be seen as resulting from the imperfections of real world capitalism, rather than from its fundamental nature, and are, in this sense, marginal. If capitalism were to be perfected, then the conditions of perfect competition would be systematically reproduced, and private profit-maximising moves would result in environmental changes that were socially beneficial. And, in this sense, the traditional neoclassical approach holds that the basic nature of capitalism is conducive to producing socially beneficial environmental outcomes (even though, in the real world, the imperfections mean that actual outcomes are often not socially beneficial). This idea - that private profit-maximisation is potentially able to deliver environmental outcomes that are systematically socially beneficial - is found in a variety of forms in most of the neoclassical texts, one such form being as follows:

> "The problem is to get the state to price common resources (inputs and the waste assimilative capacity of the environment), then, once we have faced and solved the problem of common property resources, the profit motive can once again resume its role as the engine which drives the allocation of resources in the direction of social interests."
>
> A Kneese in relation to
> environmental problems in
> general (Ref: 53, p 224).

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[13] Not all of these deviations are held to consistently result in excessive levels of pollution or rates of resource use. For example, monopolies are generally seen as using resources too slowly, and, by some authors, are seen as producing pollution levels that are too low. For discussions in relation to resource use, see D Pearce (ref: 39, pp 147-155), and in relation to pollution, see P Burrows (ref: 7, chapter 2).

The 1980s has seen the development of another body of work which argues, in a different way, that private profit-maximisation could be associated with environmental changes that are generally socially beneficial. I refer to this as the 'pragmatic neoclassical' approach, in order to distinguish it from the works illustrated above, which have a strong theoretical bias.[14] It is pragmatic in the sense that it is oriented towards the real world, and especially towards managerial policy. However, it is still essentially neoclassical in that the terms and arguments relate easily to the micro-level models of the type shown in Figure 1.1 above. It lends support to the theoretical neoclassical assertion since it argues that, even though the costs of using environmental resources are not fully represented in the market, increasingly rational behaviour by private producers should result in environmental changes that are generally socially beneficial.

For various reasons, it is argued that the pollution damage costs facing firms tend to be greater in reality than is often assumed, whereas the benefits of pollution control are generally underestimated.[15] If producers acted in a fully rational way, not only would total pollution costs be reduced, and profits increased, but levels of pollution emitted would also be reduced towards socially optimal levels. The argument is illustrated in Figure 1.2 below, using the same cost/cost formulation as in Figure 1.1.

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[14] The original, influential work was 'Pollution prevention pays' by M Royston in 1979, detailing and explaining the profitable introduction of pollution abatement technologies by the 3M company. Since then, as well as a growing literature, the impetus has led to the setting up of a register of such technologies (the 'Compendium on low and non-waste technologies' - UN Economic Commission for Europe) and to competitions being organised in order to promote their development (the 'Pollution Abatement Technology Award Scheme', devised by the CBI).

[15] For a detailed exposition, see M Royston (ref: 44, Chs 3-7).

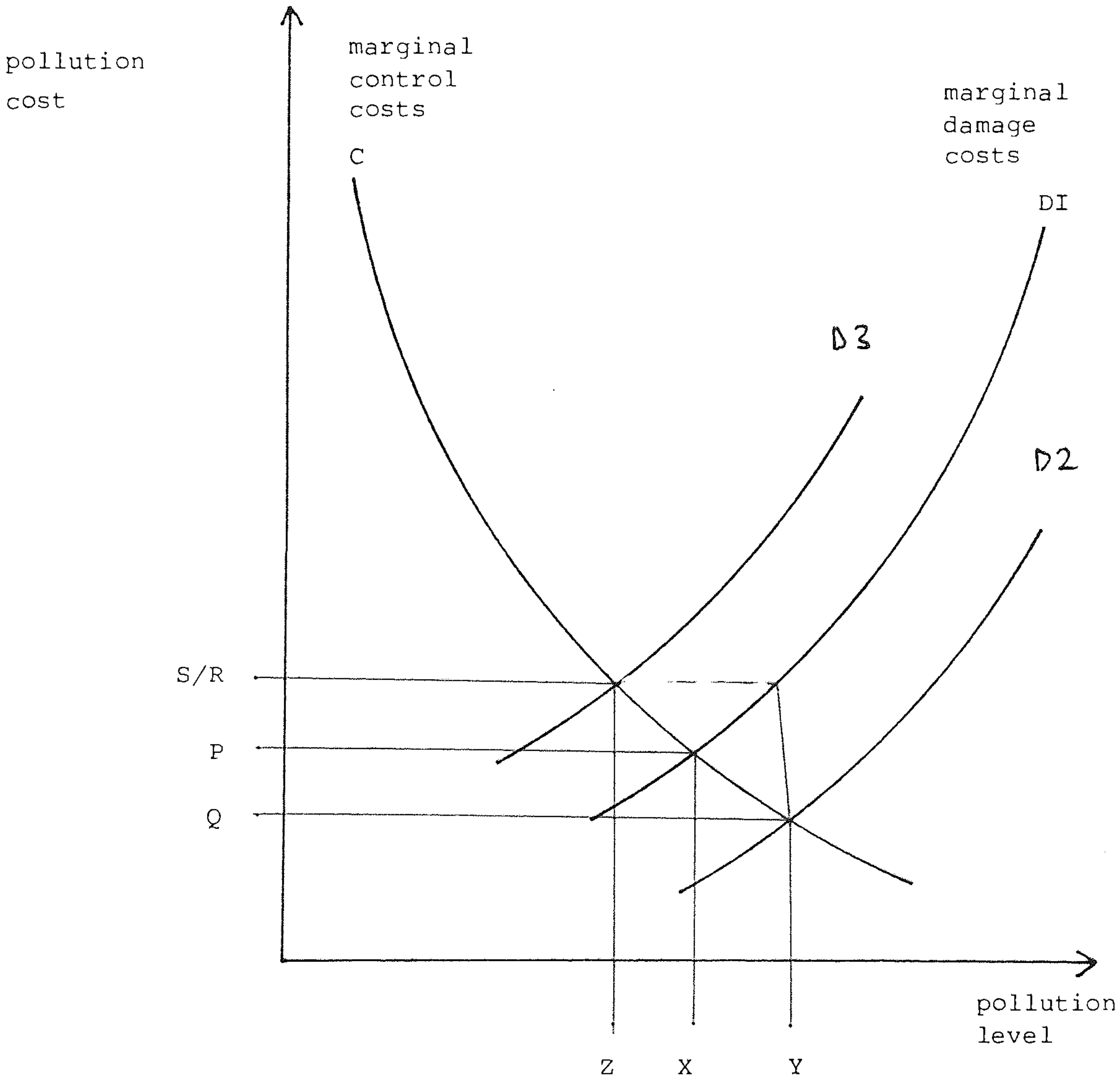

Figure 1.2 - Pollution prevention pays

The actual damage cost curve facing the producer is given above as D1, and, if acting fully rationally, production would be at the intersection of C and D1. The level of pollution emitted would be X, and total pollution cost would be P(x2). However, due to misperception on the part of management, the damage costs are assumed to be lower than they really are, and production takes place at the intersection of C and D2. At this point, the level of pollution emitted is Y, and total pollution costs are Q plus R, which is greater than P x 2. If the bias due to these misperceptions was removed, the profit-maximising adjustment would always involve reducing pollution levels.

Also, such changes would always be improvements, in the sense that they would be moves towards the theoretically given socially optimal pollution level. This is because other, real-world deviations from perfect competition conditions give rise to a bias towards excess pollution levels. This bias is shown above as the difference between X and Z, Z being the level of pollution which would be emitted if all remaining assumptions of perfect competition were met, and the damage cost curve was at the higher level of D3. In this case, the total pollution costs facing the firm would also be higher, at S x 2.

(B2) Neomarxist Positions

It is not so easy to succinctly characterise the neomarxist position since there is no central, theoretical model as there is in the neoclassical tradition. Marx himself did not deal explicitly with the issues being considered, and those who have tried to piece together his implicit views on man and nature have had to draw on widely scattered references.[16] Those works which are relevant to the issues of interest, and which can be seen collectively as representing a neomarxist tradition therefore vary considerably.[17]

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[16] See, for example, the work of A Schmidt (ref: 47).

[17] As regards how explicitly they are linked back to marxist theory, as regards the parts of marxist theory taken as key starting points and as regards the scope of the analysis defined on marxist dimensions (such as the political, economic and ideological 'spheres', or the 'interests' of capital, labour and the state).

However, the individual works are bound together, and the unifying factor is their opposition to the neoclassical assertions about the underlying macro level bias in relationships. The flavour of the neomarxist position is illustrated with the following quotations:

> "Environmental disruption cannot be seen as a case of market failure unless we mean the failure of the whole market allocative system."
>
> K W Kapp (ref: 53, p 86).

> "Much pollution abatement occurs in response to profits and growth, with no state intervention ... |but| ... the imperatives of the capitalist economy mean that the uptake of non-polluting, resource-conserving technologies is limited."
>
> F Sandbach (ref: 46, pp 10, 47).

> "The relation between increased profit and environmental deterioration is not accidental - the former is based on the latter."
>
> B Commoner (ref:10, p 15).

This macro level position, which is in direct conflict with the neoclassical one, is based on either one or both of two types of reasoning. First of all, it is often argued that the factors giving rise to, say, excess pollution levels, are not deviations away from the essential nature of capitalism (as enshrined in the assumptions of perfect competition). Rather, they themselves are seen as resulting from its inherent nature and development. The perfection of capitalism would give rise to a situation that conformed less closely, rather than more closely to the conditions of perfect competition. And private profit-maximisation would lead to a mix of environmental outcomes that is likely to be even less socially beneficial than at present. This sort of argument relates especially to the monopolisation of capital,[18] and to the fact that

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[18] For an analysis of the environmental implications, see eg A Schnaiberg (ref: 48, pp 221-230), and for a broader presentation of the necessity for the growth of monopolies, see eg E Mandel (ref: 35, pp 398-400).

producers have been able to externalise many of the costs of resource use (because of the unequal, class-related bargaining powers of producers and consumers; and because the state, in intervening mainly on behalf of capital, has failed to force the internalisation of such costs).[19] In this sort of argument, it is suggested that, even if we accept the neoclassical definitions of socially optimal levels of pollution and rates of resource use, the nature of capitalism is such that profit-maximising behaviour by producers will give rise to outcomes which, on balance, lead away from that optimum.

The second line of reasoning is based on a rejection of the neoclassical definition of optimal social welfare, which, in perfect competition, is de facto equivalent to the actual mix of goods and services produced and consumed at different levels. The essential point of the neoclassical model that is attacked is the use of subjectively expressed preferences of individual consumers for defining the social utility of consumption patterns. It is asserted that individual preference, as revealed in market demand, often fails to reflect what are objectively the best interest of either the individual or society as a whole.[20] Whilst in practical terms it is easy to agree with the assertion, the problem with this line of argument is that the marxist tradition has been unable to generate an adequate general definition of objective interest or utility to set against the neoclassical one. Even if we had the means to do it empirically, it would therefore not be possible to quantify the extent of, say, excess pollution that was due to the 'deficient' neoclassical definition of socially optimal welfare. However, it would be possible for neomarxists to argue that, say, pollution levels would be greater than the real socially optimal level, even

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[19] See eg A Schnaiberg (ref: 48, p 418 and pp 241-250).

[20] For example, there is a clear revealed preference of many for tobacco products, which are nonetheless against their objective (health) interests (ref: 50, pp 64-67). Equally, the consumption of luxury items may increase the welfare of the few, but in a world where poverty exists, this is not socially useful production, and any resources used and pollution arising therefore has no social necessity (ref: 50, p 68).

if the amount of excess could not be quantified. The main point here is that marxist economics sees capital as having a structurally located necessity to expand.[21] As part of the response to this imperative, there will inevitably be great advertising pressure on consumers to buy goods and services which they do not really want or need. In this sense, the attack on the market demand definition is that the preferences revealed are not ones that are 'freely' arrived at by consumers, but are ones that are partly determined by the needs of capital.[22]

Neomarxist explanations for particular increases or decreases in, say, pollution levels are not, as has been noted, tied to a single, central model. So a point by point comparison with the neoclassical position is not possible. What we have is a very different kind of approach, which generates an alternative sort of explanation. The neoclassical approach focusses directly on the costs and benefits of pollution and pollution control. In the dynamic equilibrium model, the other factors affecting the profitability of the firm are held constant (costs of other inputs, volume and price of goods sold, etc). In contrast, the neomarxist approach tries to explain particular outcomes in terms of the different ways that producers can increase profits in different circumstances, and, particularly, in terms of the technical strategies that may be employed.

Since most of the authors are attempting to back up the macro level assertion, the examples given are biassed towards showing how environmental deterioration is technologically linked to particular profit-maximising strategies. As the Sandbach quotation above shows, there are authors who accept that some strategies also produce a systematic bias towards improvement, but, in the approach as a whole, these cases receive scant attention. The literature contains sevel lines of argument which recur frequently, and that are applied in many different, concrete contexts.

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[21] In contrast to other classical economists, such as J S Mill, who accepted zero-growth capitalism as a theoretical possibility. See, for the arguments, P Mattick (ref: 36, pp 57-64 and pp 109-114), and E O Wright (ref: 55, pp 122-124).

[22] See, for example, A Schnaiberg (ref: 48, pp 157-161).

First of all, there are many examples which hinge on the argument that environmental improvements are hindered by the need to reduce costs in a competitive market structure. This logic has been applied both to the slow 'cure rate' for existing problems,[23] and also to the less than satisfactory 'prevention rate' for the emergence of new problems.[24]

Secondly, there are many examples where deterioration is linked, in one way or another, to the need to expand output. Though this is a constant pressure, the best way to achieve it may vary with circumstances, and the technological and environmental implications will also vary. Where total demand for existing products is expanding rapidly, there may be relatively little technical change, since output can be increased by adding further units of existing capital (plant, materials and labour). Providing the products in question are 'socially useful', then increases in resource use and pollution would be offset by increases in social welfare.

Where demand for existing products is weaker or falling, there are two common types of strategy, both of which may produce technical change of more questionable social utility. Among the strategies used to try and buoy up the markets for existing products are reductions in product life in order to increase turnover rates,[25] focussing

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[23] In this context, technology may obviously refer to hardware. Many pollution reduction techniques have been developed to prototype stage, but have not been taken up by industry because they are seen as 'unproductive' costs. See, for example, JURUE (ref: 40, pp 6-10). Less obviously, it can also apply to scientific and technological expertise. Such expertise may be mobilised in order to delay the general acceptance of, or legislation on particular problems, and so to avoid the costs that are perceived to be likely. See, for example, F Sandbach's case study of the asbestos industry (ref: 46, Ch 8).

[24] With particular reference to the stringency of testing of new products or processes for possible health or environmental side-effects.

[25] The effect of variations in product life on environmental demands is outlined in theoretical terms by D Pearce (ref: 39, p 167), and is cited as being of particular importance by, for example, A Gorz (ref: 16, pp 23, 24) and T Emerson (ref: 50, p 68).

the sales drive on smaller and smaller consumer 'units'[26] and increased dependence on packaging to sell products.[27] In all these cases, the increases in consumer utility are seen as being small in relation to the increases in environmental demands.

When demand for existing products is weak, as well as trying to prop up that demand, there will also tend to be greater pressure to develop new products as a means of increasing sales, and to increase product quality in order to capture a larger share of the market. These strategies have been technically linked to deterioration on several counts. The use of new techniques, to make new products, possibly using new inputs, implies a rate of emergence of new problems that is probably greater than in other strategies for increasing output.[28] If the development represents a major investment for the industry, and problems do arise, then the problem of a slow cure rate may be particularly acute. Relative to the high risk of environmental degradation, the potential increases in social welfare are, again, seen as being very questionable.[29]

Although not the main concern of neomarxist writers, it is worth pointing out that particular cases of environmental improvement are amenable to the same sort of explanations. For example, as a response to the pressure to reduce input costs, one technical strategy that is biassed towards improvement would be to reduce physical amounts of material inputs per unit of output - by increasing conversion efficiency, recycling, etc. Similarly, where the qualities of products under consideration are directly relevant to

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[26] Such as the shift from collective to private consumption (eg M Barrat-Brown, ref: 50, p 8), or the focus on the individual, rather than the family, as the basic unit of consumption.

[27] Cited, for example, by B Commoner (ref: 10, p 11) and T Emerson (ref: 50, pp 64, 68).

[28] See, for example, the case of product change in the detergents industry - H Rothman (ref: 43, pp 159-172).

[29] Either because increases in product quality are small, or because, in aiming the development of new products towards where the buying power is, they are often luxury items, which do little to increase the welfare of society as a whole.

the environment, then changes in product quality that are designed to increase market share may produce improvements. For example, fuel economy and resistance to rust are both attributes that have been perceived as being important by manufacturers in the drive to increase their share of the mass car market.

(B3) The limitations of traditional approaches

As regards the enquiry into relations between profits, technological change and environmental change, the problem with the traditional approaches, as characterised above, is that, collectively, they leave us in rather an impasse. Considering first the macro level question, on the social balance of good and bad outcomes, the positions of the two approaches are in direct conflict. Furthermore, one can never be proved to be correct at the expense of the other. On the theoretical side, it would be impossible since the approaches do not share the same basic assumptions about the nature of capitalist society or growth, nor do they share the same definitions for central concepts such as social welfare (and such as profit). In the last analysis, we are faced with conflicts in belief - conflicts which cannot be resolved with factual evidence alone. On the empirical side it would be even more difficult. There is, first of all, the problem that some outcomes would be evaluated as good by one approach and bad by the other. But there is also the problem that empirical work will only ever amount to a small sample of real world cases. This means, for example, that however many cases are thrown up of the 'pollution prevention pays' type, the neoclassical position will never be proved by them, since an equal number of countervailing cases could probably be found where pollution prevention would not pay. By the same token, with the inevitably small total sample, the neomarxist position could never be proved through the accumulation of supportive individual cases.

As regards the micro level, the problem is different. Although the explanatory frameworks of the two approaches are based on conflicting assumptions at the macro level, there is not necessarily any direct conflict between the two when it comes to explaining any particular outcome. Rather, they would provide alternative accounts, which might be equally good relative to their own terms of reference. And to say that one was better than the other would be virtually impossible without accepting some of the ontological and/or epistemological assumptions made by one of the approaches.

The scope for important new work on these two issues is therefore very limited. At the macro level, the basic positions are well established. And although there is some scope to develop further supportive work within each approach, such work could never resolve the fundamental conflicts between them. At the micro level, there is scope within each tradition, both for the 'fine tuning' of the explanatory frameworks, and for their application to new substantive areas. But such work is never likely to amount to more than minor improvements to the bodies of knowledge and technique already established within each tradition.

However, this problem does not mean that no more useful work can be done on relations between profits, technology and environmental change. And the underlying objective of the thesis is to try and move the enquiry into these relations beyond the impasse created by the work done in the traditional approaches. The way this is to be done, and the more specific objectives of the thesis are discussed in Section C below.

1C THESIS OBJECTIVES

The basic aim of the thesis is to try to begin to develop an analysis of relationships between profits, technological change and environmental change that lies between the micro and macro levels used in the traditional approaches - ie a 'meso level' approach. The emphasis of the micro analytic level has been on explaining the existence of the variability in outcomes, and the macro analytic level has been concerned with the general balance between different outcomes. The central issues for this meso level of analysis concern the distribution of that variability in outcomes.

The first set of questions we might look at are purely descriptive - what are the distributional patterns, if any? And there are several important dimensions on which we could look for such patterns. For example, we might ask whether different types and/or rates of environmental change have been concentrated into different historical periods. Similarly, in a given period, we might ask whether improvement and deterioration were concentrated in different sectors of the economy, or in different areas of the country. And there is also the social dimension that might be considered - which groups or classes of people were experiencing improvements or deterioration of their environment in a particular period?

To answer such questions, we have to develop descriptive categories that are appropriate to a meso level analysis. The very general categories used at the macro level may be far too broad. For example, a concept such as pollution is likely to be of little use when we are trying to map out the variations in levels or rates of change in pollution of different types. In this sense, we have to disaggregate down from the macro level of analysis. And, by the same token, we have to aggregate up from the micro level. The particular outcomes examined at this level are, in the last resort, unique, and will have no distributional characteristics at all. Clearly, we would need to deal in classes of outcome that are internally similar and could be easily distinguished from contrasting classes.

Assuming that patterns of distribution are not totally random, the second stage in developing this analysis would relate to the explanation of patterns observed. And again, this would mean using a different approach to those adopted at micro or macro levels. Clearly, if we are trying to explain patterns of distribution of variation, it is going to be useless to refer to those features that are held up as characterising the basic nature of capitalism, since such universals do not change. Instead, we would have to look at those aspects that may be subject to systematic variation over time, space and so on. Similarly, this would mean jumping up from the micro level. The neoclassical model explains a particular outcome in terms of given changes in conditions governing outcomes. But in the meso level analysis, it would be those changes in conditions that themselves needed to be explained. Alternatively, the neo-marxist approach would account for a particular outcome by reference to a particular type or blend of profit-maximising strategies. But, in the meso level analysis, we would have to explain why that blend of strategies varied as it did across the economy, over time, etc.

And to develop an explanation adequate at the meso level, we would again have to use descriptive categories that were appropriate. General concepts such as profit or technical change are not likely to be much help when we might need to look at patterns of variation in the different rates and types of each. On the other hand, the particular profit-maximising strategies or technical innovations that are important in micro level explanations may be too specific to be of much help. We would need to consider aspects of profitability and technical change that are broad enough so that their distributional characteristics could be easily studied.

As regards the impasse identified, this meso level approach may be useful in two respects. First of all, it may provide a way of partially reconciling the macro level conflict between the traditional approaches. If it can be demonstrated that the balance between improvement and deterioration, say, varies significantly between different sectors of the economy or between different historical periods, then any ultimate bias becomes relatively unimportant. In practical terms, this would mean that neither macro level assertion was generally either right or wrong, and that both would have some validity, but at particular and different times, or in particular and different sectors of the economy.

Secondly, the meso level of analysis may provide a way of bringing together the alternative micro level approaches. At present, the higher levels of theory to which they relate are in direct conflict at many points, and the two frameworks appear as being almost completely isolated. Any meso level explanation would invoke realities of capitalism that are less fundamental than those basic features over which the conflicts arise. The potential therefore exists for a theoretical model in which these conflicts are not inherent. And, in turn, the possibility therefore arises of a single, higher model to which both micro level frameworks can be related without necessarily bringing them into conflict with each other.

Chapter 2: Description of environmental change in the United Kingdom iron and steel industry (1700 to 1980)

2A INTRODUCTION

Following on from the issues raised above, this chapter set out to try and answer the question of whether or not the variability in environmental outcomes has been randomly distributed over time. In particular, we wanted to find out whether environmental change has been periodized - ie can we pick out distinct periods that were characterised by contrasting types and/or rates of environmental change, and, if so, what were they? As a first approach to these questions, a longitudinal study was carried out into aspects of environmental change in the UK iron and steel industry.

2B DATA AND METHODS

Three sets of data were used to look for any periodization of environmental change. However, not all the variables used were statistically independent. The details and implications of the dependencies are discussed below, in conjunction with the descriptions of each data set.

(B1) Impact potential data

'Hard' data on environmental change is virtually impossible to get hold of for any time but the fairly recent past, and in order to look for possible periodization over the longer term, it is therefore necessary to use 'softer' indicators. In this study, the approach used involved looking at the environmental impacts of the technical innovations in the industry. Innovations are seen as creating the 'potential' for environmental change. The extent to which the potential embodied in each innovation is translated into reality will depend on further factors, but these other things being equal, we would expect that variations in this potential for environmental change would be a reasonable indicator for actual variations.

The production of the impact potential variables involved three stages. First of all, a list of the innovations in the industry between 1700 and 1970 was compiled from existing technical and economic histories. The full list is given in table 2.1 (annex 1). At the same time, the enviornmental impacts associated with each innovation were recorded in as much detail as was possible. In order to do this, various environmental sources were used in addition to the technical and economic histories. These included the environmentally relevant research papers of the industry, annual reports of the Alkali Inspectorate (responsible for air pollution in the industry) and more general environmental texts which included reference to iron and steel. But, even so, it was only possible to record the impacts in qualitative terms. For example, it was clear from the literature that the introduction of the hot blast led to a substantial reduction in the amount of coke needed to produce a ton of pig iron, and, therefore, to a reduction in the amounts of coking wastes per ton of pig iron, but the exact amounts are not known. Most of the impacts recorded were therefore in the form of increases or decreases in amounts of given inputs and wastes for a particular output (such as pig iron) or operation (such as strip milling). In addition, where appropriate, changes in the nature of inputs and wastes were also recorded (such as changes in the acidity of slags from various furnace processes). The full list of impacts recorded is given in table 2.2 (annex 1).

The second stage involved classifying the innovations, on the basis of their impacts, as regards three aspects of environmental change. We were concerned with whether the resulting changes were quantitative or qualitative, whether they represented improvement or deterioration and with their environmental importance - the degree of improvement, for example. The three classification systems are dealt with in turn below.

In distinguishing between quantitative and qualitative change, the difference we were trying to pin down is between those innovations resulting in increases or decreases in amounts of existing inputs and wastes, and those innovations which changed the nature of inputs or wastes (for a given output or operation). But the distinction is not an absolute one given by the physical impacts of the innovation. The classification is also contingent on two further factors. First of all, it depends on how finely the relevant inputs and wastes are defined in the first place. For example, the bulk use of oxygen in crude steel production was associated with the evolution of large amounts of orange, iron oxide fume. If the distinction is made between this and other types of particulate matter emitted, then the innovation would be classified as resulting in a qualitative change in wastes from crude steel production - ie the evolution of a new type of waste. But if wastes are less finely differentiated, then the innovation might be classified as resulting in quantitative change - an increase in the amount of particulate matter produced per unit output of steel.

Secondly, the proportion of innovations classified as resulting in quantitative or qualitative change depends on the breadth of the industry sector in relation to which we consider the impacts. For example, the eighteenth century saw steam power replacing water or human labour power in many different parts of the industry, with, in each case, a variety of impacts. If the industry is considered as infinitely divided, then, in each such case, the innovation would be classified as resulting in qualitative changes to the inputs and wastes associated with that particular output or operation. But if we consider a discreet sector of the industry, such as wrought iron rolling, then, once steam power had been introduced to the operation, succeeding substitutions of the same type would be classified as resulting in changes in the amounts of inputs and wastes already associated with it.

The classification of innovations according to whether they resulted in quantitative or qualitative change is therefore dependent on the definitions made in relation to these two contingent factors. On one set of definitions we would get virtually all innovations classified as resulting in quantitative change. But at the other end of the spectrum, another set of definitions would lead to virtually all innovations being classified as resulting in qualitative change. Clearly, in neither case would we be able to look for any periodic variation in the bias of innovations towards the different types of change. And, in this sense, to make the conceptual distinction empirically workable, it was necessary that both categories should contain reasonable numbers of innovations. To achieve this, the innovations were classified on the basis of their impacts on six divisions of the industry. These were: (1) blast furnace and input preparation; (2) wrought iron production; (3) wrought iron processing and products; (4) cast iron; (5) crude steel production; (6) steel processing and products. The classification of innovations according to the type of change in which they resulted, and in which sector, is given in table 2.3 (annex 1).

As regards improvement and deterioration, those innovations with any recorded impacts were placed into one of three principal categories - improvement only, deterioration only or both (improvement and deterioration, in relation to different inputs or wastes). The main criterion used to evaluate innovations was their impact on the unit materials balance situation. Those causing reductions in the amounts of inputs or wastes per unit of output were classified as leading to improvement, and those causing increases were classified as leading to deterioration. On first sight, it would seem that this criterion can be applied only to those innovations already classified as resulting in quantitative change, and that other criteria would be needed to evaluate innovations classified as resulting in qualitative change. But, on closer inspection, this is not so. The distinction between innovations that only change amounts of inputs and wastes and those that change their nature is not synonymous with whether or not they can be evaluated by reference to the materials balance criterion.

With respect to wastes, for example, we can consider seven types of impact we might get, as follows:

1) increases in some or all existing wastes
2) increases in some existing wastes and decreases in others
3) decreases in some or all existing wastes
4) new wastes produced, with no existing ones stopped or reduced
5) new wastes produced, but some existing ones stopped or reduced
6) old wastes stopped, with no new ones produced or existing ones increased
7) physical amounts of wastes stay the same, but their nature changes.

In this breakdown, the first three impact types result in changes only in the amounts of existing wastes, while the next four lead to changes in the nature of wastes. However, impact types one and four can both be evaluated on the materials balance basis (as deterioration only), even though type four changes the nature of wastes. Similarly, impact types three and six can both be given a materials balance evaluation (as improvement only), even though impact type six changes the nature of wastes. Conversely, impacts of type two cannot be given a materials balance evaluation (as improvement or deterioration only), even though they only change amounts of existing wastes. They would therefore be classified as resulting in 'both', as would impacts of type five. The two contingencies that affected the classification of innovations as resulting in qualitative or quantitative change do not, therefore, affect their classification as regards whether they result in improvement only, deterioration only or both. The definitions used in relation to those contingencies would affect the question of whether impacts were classed as type one or four, say, but would not alter the evaluation of that innovation as resulting in deterioration only. And the same holds for the other pairs of impact types (three and six, two and five). The unit materials balance evaluation therefore cuts across the quantitative/qualitative change distinction, and allows us to classify more innovations than is at first apparent as regards their improvement/deterioration effects.

However, not all innovations could be classified on this materials balance basis - those with impact type seven, for example, and two further criteria were used. Add-on cleaners and arrestors (principally for air pollution) were classified as resulting in improvements. And, although this might be contentious in particular cases, there are two reasons why it is justifiable in general. First, in many instances, the residues from such systems are recycled, so that there actually is a materials balance improvement, rather than merely the transformation of the problem from the air to water or land. Second, even when there was no evidence for recycling, such innovations were classified as resulting in improvements becuase many were designed to alter, in a beneficial way, the conditions under which pollutants are added into the atmosphere - by dilution, or by the aggregation of very fine particles into coarser and less harmful ones.

The third criterion, relevant to impact type seven, concerned the acidity of wastes (slags, electrolytes and pickling liquors). Changes towards neutral were defined as improvements, and vice versa, the assumption being that the ecological optimum is roughly neutral.

These three criteria are not exhaustive, of course, particularly as regards those cases in which the nature of wastes was changed. We might also have used criteria such as persistence or toxicity. Clearly, the advantage of using further criteria is that more innovations can be classified as leading to improvement or deterioration, rather than as both by default. But there are also problems. First, the more criteria we use, the greater is the chance that we conflate types of improvement or deterioration that have different patterns of variation over time. Second, we also increase the chance of innovations being classified one way on one criterion and another way on a different one. The use of three criteria gave a reasonable balance between the opposing pressures. The addition of the second and third criteria allowed an increase in the number of innovations that could be classified as improvement or deterioration only (from 48 to 67), and did not lead to any conflicts. The final classification is given in table 2.3 (annex 1).

The third classification of innovations was according to their environmental importance. Their improvement and/or deterioration impacts were classified as being either major or minor. The assessment was subjective, but took four factors into account. First, there was the question of how much change was involved. We have noted that, when impacts were recorded, it was not possible to quantify them. But, in some cases, we had reference to them being large or small. For example, many innovations led to reductions in the coke rate. And we know that those reductions associated with the introduction of the hot blast were substantial, whilst those due to the bell and hopper were marginal. Second, we took into account the importance of the particular operation where the innovation occurred to the industry's total consumption of a given input or production of a given waste. For example, the use of oxygen in blast furnaces and for scarfing resulted in increases in oxygen consumption and the production of iron oxide fumes, but these were very small relative to the problems of bulk oxygen use in steel production. The third factor taken into account was the number of different inputs and wastes affected by the innovation. For example, the kaldo process steel furnace was environmentally noteworthy because it produced substantially lower emissions of carbon monoxide than existing alternatives. But this improvement seems minor compared to those brought about by the introduction of the by-product coke oven (including the recovery of oils, tars and sulphur from sulphur oxides). Lastly, as regards wastes, some account was taken of how badly polluting they were. This is not a very precise concept, nor easy to grade very finely, but there were some wastes that could clearly be seen as either major or minor. For example, reductions in flourine, arsenic, phenols and sulphur oxides were all seen as major improvements in this context, whereas reductions in waste heat, neutral slags and the coarser particulate matter were seen as minor. The full classification of innovations as regards the degree of improvement and/or deterioration associated is given in table 2.3 (annex 1).

The third stage in the production of the impact potential variables, so we could look at patterns of variation, involved aggregating with respect to time. Two procedures were used. First, in order to give a visual representation, moving averages (over twenty-five years) were calculated of the annual frequencies with which innovations in the various categories occurred. When plotted against time, these allowed us to see whether or not there appeared to be any periodization in the potential for the various aspects of environmental change. As a rough guide to identifying times when frequencies were particularly high or low, the underlying, long run changes were represented using semi-average trend lines.

But some method was also needed for assessing the statistical significance of any apparent periodization. Any time series data, when superimposed onto its underlying linear trend, will have high and low periods. The question is, how likely is it that any such pattern has arisen by chance? To answer this question, the runs test was used to analyse sequences of positive versus negative residuals. The clustering of residuals was taken as an indication of periodization, whose significance was assessed using Z tests. However, this analysis could not be applied to residuals in the moving average plots since the use of such long moving averages would introduce a large bias towards clustering. To avoid this problem, a second method of aggregating with respect to time was used. For each decade, the number of innovations in each category was counted. For each category of innovation, this process therefore yielded twenty-seven values - each a separate, period frequency count. And it was these period frequencies which were regressed on time, providing the residuals sequences analysed using runs tests. Linear regression was used since the moving average plots suggested that non linear regression would not give a substantially better fit. In this analysis, to give a more accurate representation of underlying trends, least-squares regression was used, rather than the semi-averages procedure.

The various systems of classifying innovations, and the two methods of aggregating with respect to time allowed the following annual and period frequency variables to be calculated and used:

1) fIM All innovations with environmental impacts
2) fQT Innovations resulting in quantitative change
3) fQL Innovations resulting in qualitative change

The variables fQT and fQL are mutually exclusive and collectively cover all innovations with environmental impacts. For the other two aspects of environmental potential, it was not possible to generate variables that were both mutually exclusive and covered the whole set of innovations with recorded impacts. On the one hand, we could generate pairs of variables that were mutually exclusive but that did not cover all relevant impacts. For example, those innovations classified as resulting in improvement or deterioration only are mutually exclusive subsets, but do not pick up all improvement or deterioration impacts. The pairs of variables that were of this type are as follows:

4) fIO Innovations resulting in improvements only
5) fDO Innovations resulting in deterioration only
6) fMAJI Innovations resulting in major improvements
7) fMINI Innovations resulting in minor improvements
8) fMAJD Innovations resulting in major deterioration
9) fMIND Innovations resulting in minor deterioration
10) fMAJO Innovations resulting in only major impacts
11) fMINO Innovations resulting in only minor impacts

On the other hand, by aggregation, we could generate pairs of variables that do collectively cover all relevant impacts, but which are not mutually exclusive. These are as follows:

12) fAI Innovations with any improvements associated
13) fAD Innovations with any deterioration associated
14) fMAJ All innovations with major impacts
15) fMIN All innovations with minor impacts.

However, all these variables were calculated from the same set of innovation data, and the dependencies between them limit the uses to which they can be put. Two points can be illustrated by considering the variables fQL and fQT. First of all, there are two mathematical links between the pair. The values of both variables are partly dependent on the overall frequency of innovations with environmental impacts (fIM). Clearly, when fIM is especially low, then neither fQT nor fQL can be very high. And, conversely, when fIM is high, then, other things being equal, we would expect that both fQT and fQL would also be high. But both variables are also partly dependent on a single ratio - that between fQT and fQL as proportions of fIM. Since both variables are dependent on the same two sources of variation, either one of them may provide evidence for periodization, but if the other is also periodized, then this will not constitute additional, independent evidence for periodization. The same is true for the remaining pairs of variables.

But although we know that these statistical dependencies exist, we do not know the detailed nature of the links. For example, if fQT is high at a particular time, we cannot specify what is the probability that fQL will also be high. So it is not possible to predict the pattern of variation in one variable from a knowledge of variation in the other. It may be that fQT and fQL are both high or low at the same time, or it may be that one tends to be high when the other is low. Clearly, these are different types of periodization, but knowing that dependencies exist does not allow us to specify which is more likely. So, although all the evidence for the existence or otherwise of periodization can be supplied by one of the pair of variables, we need to look at both variables to establish the nature of any apparent periodization. Again, the same is true for the other pairs of variables.

The third point concerns the difference between the 'basic' variable pairs (4 to 11) and those 'derived' from them (12 to 15). Clearly, each of the derived variables is partly dependent on its corresponding basic variable. For example, fAI is partly dependent on fIO. These are therefore alternative, but not independent ways of illustrating any periodization in the potential for improvement. The pairs of variables fIO/fDO and fAI/fAD are, similarly, alternative but not independent ways of illustrating any periodic bias in the potential for environmental change towards improvement or deterioration. And the same is true for the other cases in which pairs of basic variables are matched with pairs of derived variables. The value of having these alternatives lies in the fact that neither of them gives an unequivocably better picture of the variations we are concerned with - such as the bias towards improvement or deterioration.

(B2) Materials input data

The input data is statistically independent of the impact potential data outlined above, and variables measured actual rather than potential change. Data was collected on nine inputs to iron and steel production processes. The inputs fell into the three following groups. 'Old' inputs included coke, iron ore and total blast furnace solids. 'New' inputs included sinter, oxygen and electricity. 'Scrap' inputs included iron scrap, steelmaking scrap and total industry scrap. All variables measured physical amounts of inputs per year, though different timespans were covered. The last date at which readings for all variables were obtained was 1979, and no data was obtained earlier than 1920.

When considering patterns of change in input levels, there are two descriptive levels we can look at - the gross consumptions of inputs by the industry or sector, and the consumption per physical unit of relevant output. Eighteen variables were therefore used to examine patterns of variation in these nine inputs at the two descriptive levels. The full sets of data are given in tables 2.4 and 2.5 for unit input and gross consumption levels respectively (annex 1).

However, it was not possible to get hold of independent data for all eighteen variables, and, again, this limited the uses to which some of the variables could be put. Independent data was available in existing sources for five inputs at the unit level (ore, coke, blast furnace solids, sinter, iron scrap), and for six inputs at the gross level (coke, sinter, oxygen, electricity, total scrap, steel scrap). For the remaining seven variables, values were calculated using relevant output level data (ie unit input level = gross consumption level/output level, or gross consumption level = unit input level x output level). Details of the data sources and/or calculations relevant to the eighteen variables are given in table 2.6 (annex 1).

Within both the unit input and gross consumption level data sets, any one of the computed variables (but only one) is also independent, as well as those variables whose values were taken from published sources. The independent evidence for or against the existence of periodization at the unit input level is therefore provided by six variables, and at the gross consumption level by seven variables. The remainder of the variables cannot be seen as providing additional, indepenedent evidence for or against the existence or periodization at either level, but they were used in trying to characterise the nature of patterns observed. This was felt to be justified because it can be demonstrated that the use of output level data does not introduce substantial errors, and it is therefore a reasonable way of 'estimating' values for variables where no independent data exists. The cases of coke and sinter were used to compare gross consumption levels as given by independent data with those estimated using output level and unit input level data. As shown in figures 2.1 and 2.2 below, for both inputs, the patterns of change in estimated values conform very closely to those given by the independent data.

The same two methods were used to look for periodization in both sets of input data. First of all, the data was plotted against time in order to make a purely visual assessment. To assess the significance of any apparent periodization, the sequences of positive and negative residuals around linear regression trends were again analysed using the runs test to look for significant clustering.

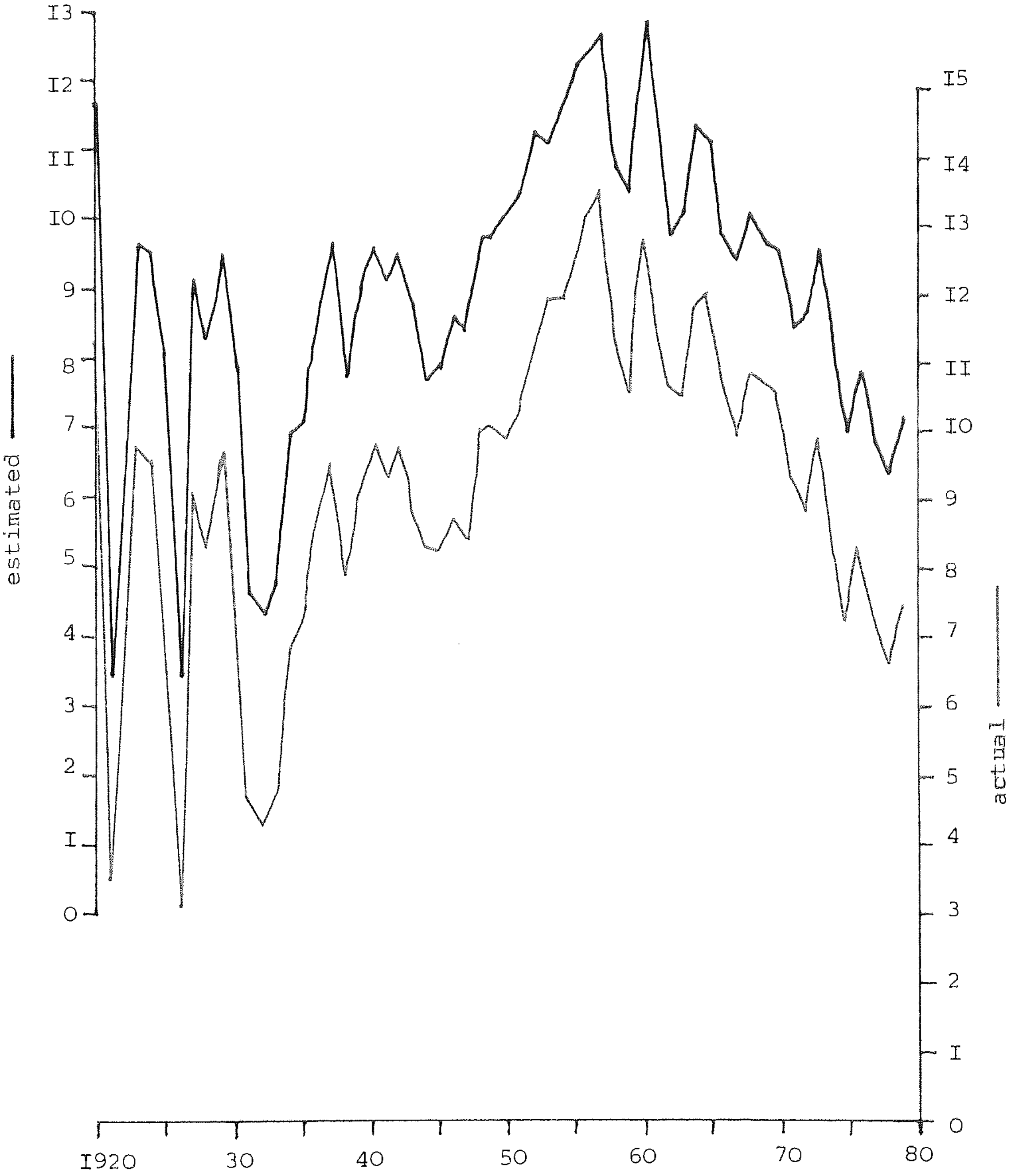


Figure 2.1 - Variations in gross coke consumption levels: actual and estimated (million tons)

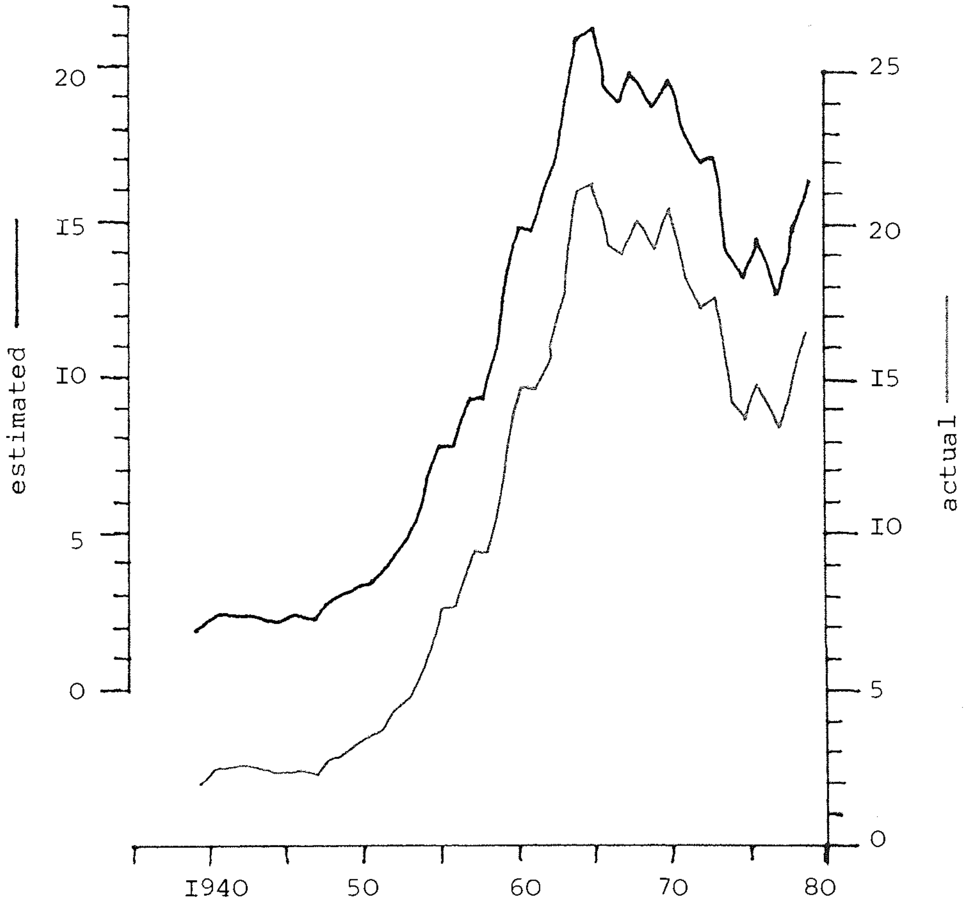


Figure 2.2 - Variations in gross sinter consumption levels: actual and estimates (million tons)

2C RESULTS

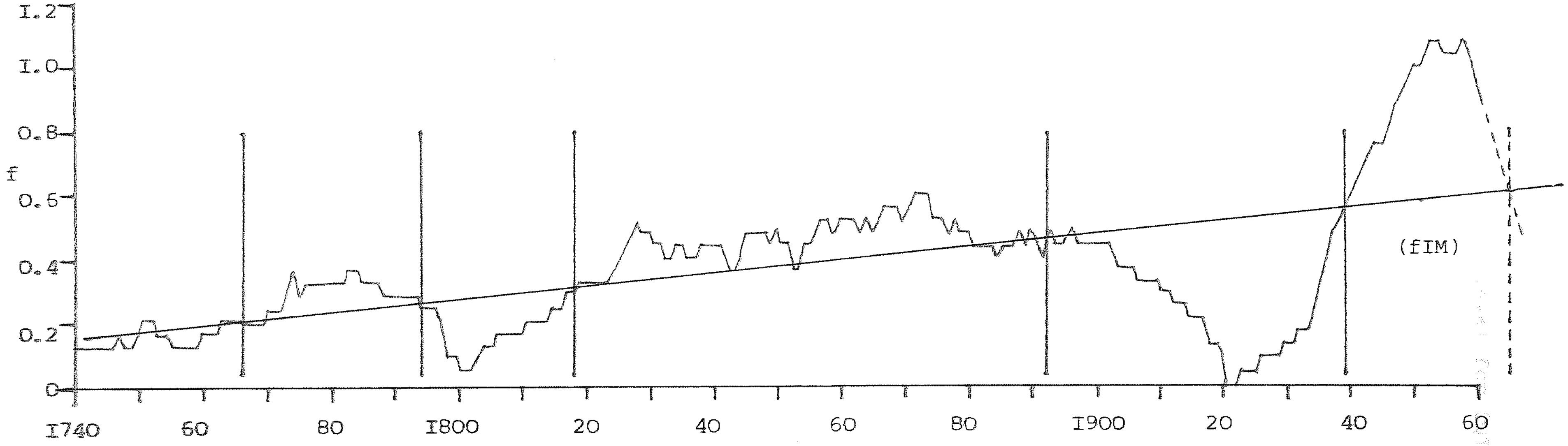
(C1) Impact potential

Figure 2.3 below shows the moving average of the annual frequency of all innovations with environmental impacts. It shows that the potential for environmental change in general appears to have been periodized. There were three periods where frequencies were relatively high and two where they were markedly low. The approximate dates of boundaries between these periods are also indicated on the figure. But although the visual evidence for the existence of periodization is compelling, it does not register as statistically significant at the .10 level. The sequence of residuals in the period frequency data does show a tendency towards clustering, but the pattern is quite likely to have occurred by chance. The detailed results of runs tests carried out on all three data sets are given in table 2.7 (annex 1).

Since all other impact potential variables are partly dependent on fIM, they are bound to reflect, to some extent, the pattern shown in figure 2.3. Indeed, if this was the only way the data was periodized, we would expect that, random variation apart, all other variables would conform to this pattern. Where patterns of variation are different from that in figure 2.3, we therefore have reason to think that the variables involved are picking up some other way in which the data is also periodized. And, in fact, patterns of change in the other variables do differ in important respects from that shown in figure 2.3.

Variations in the frequencies of innovations resulting in quantitative and qualitative changes provide one piece of evidence for the existence of a second type of periodization in the data. As shown in figure 2.13 (annex 2), when this is compounded with the periodization in the overall frequency of innovations with environmental impacts, the resulting patterns in fQT and fQL appear to have four periods of high frequencies and three periods of low frequencies (though the central low is less pronounced than the other two). The analyses of residuals sequences indicated clustering tendencies

Figure 2.3 - Variations in the potential for environmental change in general



for both variables, significant at the .02 level for fQT and at the .20 level for fQL.

As figure 2.13 also shows, the nature of the periodization was not consistent over the whole period of the study. After about 1920, the variations in fQT are very similar to those in fQL - when one frequency is high, so is the other, and vice versa. Beforehand, however, the plot for fQL consistently lagged behind that for fQT in the common sequence of high and low periods. We could therefore identify some periods when the balance of impact types was shifted towards quantitative change (when fQT was high and fQL was low), and others when it was shifted towards qualitative change (when fQL was high and fQT was low). And, as demonstrated in figure 2.4 below, there were three periods of each type. The periods of bias towards either quantitative or qualitative change followed each other in sequence, and were fairly regular in length.

Variations in the frequencies of innovations resulting in improvement and deterioration provide further, independent evidence for the existence of this second type of periodization in the data. The patterns of change in fIO and fDO are shown in figure 2.14, and those in fAI and fAD are shown in figure 2.15 (annex 2). These alternative methods of illustration reveal pictures that are very similar, both to each other, and to that shown in figure 2.13. Each of the four variables had four periods when frequencies were relatively high, and three intervening periods when they were low (though with the exception of fDO, the central low was again less marked than the other two). Although the analyses of residuals sequences again indicated tendencies towards clustering, it was significant only in the case of fIO (at the .05 level).

In both figures 2.14 and 2.15 we can see that the improvement plots consistently led deterioration through the common sequence of high and low periods before about 1920. And because of this, as figure 2.5 below illustrates, we can identify periods when the potential for environmental change was biassed towards either improve-

Figure 2.4 - Periods of bias towards either quantitative or qualitative change

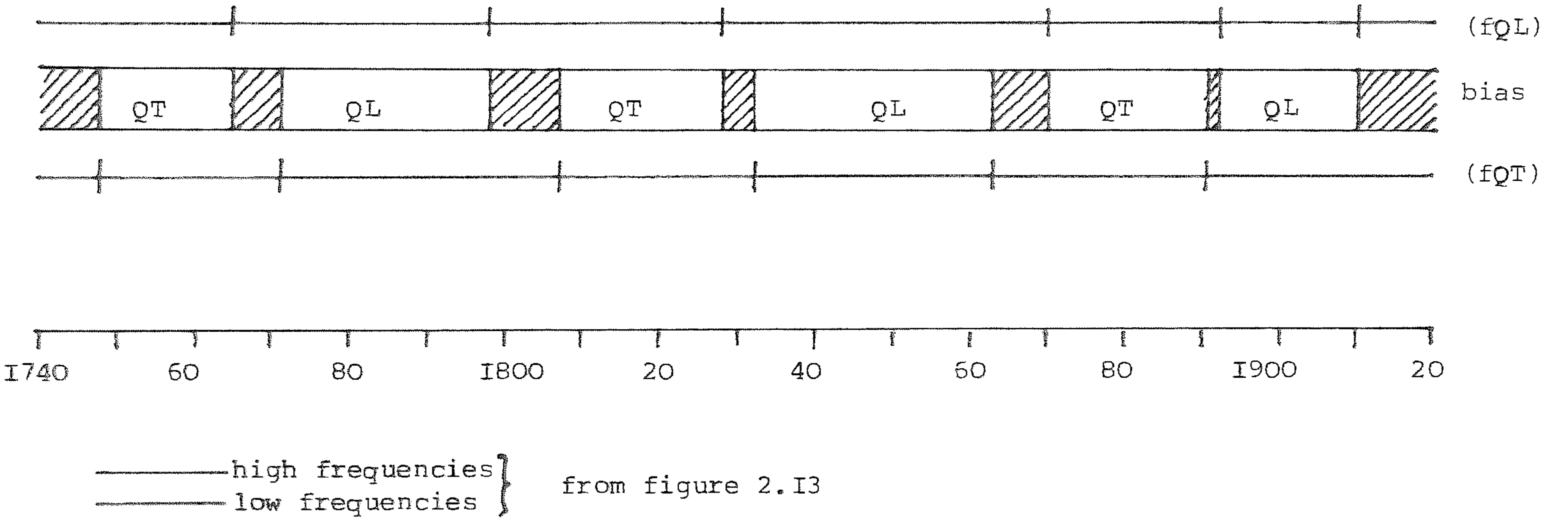
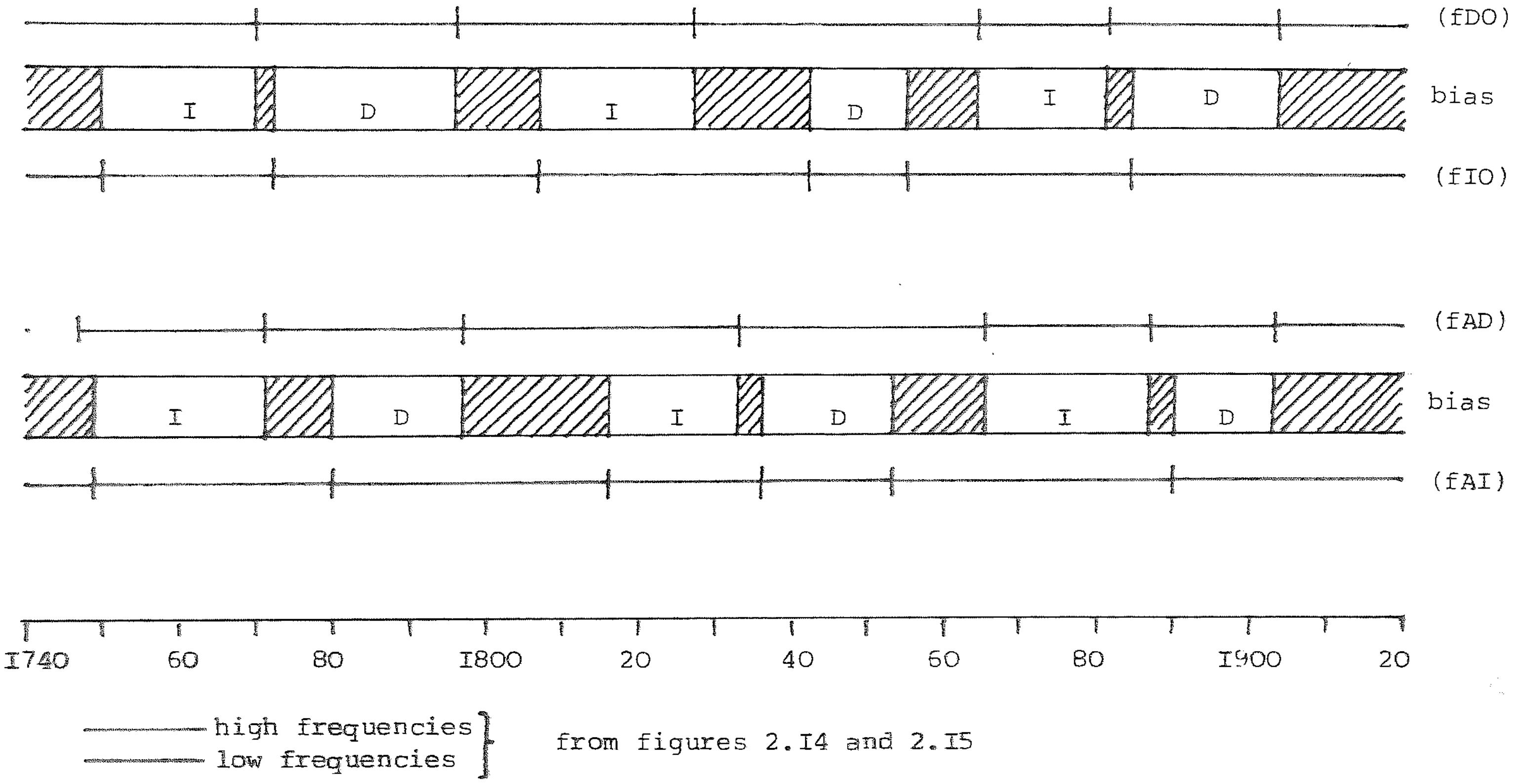


Figure 2.5 – Periods of bias towards either improvement or deterioration



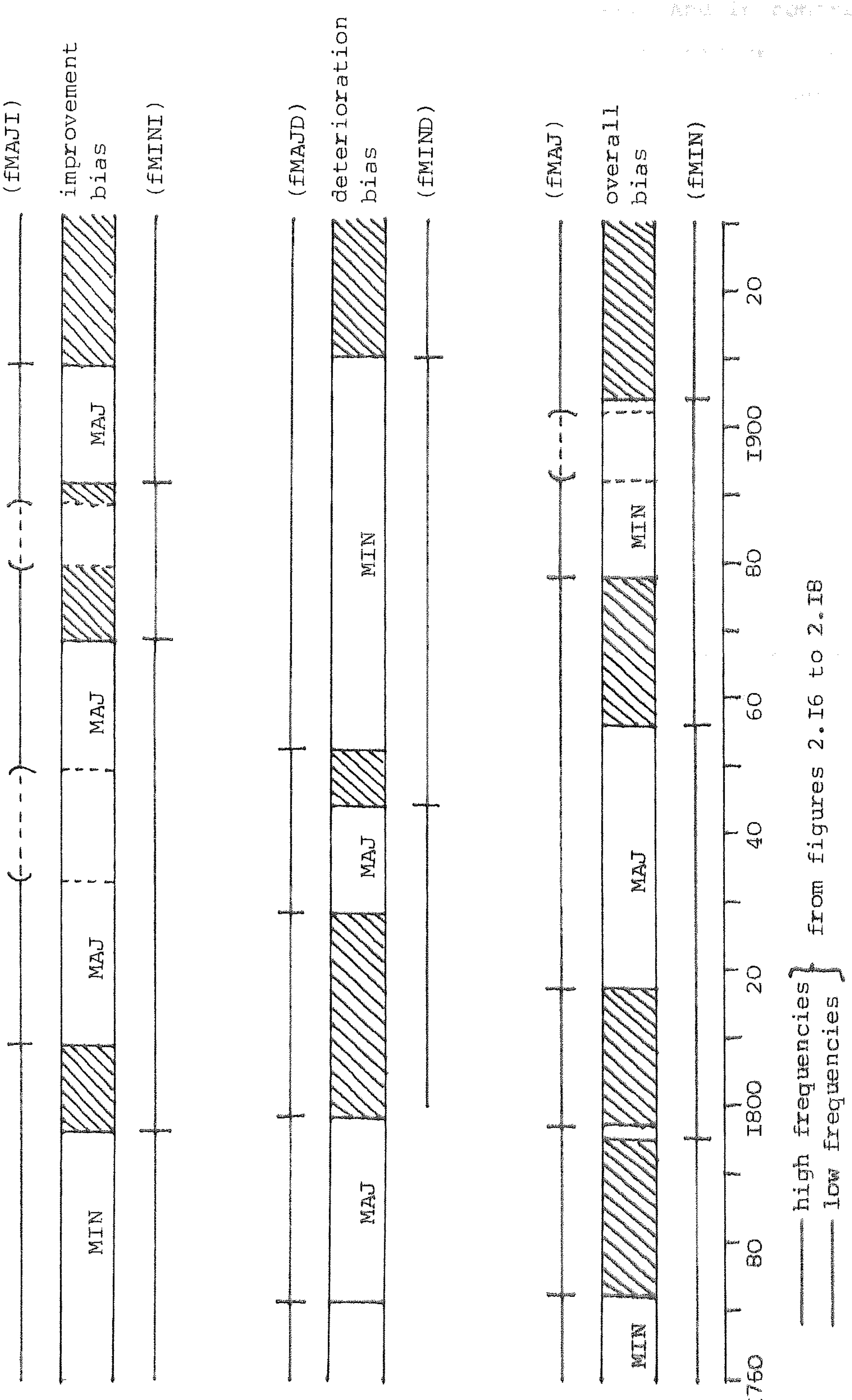
from figures 2.I4 and 2.I5

ment or deterioration. Again, whether using the basic or derived variables as illustration, these periods of bias followed each other in sequences and were apparently fairly regular in length.

Variations in the frequencies of innovations with major and minor impacts provide evidence for a possible third type of periodization in the data, though this is less clear cut. Three pairs of variables were used to look for periodization in this aspect of the potential for environmental change. Frequencies of innovations with major and minor improvement impacts are shown in figure 2.16 (annex 2). Frequencies of innovations with major and minor deterioration impacts are shown in figure 2.17 (annex 2). And frequencies of all innovations with major or minor impacts are shown in figure 2.18 (annex 2). The patterns revealed diverge from that shown in figure 2.3, suggesting that some sort of periodization is at work other than just that in fIM. They are also different from those shown in figures 2.13, 14 or 15, suggesting that this other periodization is not the same as that second type found in quantitative versus qualitative change or in improvement versus deterioration. For three of the six variables, the analyses of residuals sequences revealed tendencies towards clustering that were significant at the .02 level.

It seemed clear enough that dividing the data on the basis of the degree of environmental importance of innovations did not just give rise to random subsets as regards their patterns of variation over time, and that the variables were picking up some third type of periodization in the data. However, when compounded with the periodization in fIM, the picture that emerged was not very coherent. Figures 2.16, 17 and 18 contain considerable variation as regards the number, length and timing of high and low periods for innovations with major impacts and for those with minor impacts. Whichever of the three illustrations we use, it is again possible to identify periods when there was bias in the potential for environmental change, towards either major or minor change, and these periods are shown in figure 2.6 below.

Figure 2.6 - Periods of bias towards either major or minor change



However, the three alternative illustrations generate very different patterns as regards these periods of bias. And in contrast to figures 2.4 or 2.5, the periods of bias were neither very regular in length, nor did they follow each other in sequence (ie there are cases where one period of bias towards major change was followed by another, rather than by a period of bias towards minor change). This lack of coherence in the patterns can be traced back, in part, to the fact that there are inconsistencies in the temporal relationships between the high and low periods for innovations resulting in major and minor changes. As shown in figure 2.7 below, although there appears to have been some tendency for innovations resulting in major changes to lead those resulting in minor changes, there are two instances where the reverse was true (out of ten cases where such leads or lags could be identified).

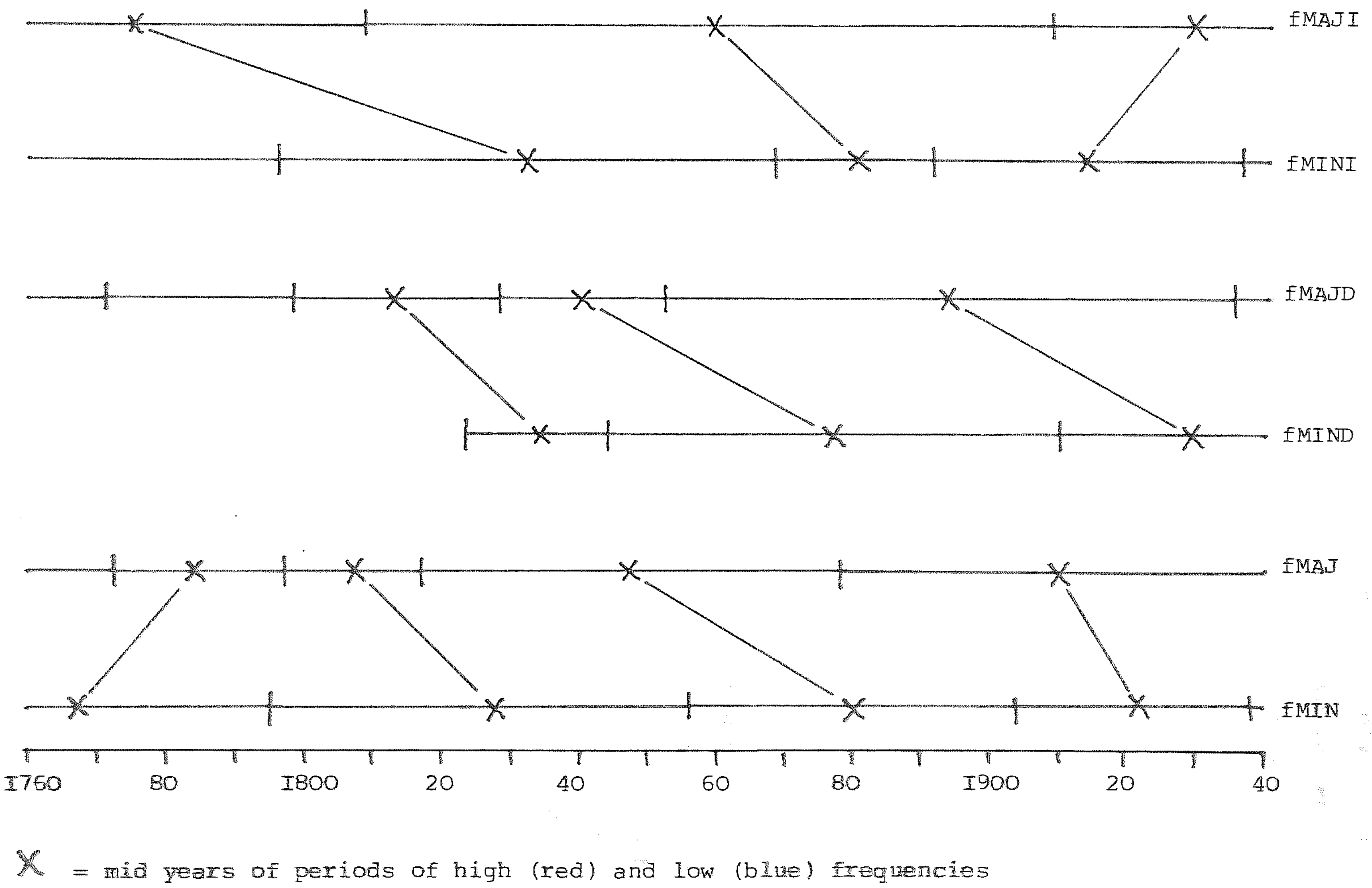
In view of this lack of coherence, it is probably better not to interpret these results as providing evidence for a third, distinct type of periodization. It may be that this does exist, and that it is only being picked out partially and imperfectly by the variables used. But it may also be that the variables are picking up and reflecting a number of different factors that, although they have some influence on patterns of variation over time, do not result in a distinctive periodization. Perhaps the best interpretation is that theses variables are picking up influences on variation over time other than the two distinctive types of periodization noted, and that, at this stage, it is not clear whether these influences themselves constitute a third and distinctive type of periodization.

In summarising these impact potential results, we can make the following points:

1) We have visual evidence that the potential for environmental change in general is periodized, as shown by the periodization of the frequency of all innovations with environmental impacts (though this does not register as statistically significant).

2) Within the overall limits set by (1), we have two independent pieces of evidence that a second, distinctive type of periodization

Figure 2.7 - Leads/lags between innovations with major or minor impacts



X = mid years of periods of high (red) and low (blue) frequencies exists. This is illustrated visually by the periodization of the frequencies of innovations associated with qualitative versus quantitative change, improvement only versus deterioration only and all improvement versus all deterioration. But of the six variables apparently exhibiting this type of periodization, only two show it as being statistically significant at the .10 level.

3) In contrast to that in (1) above, the second type of periodization appears to have been very regular. Though only two of the variables showing this periodization provide independent evidence for its existence, all six provide alternative, valid ways of trying to characterise its features. As table 2.8 (annex 1) shows, on average, the high periods given by the six variables were twenty-eight years long, and the low periods were thirty-two years long. This suggests an overall 'cycle periodicity' of sixty years. The three cycles actually observed in these variables were, on average, sixty-one, fifty-two and sixty-seven years long.

4) Within the limits set by (1) above, there is evidence for the existence of a third factor or set of factors influencing variations over time in the potential for environmental change. There is both visual and statistical evidence of this influence in the patterns of variation in the frequencies of innovations with major versus minor impacts. But although the existence of this influence can be established, its nature is not amenable to simple and coherent characterisation.

(C2) Unit input levels

The statistical evidence for the existence of periodization of changes in unit input levels is provided by the fact that sequences of residuals were consistently found to be significantly clustered. For the five variables whose values were taken from existing sources, the clustering was significant at the .01 level in each case. For the four remaining variables, any one of which constitutes additional, independent evidence, the clustering was significant at least at the .10 level.

In trying to characterise the nature of this periodization, all nine variables were used, the data being plotted in figures 2.19 to 2.27 (annex 2). Lying beneath the year to year variations, we can identify a periodization on the basis of the rate at which unit input levels changed. We can distinguish some periods of rapid change - either increase or decrease, and others where levels were basically stable, or changed only relatively slowly. As picked out by eye, the approximate dates of boundaries between such periods have been shown on the figures.

There are sufficient similarities between the inputs in each class so that we can abstract patterns of change that are characteristic of each class as a whole.

All three old inputs have a central period in which unit levels decreased rapidly, followed by one in which they were very stable. Each also has an initial period in which levels oscillated around stability (ore and BF solids) or slower decline (coke). As well as this basic pattern being held in common, the length of periods and the dates of the boundaries were similar in all three cases. The pattern for old inputs in general can therefore be abstracted as shown in figure 2.8 below.

Apart from the rapid decline in unit levels of scrap iron used from about 1968, the most important feature of variation in scrap usage is that they have basically been stable over the period of study.[1] There is evidence that variation around these constants was not random. As the plot for total scrap (figure 2.23) shows, there appears to have been a cyclical variation around the trend, with a periodicity of five or six years - clearly a different phenomenon to the periodization of the underlying rate of change observed for old inputs.

The plots for the new inputs provide evidence of a character-

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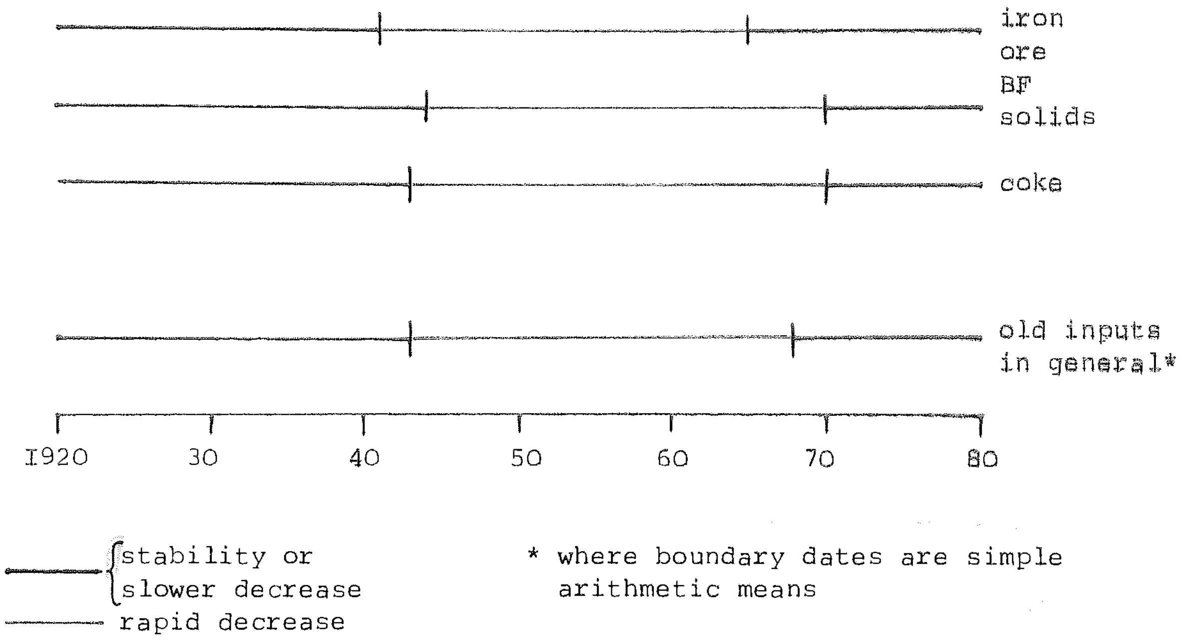
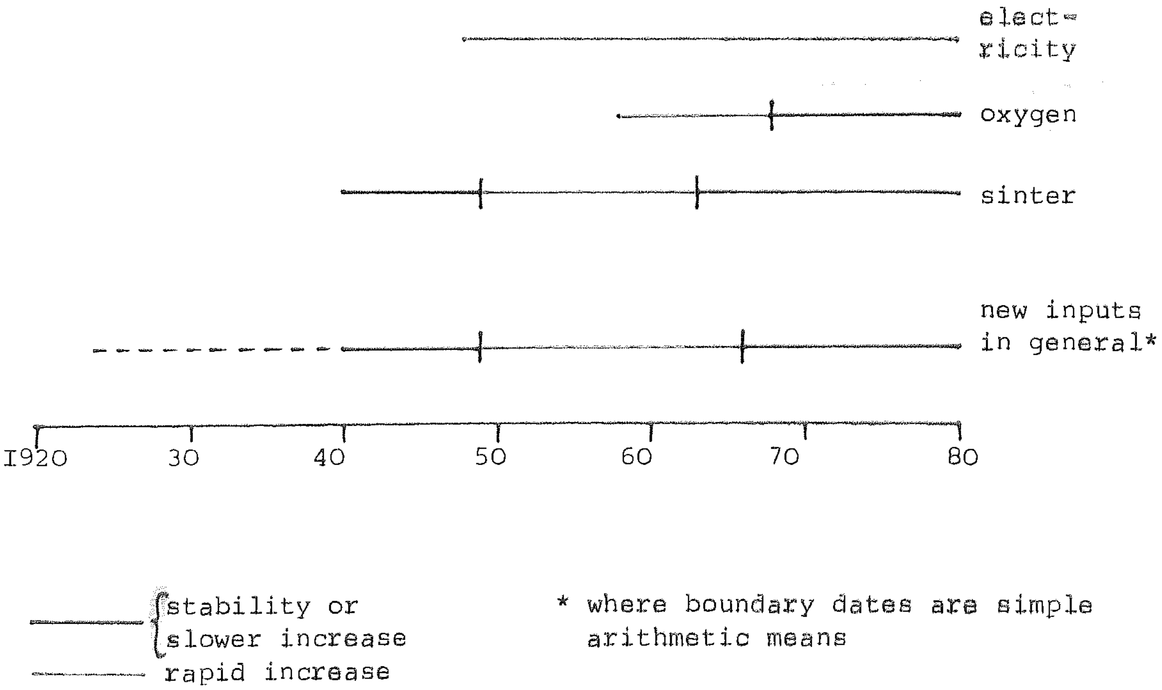
[1] The linear regression slope coefficients for steel scrap and total scrap are virtually identical to zero.



* where boundary dates are simple arithmetic means

Figure 2.8 - Distinctive periods of change in unit input levels of old inputs

istic pattern similar to that in old inputs, though less clear cut. From about 1950 to 65, all three new inputs experienced very rapid increases. In the case of sinter, which has the longest data coverage of the three, this was preceded by a distinct period in which unit input levels were stable. For both sinter and oxygen, the rapid increase phase was also followed by one of stability, though rates of increase of electricity did not fall off in the same way. With this exception, and bearing in mind the shorter data coverage, it seems that unit levels of new inputs were periodized in the same way as those of old inputs - ie phases of stability or rapid change. So we can again abstract a characteristic pattern for new inputs in general, as shown in figure 2.9 below.



* where boundary dates are simple arithmetic means

Figure 2.9 - Distinctive periods of change in unit input levels of new inputs

The generalised patterns for old and new input classes are not only similar in their basic form, but also as regards the length and timing of the periods. As shown in figure 2.10 below, we can, therefore, further abstract to a descriptive model of changes in unit input levels in general. Scrap levels are seen as being constant,[2,3] and all other inputs are seen as having a central period of rapid change surrounded by periods of stability. Figures 2.19 to 2.27 provide only two cases of deviation from this model (both in the period after 1969 - the decrease in unit scrap iron levels and the increase in unit electricity levels).

(C3) Gross consumption level

The statistical evidence for the existence of periodization of changes in gross consumption levels is also very strong. The six independent variables whose values were taken from existing sources all showed clustering of residuals that was significant at the .01 level. The three variables whose values were computed, any one of which constitutes additional evidence, also showed clustering of residuals significant at the .01 level.

In trying to characterise the nature of this periodization, all nine inputs were again used, the data being plotted in figures 2.28 to 2.36 (annex 2). Lying beneath the year to year variation there was a distinctive and common pattern. Where data coverage

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[2] Over this particular sixty year period. Clearly, there is no implication here that unit scrap input levels have been constant for ever. We can speculate, however, that scrap inputs are likely to conform to the pattern of change in old and new inputs after 1920. In this case, we would expect that changes in scrap input levels in the past were probably concentrated into fairly short periods when other input classes were also undergoing rapid change.

[3] The assumption of constant levels of unit scrap inputs does not sit very easily with the fact that the scrap variables also showed significant clustering of residuals. But the visual evidence clearly showed that the periodization was of a different type to that in old and new inputs. And this also shows up in a detailed look at the statistical analysis. Of the three input classes, the scrap input variables had the shortest average 'run length' and the lowest average Z score. Both features are indicators of a periodization which, if regular, would have a shorter 'cycle length'.

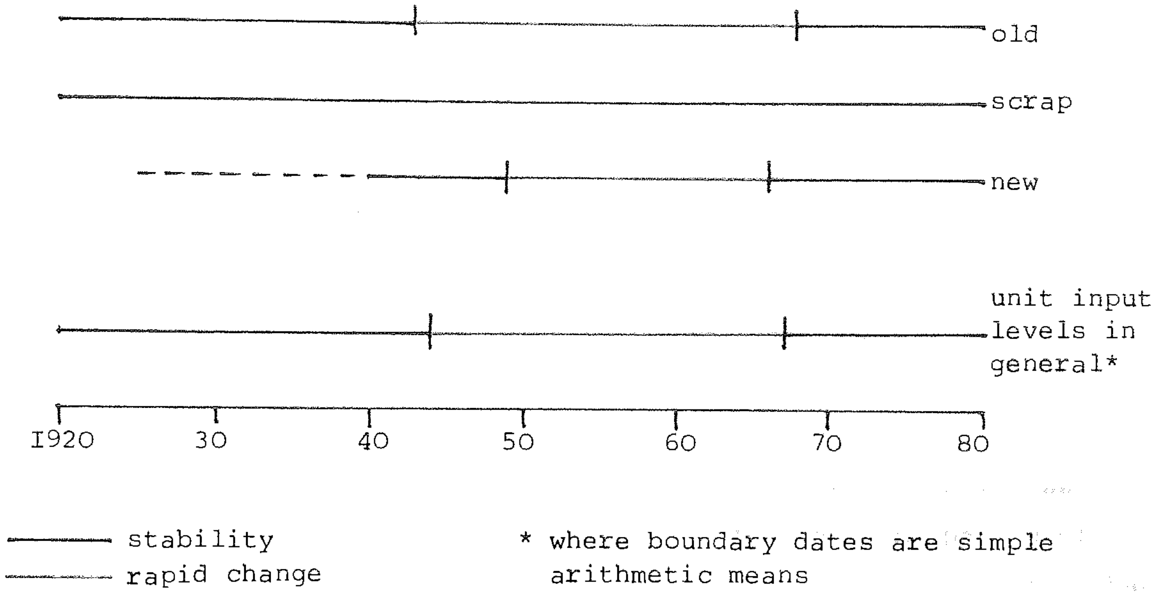


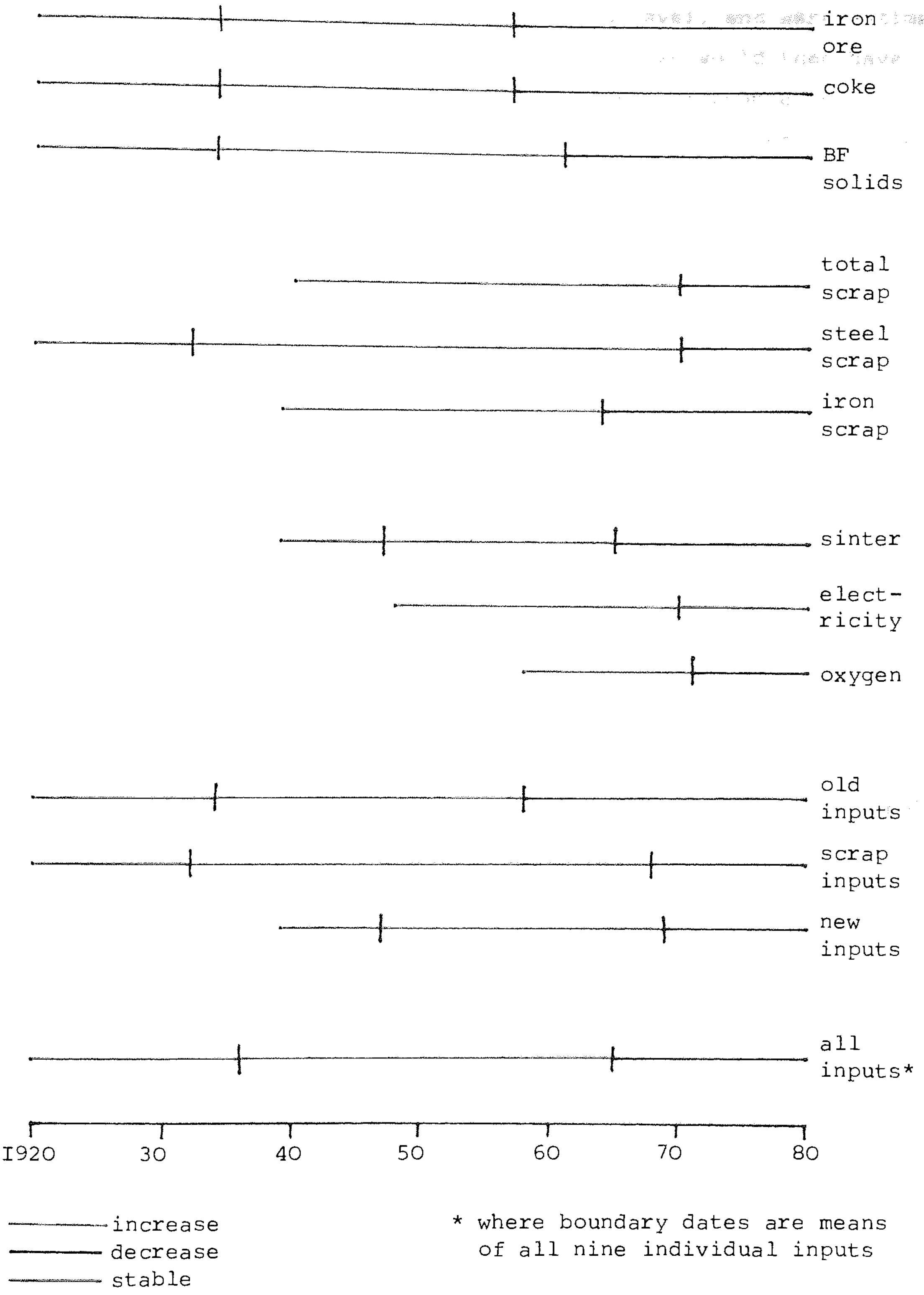
Figure 2.10 - Distinctive periods of change in unit input levels in general

was long enough, all variables showed an initial period in which gross consumption levels were stable or falling slowly. All variables indicated a central period where levels increased rapidly. And for all inputs except one, the final period was one of rapid decrease in consumption. The exception was electricity, the consumption of which remained stable over the final period. The approximate dates of the boundaries between these periods have again been shown on the figures.

The distinctive periods for all inputs are shown schematically in figure 2.11 below, and, as we can see, there is a broad similarity between the nine as regards the timing of the periods. On the basis of this similarity, a descriptive model can be abstracted that typifies the pattern of change in gross consumption levels of all inputs.

As well as the broad similarity, however, figure 2.11 also shows that there were apparently minor differences between input classes in the timing of the three phases. In particular, the period of rapid increase in old inputs ends, on average, a decade earlier than that in new or scrap inputs. Also, it may be that the period of rapid increase in new inputs starts later than in old or scrap inputs (though this is based on only a single observation).

Before going on to summarise all the results of Section C, there is one further point concerning data dependency that needs to be discussed. There are only two inputs for which the data at unit and gross consumption levels were independent (coke and sinter). For the remaining seven inputs, there were mathematical links between the variables used to measure changes at the two descriptive levels. There is, therefore, a question about the extent to which the patterns described at the two levels can be seen as being separate. The problem is that the periodization observed in a computed variable at one level may just be a reflection of, or an alternative way of illustrating that which already exists in the independent data at the other level. This would be a serious problem if all the estimations were in the same direction. For example, if the seven variables with computed



* where boundary dates are means of all nine individual inputs

Figure 2.11 - Distinctive periods of change in gross consumption levels

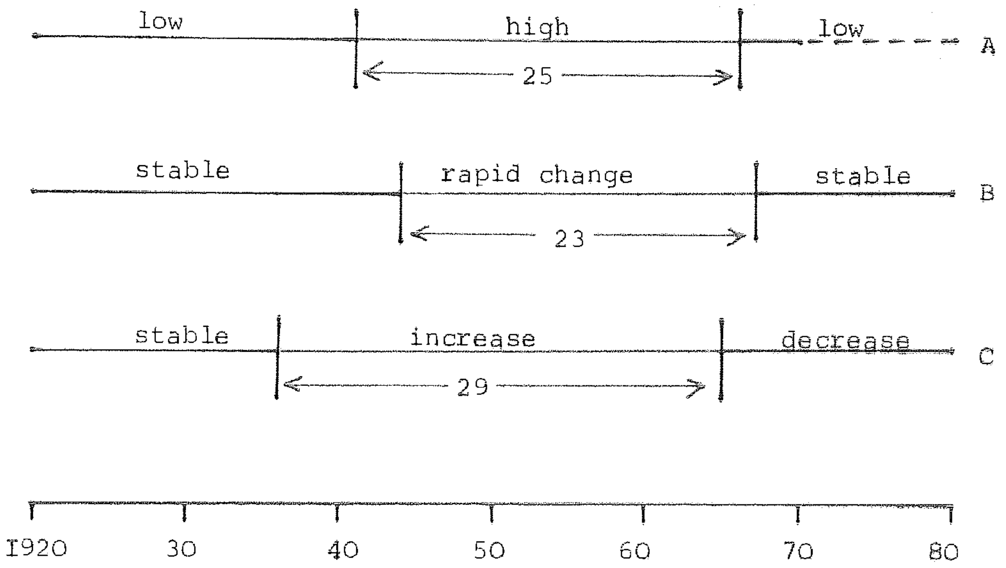
values all referred to the gross consumption level, and were estimated from independent data at the unit input level, we would then have very little independent evidence about patterns of change in gross consumption levels. And in this case, we would hardly be justified in concluding that any periodization in gross consumption level was separate from that seen in unit input levels. However, all the estimation is not in the same direction, and this potential problem is not actually very serious. Evidence for the existence of periodization in unit input levels was given by five independent variables, as well as by the four which were computed using gross consumption level data. Similarly, evidence for the existence of periodization in gross consumption levels was given by six independent variables, as well as by the three which were computed using unit input level data. Despite the existence of these links between variables at the two descriptive levels, we therefore felt justified in concluding that at neither level was the general model a simple mathematical product of that evolved at the other.

(C4) Summary of results

There are three main points to make in summarising these results:

1) There is visual and statistical evidence for the existence of the periodization of environmental change at all three descriptive levels examined (though the statistical evidence is weaker in relation to the potential for environmental change than it is in relation to the actual changes in input levels).

2) Although the overlap between the impact potential and the input data sets is not very long, the visual evidence suggests a close similarity between the three levels as regards the length and timing of the distinctive periods (if the phases of decline and stability in gross consumption levels are seen collectively as equating with periods of low impact potential and stability in unit input levels). The comparison is shown in figure 2.12 below.



A - potential for environmental change (boundary dates from table 2.9)
B - unit input levels (boundary dates from figure 2.10)
C - gross consumption levels (boundary dates from figure 2.11)

Figure 2.12 - Distinctive periods of environmental change at the three levels of description

3) There is no evidence in the unit input data that we can recognise periods of bias, towards either improvement or deterioration, or towards either quantitative or qualitative changes. But we would not expect to be able to see such periods. In the first place, the unit input level variables are not capable of distinguishing between, say, quantitative and qualitative change. And, secondly, these periods of bias were only evident in the impact potential data before about 1920 - ie the start date for the unit input level data.

2D DISCUSSION

The results can be evaluated from two different perspectives, which are taken in turn below. First of all, we consider the results from within the study's own terms of reference. A point to stress in making this assessment is that the study represents a rather crude, first attempt to get at issues raised in the opening chapter. The central question, of whether or not environmental change has been periodized, was not precisely formulated beforehand. No particular guidelines were set out as to what would or would not constitute periodization, in terms of length, regularity or distinctiveness. And although the broad types of data sought were guided by theoretical considerations, the actual data used was rather an ad hoc mixture - one experimental set of soft indicators, and the harder data dictated by what happened to be available. Consequently, the statistics used had to be adaptable and robust. The use of more sophisticated techniques was neither possible nor justified.

Given this context, there are two features of the results that were particularly gratifying. First of all, the study did provide a very clear affirmative answer to the central question about the existence of periodization. And, furthermore, it was generally possible to draw up simple and clear descriptions of the patterns, descriptions that were deviated from considerably less than might have been expected (given, for example, the relatively small number of inputs examined).

The second pleasing feature of the results is the fact that the impact potential data proved to be quite a good indicator for the broad outline of periodization in the harder, input data. This suggests that innovation-based indicators may be a very useful approach to historical, environmental research.[4]

However, there were also problems arising from the rough-and-ready nature of the project. First of all, the impact potential data rather fell between two stools. It was more than adequate for giving an answer to the basic question, in the sense that it suggested at least two, and possibly three separate periodizing influences. However, it was not sufficiently sophisticated to really separate out and characterise these influences. They were compounded in the variables used, and not much other than their existence could be deduced. The results therefore served as a hint of the possibilities that the innovation-based approach to environmental change contains. But to further explore and develop these possibilities, we would need finer data than was used in this study. In this context, it would probably be a useful exercise to take a shorter time period, such as just the nineteenth century, and study the patterns of innovations and their environmental implications in greater depth, perhaps using a number of particular iron and steelmaking locations as case studies, rather than taking in the whole national industry.

The second problem is highlighted by the generally low significance levels attached to the periodization in the impact potential data. The contrast between this and the often compelling visual

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[4] Where they would be a welcome addition to the very small collection of softer indicators that have already been tried. For example, T Baines (ref: 5) used state regulatory action on the environment as the basis for a long term historical indicator (also, incidentally, finding evidence of periodization). This is a 'response' type of indicator, measuring concern, and, because of its data sources, is inherently an indicator relevant to the national level. In contrast, and as a complementary tool, the innovation-based indicators used in this study are industry-specific and look at causes of environmental change, rather than responses to it.

evidence pointed to a problem of method. The Z scores obtained from the runs test, and their significance levels depend on two factors. The first is the periodicity of any cyclical variation that may exist in the real world. The second is the way we aggregate the point-in-time events (innovations). In this case, aggregating into frequencies per decade, and assuming a perfectly regular cyclical variation of sixty years periodicity, each 'run' of positive or negative residuals would cover only three observations. On average, over the two hundred and seventy years, we would expect ten runs, giving a Z score of about -1.8, significant at the .05 level. And, as table 2.7 shows, even two or three extra runs in the data yield Z scores with very low significance levels. Although adequate in relation to the input data, it might have been better, in retrospect, to have used some other method of assessing the significance of apparent periodization in the impact potential data.

The second perspective from which the results were assessed is given by putting them in a broader context. The general question is to what extent are the results likely to apply outside the immediate scope of the study? And several particular questions follow from this. First of all, the data was very much biassed towards the resources side of 'environmental change'. The impact potential data did take into account the pollution changes associated with innovations, and therefore provided evidence that the potential for changes in pollution was periodized. But all the materials balance data related to inputs, and the study therefore provided no evidence that changes in actual unit or gross pollutant levels were periodized. The question, therefore, is whether or not the patterns of change in pollutant levels actually were similar to those observed in input levels. We can speculate that this is likely. First of all, the unit input level patterns were almost exactly what we would expect from those in the impact potential data - ie rapid changes in input levels coinciding with high frequencies of innovations with environmental impacts, and stable input levels coinciding with low frequencies. And there is no obvious reason to think that the relationship between innovation frequency and rate of change in unit pollutant levels should be any different. Secondly, changes in unit input levels are themselves one of the main sources of variation in unit pollutant levels. Other things being equal, we would therefore expect patterns of change in unit input levels to be transmitted to, and reflected in changes in unit pollutant levels. However, technical change may also affect the ratio between amounts of inputs and wastes per unit of output, and the study provides no evidence about the stability or otherwise of this ratio. So, although we can speculate, with reason, that similar patterns of change are likely to have characterised pollution levels, without some further work the case cannot be proven either way, and conclusions about the periodization of 'environmental' change must remain qualified.

Secondly, the input data was quite short, and there is clearly a question as to whether the distinctive periodization observed after 1920 was actually present beforehand. This is not a question that can be given a certain answer, since the data does not exist. But further work would make it possible to give a likely answer. In the period after 1920, the impact potential data appears to give a reasonably good 'prediction' of the broad patterns of change in unit and gross consumption levels. And, of course, if it provides the same accuracy of prediction over the whole study period, we would then expect to find that input levels were indeed periodized before 1920. To find out whether the impact potential data is likely to have the same predictive use before 1920 would involve two stages. First of all, we would have to establish the source of this accuracy over the last sixty years of the study. And this would involve looking at patterns of change in the factors other than innovation that influence input levels. If innovation creates the potential for change, the main factor that determines whether and how rapidly that potential is fulfilled is the rate of diffusion of relevant innovations. Over the last sixty years of the study, it is therefore likely to have been a particular pattern of diffusion that has 'allowed' the periodization of the potential to be straightforwardly transformed into an observable periodization of actual change in unit input levels. And, similarly, a particular pattern of change in output levels is responsible for the link between the patterns observed after 1920 in unit and gross consumption levels. The first stage would therefore be to map out the patterns of diffusion and output growth since 1920. And the second stage would be to establish whether these patterns extended back into the period before 1920. If the relationships between innovation, diffusion and output were the same before 1920 as they were afterwards, we would then be in a strong position to argue that relationships between innovation, unit and gross consumption levels would also be the same. And, conversely, such an analysis could, of course, also serve to suggest that the impact potential data would provide a less accurate indicator of actual patterns of change in input levels before 1920.

The third respect in which the study data is restricted is that it only measures environmental change at levels within what we might call the 'production' sub-system. We have no data relating to the objective, 'ecological' levels - such as changes in ambient carriers or in impacts on targets. Nor do we have any data relevant to the levels of 'social' recognition, concern or response to environmental problems. And the question therefore arises as to whether or not the periodization observed at the level of the production sub-system was also present at the ecological and social levels of description. The fact that changes at the materials balance levels may have no impact at ecological or social levels is well put by N Haigh, in relation to the possible policy responses to pollution problems:

> "(It follows from this definition that) if the pollutant reaches no target in damaging quantities because it has been rendered harmless either by being transformed into another substance or into a form where it cannot affect the target because it has been diluted to harmless levels, then there has been no pollution. It also follows that the mere emission of a potential pollutant to the environment does not necessarily constitute pollution (and that to eliminate pollution, one does not have to restrict emissions to zero)."
>
> N Haigh (ref: 19, p 27).

There are problems with this definition. In particular, it seems to exclude from the definition of pollution those emissions that raise the concentrations of 'potential' pollutants in ambient carriers towards, but not beyond some threshold that is critical for given targets. (For example, do radioactive discharges into the Irish Sea constitute pollution or not?) But, even if we accept the general validity of the point being made, there is ample evidence that, in the iron and steel industry at least, changes at the production levels have led fairly directly to pollution problems at these other levels of description, problems that have long been of concern to the industry, the public and the state. And, indeed, the industry was chosen partly because it would minimise the extent to which the study could be charged with dealing in 'potential' rather than 'actual' environmental problems.

But even if it is undeniable that production level changes have had their impacts at these other levels of description, the question still remains as to whether or not there was any periodization. In trying to answer this question, the first point to make is that if we had the relevant empirical data, it would no longer be industry specific. For example, the iron and steel industry is a producer of sulphur oxide pollution, but so are many other industries. Whether or not there has been any periodization in the concentrations of sulphur oxides in the atmosphere therefore depends on patterns of variation in the amounts emitted by these other industries as well as on the activities of the iron and steel industry. Carrying on with the example of sulphur oxides, we don't know whether, and how directly any periodization of gross amounts emitted might be reflected in the periodization of ambient concentrations.[5] But, for there to be any similarity between the periodization of changes at the gross materials balance level in the iron and steel industry and patterns of change in ambient conditions or impacts on targets, it would clearly be a prerequisite that emissions from the other industries relevant to a given pollution problem followed the same sort of pattern of change as did those in the iron and steel industry (otherwise the

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[5] And to take things a stage further, whether, and to what extent it might show up as periodization of the impact on targets such as trees, fresh water crustacea or masonry.

patterns of emission from the individual industries would tend to conflict, rather than reinforcing each other, so that no periodization of ambient conditions would occur).

So, we cannot adequately address the question of whether periodization of environmental change is likely at ecological and/or social levels of description without reference to the question of whether the patterns of change observed in the iron and steel industry are likely to have been present in other industries as well. And this is the fourth aspect of the restricted nature of the study that we need to consider when evaluating its results. The first point to note, in this context, is that the environmental changes described in the study are outcomes, whose causes, at this stage, are not known. It is hypothesised that they result from periodization in aspects of profitability and technical change that are assumed to be causally linked with environmental change. But, so far, we have no evidence to this effect.

And given that this is the case, there are three interpretations we can make of the results. First of all, it may be that all the causal factors are tied together in a single, systematic and periodized relationship that explains all the observed results. Second, it may be that the results can be explained by the factors assumed to be causally important, but in terms of a series of basically separate events that are not a part of a single dynamic process operating over time. Thirdly, it may be that, despite their apparently clear-cut nature, the periodizations observed cannot be accounted for by reference to those factors assumed to be causal. In this last case, we might conclude that, despite the evidence to the contrary, the results had actually arisen by chance, and that there was therefore no reason to expect to find the same patterns of change in other industries. Under both the other interpretations, the implications for other industries would depend on how widespread in the economy were the processes or events held to be responsible for the observed patterns of change in the iron and steel industry.

At one extreme, the explanations might invoke processes or events that were specific to iron and steel, in which case we would not necessarily expect the pattern of outcomes to be the same in other industries. At the other extreme, explanations may involve processes or events relevant nationally or even internationally. In this case we would expect to find that environmental change had in some way been similarly periodized in many other industries. And in this last case, of course, we would then have the condition stated as a prerequisite for expecting that there might be periodization of environmental change, as measured at ecological and/or social levels of description.

2E CONCLUSIONS

We can conclude that, in the UK iron and steel industry between 1700 and 1980, there were significant patterns in the distribution over time of the variability in environmental outcomes. In particular, at all descriptive levels examined, we could identify distinct periods, contrasted in terms of types and/or rates of environmental change.

The study therefore provides some evidence of the utility of the focus on questions of distribution. It helps us to progress beyond the apparent impasse created by the traditional approaches to relationships between profits, technical and environmental change. In particular, it provides an empirical input to the meso level of analysis that offers hope of bringing micro and macro levels of analysis together without an irreconcileable conflict. In the traditional micro level analyses, the conditions governing environmental outcomes are taken as given, so that we have no way of predicting outcomes without reference to those conditions. By showing that outcomes are periodized, the study suggests a periodization in those conditions which govern the sort of outcomes resulting from profit-maximisation. And, in turn, this draws us away from the ideas about the 'universal nature' of capitalism that are at the source of the conflict between the neoclassical and neomarxist macro levels of analysis. Perhaps, with regard to environmental change, the important thing is not those aspects that are universal (whatever we believe them to be), but rather, is those aspects, those conditions that appear to change periodically. Any proposed, but unproveable, fundamental bias towards improvement or deterioration, say, is less important an influence on actual outcomes than the apparent periodization of conditions that are not the universal, defining features of capitalism. For practical purposes, the case study results suggest that neither macro level proposition has any validity in general, though both have in particular and different periods.[6] The meso level of analysis therefore gives us a way of partially reconciling the conflict present in traditional macro level approaches, as well as grounds for seeing the variability in conditions governing particular outcomes as being other than randomly distributed over time.

A glimpse of the possible utility of this approach is therefore provided, despite the fact that this study represents rather a crude first attempt to get at these issues. But, as the discussion above demonstrates, the implications we can draw from the results are limited by the nature and scope of the study. And three areas of further work are seen as being particularly important in this context. First, in order to further explore the utility of innovation-based indicators of environmental change, and in order to more clearly understand the role of innovation itself, it would be useful to study in greater depth and detail the patterns of innovation over time, and their environmental implications. Second, some sort of work on the pollution side is really needed before we are justified in talking about the periodization of environmental change, even in the restricted sense of changes at levels within the production subsystem. And third, it would be of great value to try to account

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[6] At impact potential and gross consumption levels, at least, where there was evidence of improvement and deterioration being concentrated into different periods. At the unit input level, the breakdown was into periods of no improvement or deterioration and periods of both.

for these case study results in terms of those aspects of profitability and technical change assumed to have a causal influence. In the absence of data that is either difficult or impossible to get hold of, this should allow us to make reasoned arguments about the broader applicability of the results as regards materials balance changes before 1920, as regards other industries and as regards the ecological and social levels of description of environmental change.

2F Annex 1: Data Tables

Table 2.1 - Innovations in the UK iron and steel industry

Code	Date[2]	Description	Sources[1]
*1		Bloomery wrought iron process	
*2	1500	Early blast furnace cast iron	(15:20-23, 70)
*3		Thick walled cast iron	
*4	1590	Water powered slitting mill (wrought iron strips)	(15:26-28)
*5		Cementation process (blister and shear steel)	
6	1709	Coke-fired blast furnace	(15:31-33)
7	1740	Crucible steel process (mild carbon)	(15:35-36)
8	1775	Reciprocating blowing engine (Watt)	(15:38,39)
9	1762	Rotative blast furnace blowing engine (Boulton and Watt)	(15:42)
10	1785	Reverberatory furnaces for wrought iron production (dry puddling)	(15:43-45, 62,65)
11	1784	Grooved rolling mills to conslidate wrought iron bloom	(15:47) (24:88)
12	1795	Cupola for remelting iron	(15:51)
13	1829	Hot blast	(15:55-58)
14	1835	Water-cooled tuyeres in blast furnaces	(15:58)
15	1832	Round hearths in blast furnaces	(15:59)
16	1838	Pressurised blast	(15:59)
17	1820	Recycling of cinders to blast furnace input charge	(15:59,60)
18	1816	Use of iron oxide linings in wrought iron furnaces (wet puddling)	(15:62-65, 70)
19	1839	Fettling	(15:64)
20	1827	Use of waste heat from puddling furnaces in boilers	(15:66)
21	1846	Heat extracted from blast furnace waste gases and recycled	(15:67)
22	1850	Single bell and hopper (reduces blast furnace gas escapes to charging phase)	(15:68,69)
23	1840	Steam hammer for shingling bloom	(15:74,75)

Code	Date	Description	Sources
24	1856	Acidic Bessemer process (flawed)	(15:90-96, 103,111)
25	1857	Use of phosphorous-free pig iron in acid Bessemer process	(15:95)
26	1857	Use of magnesite in acid Bessemer process (reduces oxygen content of steel)	(15:95)
27	1868	'Self-hardening' tungsten steel	(15:96,97)
28	1864	First book on scientific analysis of iron	(15:98)
29	1866	Open hearth steel process	(15:98-102)
30	1879	Basic Bessemer process (use of dolomite allows phosphoric pig iron input)	(15:107,108)
31	1855	Cast steel	(15:113)
32	1876	Sheet steel (first rolled)	(15:114)
33	1857	Cowper regenerative hot-blast stove	(15:115)
34	1861	Copper/gunmetal tuyeres	(15:115)
35	1868	Closed forepart to blast furnace	(15:116) (28:2)
36	1898	Pig casting machines	(15:119)
37	1900	Taphole clay gun	(15:119) (8:209)
38	1905	Mechanical blast furnace charging	(15:119,121)
39	1902	Double bell and hopper	(15:120) (8:209)
40	1883	Electricity used for light steel rolling	(15:121)
41	1878	Universal steel plate mill	(15:122)
42	1905	Universal steel beam mill	(15:123)
43	1948	Meehanite cast iron	(15:125)
44	1948	Spheroidal graphite cast iron	(15:125)
45	1890	Nickel/iron alloy (cast iron)	(15:125)
46	1892	Chromium/iron alloy (cast iron)	(15:125) (25:1892)
47	1894	Cupronickel/iron alloy (cast iron)	(15:125)
48	1887	Manganese alloy steel	(15:127) (13:Vol 17:642)
49	1902	Silicon alloy steel	(15:128) (13:Vol 17:642)

Code	Date	Description	Sources
50	1893	Chromium alloy steel	(15:128-146)
51	1908	Electric reverse-rolling mill	(15-146)
52	1903	Standards set for iron and steel beams and sections	(15:147)
53	1908	Electric arc furnace (steel)	(15:147,148) (8:219) (6:185)
54	1938	Continuous wide strip rolling mill	(15:149,150)
55	1944	Electrolytic tin plating of sheet steel	(15:151) (13:Vol 17:642)
56	1938	Fully automatic blast furnace charging	(15:155) (8:552)
57		Partial sintering of blast furnace charge	
58	1960	Bulk oxygen steelmaking (L D process)	(15:156-158) (9:64)
59	1939	In-furnace spectrographic steel analysis	(15:158) (25:1939)
60	1946	Continuous steel casting	(15:159,160)
61	1788	Steam lifts for blast furnace charging	(15:119)
62	1785	Steam power used to haul blast furnace charging waggons	(15:161)
63	1785	Refining of pig iron before dry puddling	(15:46)
64	1965	Improved continuous steel casting	(15:161)
65	1954	Automatic gauge and tension control in sheet steel milling	(15:161)
66		Flying micrometer gauge controls	
67	1922	Electric induction furnace for alloy steels	(15:163) (8:219)
68	1955	Vacuum melting of special steels	(15:164) (30:13)
69	1962	Vacuum degassing in bulk steel production	(15:165) (30:13)
70		Aston Byers process (wrought iron)	
71		Water powered tilt hammer for wrought iron processing	
72	1782	Helve hammer	(15:24,75,76) (49:472)
73		Wrought iron grades, established	
74	1852	Wrought iron joints (first rolled)	(15:79)

Code	Date	Description	Sources
75	1863	Microscope analysis of iron and steel	(15:98)
76	1952	Fully sintered blast furnace charge	(15:155)
77	1961	Automatic steel billet cutting	(15:167,168)
78	1862	Continuous rolling of wrought iron	(15:105)
79		Two-high rolling mills (wrought iron)	
80	1815	Three-high rolling mills	(15:83)
81		Rolling mill guide passes	
82	1850	Hot-saw billet cutting	(15:86)
83	1884	Gauge standards for wrought iron sheet	(15:87)
84	1862	Mechanical manipulation in rolling mills	(15:103)
85	1866	Reversing mill	(15:103)
86	1864	Looping mill	(15:104)
87	1888	Nickel steel	(32:54-56)
88	1903	Molybdenum steel	(32:54-56) (13: Vol 17: 642)
89	1903	Vanadium steel	(32:54-56)
90	1903	Titanium steel	(32:54-56)
91	1937	Chemical production of refractory magnesia	(32:57)
92	1941	Improvements to hydraulic forging presses	(32:68)
93	1905	Heat-resisting steel alloys ('high speed')	(32:71) (8:221)
94	1840	(Zinc) galvanised sheet steel	(32:71) (49:625)
95	1887	Seamless steel tubes	(32:73,74) (49:629)
96	1897	Ferro-concrete	(32:92) (49:490)
97	1955	Four-high steel plate rolling mills	(32:109)
98	1869	Use of fuel oil in blast furnace charge	(32:113)
99	1868	Iron and Steel Institute (cooperative research and development)	(32:116)
100	1890	Active mixers (prerefining of molten pig for open hearth steel)	(32:117) (8:217)
101	1948	Oxygen use in electric arc furnaces	(32:117) (9:117)
102	1947	Oil-firing of open hearth furnaces	(32:121) (3:197)

Code	Date	Description	Sources
103	1720	Hot-dip tinplating	(15:46)
104	1830	Pickling (acid cleaning of steel sheet)	(15:150) (49:616)
105	1708	Thin-walled iron casting	(24:40)
106	1742	Newcomen engine (steam assistance in blast furnace blowing)	(24:70)
107	1735	Use of coal as coal in wrought iron chafery	(24:82,83)
108	1762	Coal-fired potting process (wrought iron)	(24:83)
109	1772	Coke-fired potting process	(24:84)
110	1790	Cast iron tops to dry puddling furnaces (replaces clay)	(24:100)
111	1790	Sea sand floors to dry puddling furnaces	(24:100)
112	1818	Cast iron floors to puddling furnaces	(24:142)
113	1823	Use of molten pig iron in wrought iron puddling	(24:143)
114	1837	Use of anthracite in blast furnaces	(24:159)
115	1942	Hot-blast cupolas in steel foundry sector	(13:Vol 17:643)
116		Stainless steel electrostatic precipitation in crude steel production	
117		'First stage' particulate matter arrestors used in blast furnaces	
118		'Second stage' PM arrestors	
119		'Third stage' PM arrestors	
120	1891	Tropenas furnaces in steel foundries	(8:214)
121	1964	Fume arrestors fitted to tropenas furnaces	(2:1973)
122		Cold-blast cupolas in foundry sector	
123*	1970	PM arrestors in open hearth furnaces using light oxygen	(2:1973)
124	1956	Use of light oxygen in open hearth furnaces	(3:143)
125	1959	Bulk use of oxygen in open hearth furnaces	(3:143)
126		Iron ore calcination	
127	1955	Use of cyclone arrestors in hot-blast cupolas	(2:1960)
128		Use of electrostatic precipitation for PM reduction in steel making	

Code	Date	Description	Sources
129	1893	Nickel/chrome steel	(13:Vol 17:642)
130	1942	Boron steel	(13:Vol 17:642)
131	1947	Continuous galvanising	(13:Vol 17:642)
132		Aluminium steel coating	
133		'Organic' steel coating	
134	1881	Use of fluorspar as flux in basic steelmaking	(13:Vol 17: 642)
135	1947	Oxygen enrichment of basic Bessemer blast	(3:129) (3:181)
136	1958	Oxygen/steam enrichment of basic Bessemer blast	(3:129) (3:191)
137		Oxygen/carbon dioxide enrichment of basic Bessemer blast	
138	1963	LD/AC process (bulk oxygen steel)	(3:136) (3:206)
139	1965	Kaldo process	(3:138) (3:141)
140	1961	Rotor process	(3:140) (27:52)
141	1836	Mechanical puddling furnaces	(8:56)
142	1786	Steam-powered slitting and rolling mill	(8:57)
143	1845	Corrugated iron sheet	(8:58)
144	1866	Hydraulic forging press	(8:61) (49:616)
145	1882	By-product coke oven (for tar and oils)	(8:153)
146	1892	Flying shear (billet cutting)	(8:162)
147	1907	Gayley's dry air blast (blast furnaces)	(8:210)
148	1903	Stock converter (steel foundries)	(8:215)
149	1902	Tilting open hearth furnaces (continuous production)	(8:215)
150	1913	Ferro-uranium	(8:222)
151	1913	Ferro-tantalum	(8:222)
152	1935	Blast furnace slag granulated for building blocks	(8:551)
153		Steel/plastic laminates	
154	1880	Steel tinplate	(8:114)
155	1759	Beehive coke ovens	(8:54)
156	1872	Retort coke ovens (non-recovery)	(8:54)

Code	Date	Description	Sources
157	1951	Use of oxygen for prerefining molten pig iron (in ladles or mixers)	(9:20)(9:33)
158	1947	Use of oxygen in tropenas furnaces	(9:74)
159	1949	Oxygen enriched blast (blast furnaces)	(9:159)
160	1954	Pelletising (blast furnace charge preparation)	(9:160)(13: Vol 9:895)
161	1948	Oxygen enrichment of cupola blast	(9:204)
162	1881	Blast furnace gas washing, to reclaim ammonium sulphate	(28:3)
163	1884	Carvés process (removes sulphur from sulphur oxides in coke oven gases)	(28:133)
164	1950	Scarfing (oxygen billett cleaning)	(9:162)
165		Coke oven gas washing	
166		Activated sludge process to deal with coke oven liquors	
167	1947	British Iron and Steel Research Association	(3:184)
168	1918	National Federation of Iron and Steel Manufacturers	(3:155)
169	1969	Regenerative process to reclaim acids from pickling liquors	(38:133)
170*	1972	Ion exchange process to deal with tinplating electrolytes	(28:242)
171	1894	Electric drives for heavy steel mills	(49:594)
172	1949	Automatic combustion control in open hearth furnaces	(27:2)
173		Reduction of sulphur oxide content of waste gases from open hearth and electric arc steelmaking	
174		Carbonate process for pickling liquor acids (neutralises them)	
175		Oxide process (uses iron oxide to remove hydrogen sulphide from coke oven gases)	
176		Electrostatic precipitators used to clean scarfing fumes	
177		Mechanical extractors and tall chimneys used to control fume from electric arc furnaces	
178	1960	Fume arrestors applied to oxygen converter steelmaking processes	(29:80)
179	1962	Electrostatic precipitators used in open hearth furnaces using bulk oxygen	(29:65)

Code	Date[2]	Description	Sources[1]
180	1959	Bag filters in electric arc furnaces using bulk oxygen	(29:144)
181	1953	Wet washers in electric arc furnaces using bulk oxygen	(29:150)

[1] In addition to sources cited in relation to innovation dates, further works were used to gather information on other technical and environmental aspects of the innovations (see references 79 to 85).

[2] In most cases, the exact date of the innovation is known (where innovation was defined as first commercial use in the UK). In the remainder, innovation dates were estimated to within two or three years. For example, references to innovations in the 'early', 'mid' or 'late' 1880s would be recorded as 1882, 85 and 88 respectively.

*Innovations not used when calculating period frequency data which runs from 1700 to 1969 inclusive.

Table 2.2 - Environmental impacts of innovations

Notes

(1) When trying to detail the environmental impacts of innovations, there was a boundary question to be addressed, particularly with reference to inputs, but also as regards the wastes produced in their collection and use. Considering iron and steel production as a linear process chain, the question was how far back along the chain should we go? For example, iron ore is the essential ingredient in pig iron, and since 1700 the unit amount needed has been substantially reduced by technical change. But the mining and transport of the ore also requies inputs and produces pollution, and these operations have also been altered by technical change. Clearly, we cannot include all these inputs or wastes. For instance, one of the inputs is human labour power, but the reproduction of the labour force involves environmental withdrawals and additions way beyond the scope of this study. It was necessary to draw the boundary line somewhere, and certain 'basic' inputs were taken as given. Those occurring most often included iron ore, coal, wood, oil, oxygen and human labour power. Others occurred less frequently, and these included dolomite, animal power, sulphuric acid, tin and gravity.

(2) Where known, all impacts were recorded, as far back along the relevant process chain as possible. For example, there were several innovations resulting in a reduction in the amount of pig iron needed to produce a unit amount of crude steel. Since less pig iron was needed, there was also a reduction in the amount of blast furnace wastes per unit of crude steel. Similarly, there were reductions in amounts of blast furnace inputs needed, such as coke and prepared ore. But these inputs are 'intermediate' rather than basic. The reduction in coke, for example, implies a reduction in the amount of coal needed per unit of crude steel. It also implies a reduction in the amount of coking wastes per unit of crude steel. In the table below, the intermediate inputs are shown in brackets because any increases or decreases they experienced are not additional to, or separate from those in the associated basic input.

(3) There are two ways in which the detail in the descriptions varies. First of all, we can contrast those cases where changes were recorded for quite specific inputs or wastes (eg sodium dichromate) with those cases where we had to refer to a broader group or class (such as coal combustion wastes).

Some of these broader classes recurred frequently, and their individual members have not been itemised each time in the table below. Rather, they are given in the list at the end of the table. The list demonstrates the second way in which the descriptions vary as regards detail. In some classes, such as coking wastes, we were able to break these down quite finely. But in other cases, such as producer gas combustion wastes, we had no information with which to break the class down into separate pollutants.

(4) According to the nature of the innovation and of the source material, there are also variations in the terms used to describe impacts. First, some changes are recorded as start/stop, whilst others are recorded as increase/decrease. Secondly, some changes are recorded in relation to units of given outputs, such as coal per ton of pig iron, and other changes are recorded in relation to particular operations within the industry, such as casting, milling or blast furnace charging.

Innovation Code	Description of impacts	Number of separate impacts
6	In blast furnace (BF) pig iron production: start - coal input (as coke) - coking wastes - coke BF wastes stop - wood input (as charcoal) - charcoal production wastes - charcoal BF wastes increase - slag produced/ton pig - power input/ton pig, since coke is not as combustible as charcoal, and needs stronger blast for furnace to reach operating temperature (water power at first)	26
7	In steel production: start - coal input - coal combustion wastes stop - wood input (as charcoal) - charcoal production wastes - charcoal combustion wastes decrease - slag produced/ton steel	(17)
8	Per ton pig iron: increase - coal input - coal combustion wastes decrease - water power input	9
9	Per ton pig iron: Decrease - coal input - coal combustion wastes	8

Innovation code	Description of impacts	Number of separate impacts
10	In wrought iron (WI) production: increase - acidity of slag stop/decrease - wood input (as charcoal) - charcoal production wastes - charcoal consumption wastes start/increase - coal input - coal combustion wastes - both in the furnace and in the prerefining necessary for dry puddling which could only use 'white' pigs (iron low in carbon and silicon)	(15)
11	In 'consolidating' WI blooms: start/increase - milling wastes - oil, millscale - coal input - coal combustion wastes stop/decrease - water power input	10
13	Per ton of pig, blast heating requires: increase - coal input - coal combustion wastes But resulting increases in BF efficiency mean that, per ton of pig: decrease - coke BF wastes - coal (as coke) - ore (as prepared) - coking wastes - ore preparation wastes	32
16	Per ton of pig iron, stronger blast requires: increase - coal input - coal combustion wastes	

	But resulting increases in BF efficiency mean that, per ton of pig: decrease - coke BF wastes - coal (as coke) - ore (as prepared) - coking wastes - ore preparation wastes	32
17	Per ton of puddled WI: decrease - cinder waste Use of puddling cinder as part of BF charge means, per ton of pig iron: decrease - ore input (as prepared) - ore preparation wastes	5
18	Wet puddling WI production: stops - acid slag problem of dry puddling - input of virgin sand as furnace lining starts - use of iron oxide as furnace lining, recycled from its own cinder waste, and therefore decrease - amount of cinder waste/ton WI Process removes the need to prerefine pigs, and therefore, in this operation: stops - wood input (as charcoal) - charcoal production wastes - charcoal combustion wastes Process substantially reduces amount of pig iron needed, and therefore, per ton of wrought iron: decrease - coke BF wastes - coal (as coke) - ore (as prepared) - coking wastes - charcoal combustion wastes	(36)

19	Roasting of puddling furnace slag (fettling) in order to stop it attacking cast iron (CI) furnace linings means that, per ton of wrought iron start - fettling wastes increase - coal input - coal combustion wastes	(11)
20	Rastrick's waste heat boiler helps power rolling mills etc so that, per ton of processed bar iron: decrease - coal input - coal combustion wastes	8
21	Use of BF gas wastes for blast heating means, per ton of pig iron: decrease - coal input - coal combustion wastes	8
22	Restriction of BF gas escapes to charging period means that, per ton of pig iron: decrease - coke BF gas wastes and reduced heat loss means that less blast heating needed, and therefore, per ton of pig: decrease - coal input - coal combustion wastes	13
23	In shingling wrought iron bloom: start/increase - coal input - coal combustion wastes stop/decrease - water power input	9
24	Acid Bessemer process for crude steel production needed phosphorous-free inputs. Blast furnaces could no longer use recycled puddling furnace slag as part of their charge, since it was phosphorous-rich. For steel produced by this process, this therefore meant, per ton of steel: increase - ore (as prepared) - ore preparation wastes	

24	But process used pig iron directly, rather than wrought iron, so that, per ton of steel: stops - puddling wastes (wet) - puddling inputs (other than pig iron) In contrast to crucible process, Bessemer could use molten pig iron directly from blast furnace. No reheating was needed, and therefore, per ton of steel: decrease - coal input - coal combustion wastes	22
26	To reduce the oxygen content of Bessemer steel, and improve its quality, furnaces were lined with magnesite bricks, resulting in: start - input of spiegeleisen (manganese source) - production of very acidic slags (hence 'acid Bessemer' process)	2
29	Open hearth process could use greater proportions of scrap as input than other steel processes, and a wider variety of scrap types, so that less pig iron was needed and, per average ton of crude steel: decrease - coke BF wastes - coal input (as BF coke) - ore input (as prepared) - coking wastes - ore preparation wastes Regenerative heating allowed substantial fuel savings: decrease - coal/ton steel Immediate fuel input was producer gas (LPG), so that substitution of steel production wastes was as follows: start - LPG combustion wastes - LPG production wastes stop - coal combustion wastes	(40)

30	Basic Bessemer able to use phosphoric pig inputs. Blast furnaces supplying pig iron can again use puddling slag as input charge, and so, per ton of steel: decrease - BF ore input (as prepared) - ore production wastes Change in furnace lining means that, for Bessemer steel production: start - dolomite input decrease - spiegeleisen input - acidity of furnace slag and because basic slag could be sold as by-product, per ton of Bessemer steel: decrease - amount of slag waste but also: increase - dust/fume waste/ton steel	9
33	Cowper regenerative stove uses BF waste heat more efficiently, and in blast heating: decrease - coal input - coal combustion wastes Resulting increases in BF efficiency lead to reduction in coke rate, and therefore, per ton of pig iron: decrease - coal input (as coke) - coking wastes	19
35	Per ton pig iron: decrease - BF gas wastes	5
36	Mechanised casting means that, for finished pigs: stop - sand input (no longer needed in pig beds) - human labour input (no longer needed for breaking up and loading pigs) - gravity (no longer used to feed beds) start - coal input (as electricity) - electricity production wastes	(11)

37	In rebuilding BF tapholes: stop - human labour power input start - coal input (as electricity) - electricity production wastes	(9)
38	In BF charging: stop - human labour power input start - coal input (as electricity) - electricity production wastes	(9)
39	Per ton pig iron: decrease - BF gas wastes	5
40	For light steel rolling: stop - coal combustion wastes (in steam power) start - electricity production wastes	(14)
41	Per unit of steel plate: decrease - coal input decrease - coal combustion wastes	8
42	Per unit of steel beams: decrease - coal input decrease - coal combustion wastes	8
51	Per unit of steel sheet or billet: decrease - coal combustion wastes increase - electricity production wastes	(14)
53	Greater thermal efficiency of arc furnace means that, per ton of steel: decrease - coal input Furnace could also use light steel scrap, so that, on average, less pig iron needed, and therefore, per ton of steel:	29

	decrease - BF wastes - coal input (as coke) - coking wastes - ore input (as prepared) - ore preparation wastes - other BF inputs/wastes	
55	Per unit of sheet tinplate: decrease - tin input used - coal input (since no heating of hot dip) - coal combustion wastes start - electrolyte wastes (including chromates and phenolsulphonic acid)	11
56	Increased furnace efficiency means: decrease - BF wastes - coal input (as coke) - coking wastes - ore input (prepared) - ore preparation wastes - other BF inputs	29
57	Sintering allowed ore fines to be used for the first time, and therefore, per average ton of pig iron: decrease - ore fines waste - ore input (as prepared) Also, per ton pig iron: decrease - coal input (as coke) - coking wastes In ore preparation: starts - sintering wastes reduces - calcination wastes	19
58	Per ton of steel: new source - iron oxide fume - oxygen input	2

60	Continuous casting bypasses need for primary mill, and therefore, in steel casting: decrease - milling wastes - coal input (as electricity) - electricity production wastes	(17)
61	In BF charging: decrease - water/animal power input increase - coal input - coal combustion wastes	9
62	In BF charging: decrease - water/animal power input increase - coal input - coal combustion wastes	9
65	Better gauge and tension controls in sheet steel rolling means that, per unit of sheet steel, less crude steel needs to be produced, and therefore: decrease - steel furnace wastes - steel furnace inputs (other than pig iron) Reduced pig iron input means that, per unit of sheet steel: decrease - BF wastes - coal input (as coke) - coking wastes - ore input (as prepared) - ore preparation wastes - other BF inputs	38
66	As innovation 65	
72	In wrought iron forging: stop - water power input start - coal input - coal combustion wastes	9

74	In production of joints: stop - human labour power input start - coal input - coal combustion wastes	9
76	Per ton pig iron: decrease - ore fines wastes - ore input (as prepared) - coal input (as coke) - coking wastes - calcination wastes increase - sintering wastes	19
78	Bypassing the need to reheat means that, per unit of wrought iron sheet or bar: decrease - coal input - coal combustion wastes	8
80	Due to time saved, need for reheating is reduced, and impacts as innovation 78	8
81	Reduce weight of wrought iron per unit product, and therefore: - puddling wastes - ore input - ore preparation wastes - coal input (as coke) - coking wastes - puddling inputs - BF wastes	(35)
84	Per unit of wrought iron bar or sheet: decrease - human labour power input increase - coal input - coal combustion wastes	9
86	As innovation 80	8

94	Start - zinc input - zinc galvanising wastes - pickling wastes (needed to clean sheets before galvanising process)	(6)
98	Per ton pig iron: start - fuel oil input decrease - slag waste - coal input (as coke) - coking wastes	13
100	In active mixer: start - input of desulphurising agents (eg lime chloride) start - coal input (as LPG) - LPG production wastes - LPG combustion wastes But reduced heat time in open hearth furnace means that, per ton steel: decrease - coal (as LPG) - LPG production wastes - LPG combustion wastes	(19)
101	In electric arc steel: start - oxygen input - iron oxide fume waste increase - scrap input decrease - iron ore input (as pig iron) - ore preparation wastes - BF wastes - coal (as BF coke) - coking wastes - other BF inputs Reduced heat time in arc furnace means that per ton of steel: decrease - electricity input (basic input unknown) - electricity production wastes	(40)

102	In open hearth furnace steel stop - coal input (as LPG) - LPG production wastes - LPG combustion wastes start - oil input - oil combustion wastes	9
103	Per unit of wrought iron product: start - tin input - tinplating wastes (acids, oil and grease) And in heating the hot dip: increase - coal input - coal combustion wastes	12
104	In wrought iron processing start - input of sulphuric acid - pickling wastes	3
105	Per iron casting, less pig iron needed, and therefore: decrease - charcoal BF wastes - wood input (as charcoal) - charcoal production wastes decrease - ore input (as prepared) - ore preparation wastes - other charcoal BF inputs	21
106	In BF furnace blowing: start - coal input - coal combustion wastes decrease - water power input	9
107	In production of wrought iron: start - coal input - coal combustion wastes	(16)

	stop - wood input (as charcoal) - charcoal production wastes - charcoal combustion wastes	
108	In production of wrought iron: stop - wood input (as charcoal) - charcoal production wastes - charcoal combustion wastes increase - slag/ton WI start - coal input - coal combustion wastes - limestone input (as flux in pots) Process uses more pig iron than finery/chafery process, so, per ton wrought iron: increase - BF wastes - ore input (as prepared) - ore preparation wastes - wood input (as charcoal) - charcoal production wastes - other charcoal BF inputs/wastes	(40)
109	Flux no longer needed, so in WI production: stop - limestone input decrease - slag waste stop - coal combustion wastes start - coking wastes	19
112	Per ton of puddled wrought iron decrease - slag waste - iron ore input (as pig iron) - coke BF wastes - ore preparation wastes - coal input (as coke) - coking wastes - other BF inputs	30

113	Use of molten pig bypasses need for reheating, and therefore, per ton of puddled wrought iron: decrease - coal input - coal combustion wastes	8
114	Per ton of pig iron: decrease - coal input increase - BF fume waste	2
115	Per ton of cast steel: decrease - coal input (as coke) - coking wastes - coke combustion wastes	(15)
117	Per ton of pig iron: decrease - BF particulate matter wastes	1
118	As innovation 117	1
119	As innovation 117, especially fine fume	1
120	Per average ton of cast steel: increase - fume wastes	1
121	Per average ton of cast steel: decrease - fume wastes	1
123	Per ton of crude steel: decrease - fume wastes	1
124	Per ton of crude steel: increase - oxygen input - iron oxide fume waste But reduces furnace melt time, and therefore, per ton of crude steel: decrease - oil input	3

125	As innovation 124	3
126	In ore preparation: start - calcination wastes	3
127	Per ton of cast steel: decrease - particulate matter waste (especially coarse)	1
128	Per ton of crude steel: decrease - fine fume waste	1
135	Per ton of Bessemer steel: start - oxygen input - iron oxide fume waste increase - scrap input Increased scrap use and increased converter efficiency means that, per ton of steel: decrease - iron ore (as pig iron) - ore preparation wastes - coke BF wastes - coal input (as coke) decrease - coking wastes - other BF inputs	32
136	Per ton of Bessemer steel: decrease - iron oxide fume waste	1
138	In order to allow high phosphorous pigs to be used, per ton Bessemer steel: start - input of lime flux increase - iron oxide fume waste	2
139	Per ton of pneumatic (oxygen) steel: decrease - carbon monoxide waste	1

141	In puddled wrought iron: decrease - human labour power input increase - coal input - coal combustion wastes	9
142	In wrought iron rolling: decrease - water power input increase - coal input - coal combustion wastes	9
145	Per ton of coke: decrease - wastes of oil and tar and because heat was also recycled: decrease - coal input/ton coke	3
147	Refrigeration used to dry air blast, so that, per ton of pig iron: increase - electricity input (basic input unknown) - electricity production wastes But resulted in improved coke rate, so that, per ton of pig iron: decrease - coal input (as coke) - coking wastes	(19)
152	Per ton pig iron: decrease - slag waste	1
155	Greater thermal efficiency than open coking means that, per ton of coke: decrease - coal input - coking wastes	11
156	As innovation 155	11

157	In prerefining open hearth pig input: start - oxygen input - iron oxide fume waste But decreases open hearth melt time, and per ton of crude steel: decrease - furnace wastes, especially slag - oil input	10
158	Per average ton of cast steel: increase - oxygen input - iron oxide fume waste	2
159	Per ton of pig iron: start - oxygen input increase - BF carbon monoxide waste - BF dust waste But reductions in coke rate mean that, per ton of pig iron: decrease - coal input (as coke) - coking wastes	14
161	Per ton of cast steel: increase - oxygen input - wastes of iron oxide fume, carbon monoxide and other fume decrease - coal input (as coke) - coking wastes	14
162	Per ton of pig iron: decrease - sulphur oxide wastes increase - liquid BF wastes, especially suspended solids, ammonia and cyanides	4
163	Per ton of coke: decrease - sulphur oxide wastes	1

164	In steel billet cleaning: start - oxygen input increase - fume wastes	2
165	Per ton of coke: decrease - gaseous wastes increase - liquid wastes, especially phenols, suspended solids, cyanides, ammonia	10
166	Per ton of coke: decrease - waste phenols	1
169	Per unit of steel product: decrease - sulphuric acid waste	1
170	In tinplating: decrease - sodium dichromate waste	1
171	In sheet steel rolling: decrease - coal combustion wastes increase - electricity production wastes	(14)
172	Increases in furnace efficiency means that, per ton of crude steel: decrease - open hearth furnace wastes - oil input - iron ore input (as pig iron) - BF wastes - ore preparation wastes - coal input (as BF coke) - coking wastes - other BF inputs	36
173	Per ton of crude steel: decrease - sulphur oxide waste	1

174	Per unit of steel product: decrease - acidity of pickling wastes	1
175	Per ton of coke: start - input of iron oxide decrease - hydrogen sulphide waste	2
176	Per unit of steel billet: decrease - fume wastes	1
178	Per ton of pneumatic steel: decrease - fume wastes	1
179	Per ton of open hearth steel: decrease - fine fume wastes, especially iron oxide	1
180	As innovation 179, for electric arc steel	1
181	Per ton of electric arc steel: decrease - particulate matter wastes increase - liquid wastes	(4)

Those broader classes of wastes or inputs used above are described in greater detail below. Given in brackets are the known or estimated numbers of separate inputs or wastes in the class.

(1) Ore preparation wastes (3). Either calcination (dust, smoke, fluorine) or sintering (fume, dust, sulphur oxides).

(2) Pickling wastes (2). Dissolved metals and acids.

(3) Coking wastes (10). Composed of (a) gaseous (sulphur oxides, smoke, hydrogen sulphide, particulate matter), (b) liquids (phenols, oil, tar, suspended solids, ammonia, cyanides).

(4) Blast furnace wastes (9). Composed of (a) slag, (b) gaseous (smoke, carbon monoxide, sulphur oxides, particulate matter, nitrogen oxides), (c) liquids (suspended solids, cyanides, ammonia).

(5) Coal combustion wastes, where used as source of direct heat or steam power (7), smoke, carbon monoxide, particulate matter, sulphur oxides, tar, ash, nitrogen oxides.

(6) Charcoal production wastes (3), smoke, carbon monoxide, nitrogen oxides.

(7) Charcoal combustion wastes (4) estimate, includes ash.

(8) Producer gas production wastes (4) estimate.

(9) Producer gas combustion wastes (4) estimate.

(10) Electricity production wastes, will vary according to basic input used as source (7) estimate.

(11) Milling wastes (9). composed of (a) fuel combustion (7), and (b) processing wastes - oil, millscale (2).

(12) Crude steel furnace wastes (11). composed of (a) slag, (b) liquids (3) estimate, (c) fuel combustion wastes (7).

(13) Other blast furnace inputs (apart from ore and coke in charge). For operations such as charging, blowing, blast heating, tapping and casting (5). Combinations of different basic inputs including gravity, water power, animal power, human labour power, coal, oil, natural gas.

(14) Puddling wastes (8) slag plus coal combustion.

(15) Tinplating wastes (10) fuel combustion (7) plus acids, chromates, oil.

(16) Fettling wastes (3) estimate.

(17) Galvanising wastes (3) estimate.

(18) Steel furnace inputs (5). Pig iron, steel scrap, flux, basic power source, additions such as oxygen, steam etc.

(19) Oil combustion wastes (3) sulphur oxides, nitrogen oxides, carbon monoxide.

(20) Puddling inputs (3) coal, pig iron, human labour power.

In the right hand column of table 2.2, an attempt has been made to identify roughly the number of separate impacts associated with each innovation. Where total impact frequencies are shown in brackets, the innovations affected broad classes of inputs or wastes where numbers of separate, individual inputs or wastes are estimated rather than known.

Table 2.3 - Classification of innovations according to aspects of environmental change

Industry sector - BF blast furnace and input preparation
- CI cast iron
- WIP wrought iron production
- WIT wrought iron products and processing (treatment)
- SP steel production
- ST steel products and processing (treatment)

Environmental change
- QL qualitative } A
- QT quantitative } A
- IO improvement only } B
- DO deterioration only } B
- B both } B
- MAJI major improvement } C
- MINI minor improvement } C
- MAJD major deterioration } D
- MIND minor deterioration } D

Innovation code	Industry sector	Environmental change			
		A	B	C	D
006	BF	QL	B	MINI	MAJD
007	SP	QL	B	MINI	MAJD
008	BF	QL	DO		MAJD
009	BF	QT	IO	MAJI	
010	WIP	QT	B	MAJI	MAJD
011	WIT	QL	DO		MAJD
012	CI	QL	B	MINI	MAJD
013	BF	QT	IO	MAJI	
014	BF				
015	BF				
016	BF	QT	IO	MAJI	
017	BF,WIP	QT	IO	MAJI	
018	WIP	QT	IO	MINI	
019	WIP	QL	DO		MAJD

020	WIP,WIT	QT	IO	MAJI	
021	BF	QT	IO	MAJI	
022	BF	QT	B	MAJI	MIND
023	WIT	QL	B	MINI	MAJD
024	SP	QT	B	MAJI	MIND
025	SP				
026	SP	QL	DO		MIND
027	ST				
028	*				
029	SP	QL	B	MAJI	MAJD
030	SP	QT	B	MINI	MIND
031	ST				
032	ST	QT	IO	MINI	
033	BF	QT	IO	MAJI	
034	BF				
035	BF	QL	IO	MINI	
036	BF	QL	B	MAJI	MIND
037	BF	QL	B	MAJI	MIND
038	BF	QL	B	MAJI	MIND
039	BF	QL	IO	MINI	
040	ST	QL	B	MINI	MIND
041	ST	QT	IO	MINI	
042	ST	QT	IO	MINI	
043	CI				
044	CI				
045	CI				
046	CI				
047	CI				
048	ST				
049	ST				
050	ST				
051	ST	QL	B	MAJI	MIND
052	*				
053	SP	QL	B	MAJI	MIND
054	ST				
055	ST	QL	B	MAJI	MAJD
056	BF	QT	IO	MINI	

057	BF	QL	B	MAJI	MAJD
058	SP	QL	B	MINI	MAJD
059	SP				
060	ST	QT	IO	MAJI	
061	BF	QL	B	MINI	MAJD
062	BF	QL	B	MINI	MAJD
063	WIP				
064	ST				
065	ST	QT	IO	MINI	
066	ST	QT	IO	MINI	
067	SP				
068	SP				
069	SP				
070	WIP				
071	WIT				
072	WIT	QL	DO		MAJD
073	*				
074	WIT	QL	DO		MAJD
075	*				
076	BF	QT	B	MAJI	MAJD
077	ST				
078	WIT	QT	IO	MAJI	
079	WIT				
080	WIT	QT	IO	MAJI	
081	WIT	QT	IO	MINI	
082	WIT				
083	*				
084	WIT	QL	B	MAJI	MIND
085	WIT				
086	WIT	QT	IO	MAJI	
087	ST				
088	ST				
089	ST				
090	ST				
091	SP				
092	ST				
093	ST				

094	ST	QL	DO		MAJD
095	ST				
096	ST				
097	ST				
098	BF	QL	B	MAJI	MIND
099	*				
100	SP	QT	B	MINI	MAJD
101	SP	QL	B	MINI	MAJD
102	SP	QL	B	MINI	MIND
103	WIT	QL	DO		MAJD
104	WIT,ST	QL	DO		MAJD
105	CI	QL	B	MAJI	MAJD
106	BF	QL	DO		MAJD
107	WIP	QL	B	MAJI	MAJD
108	WIP	QL	B	MINI	MAJD
109	WIP	QL	IO	MINI	
110	WIP				
111	WIP				
112	WIP	QT	IO	MAJI	
113	WIP	QT	IO	MAJI	
114	BF	QT	IO	MINI	
115	SP	QT	B	MINI	MIND
116	SP				
117	BF	QT	IO	MINI	
118	BF	QT	IO	MINI	
119	BF	QT	IO	MAJI	
120	SP	QT	DO		MIND
121	SP	QT	IO	MAJI	
122	SP				
123	SP	QT	IO	MAJI	
124	SP	QL	B	MINI	MIND
125	SP	QL	B	MINI	MAJD
126	BF	QL	DO		MAJD
127	SP	QT	IO	MINI	
128	SP	QT	IO	MAJI	
129	ST				
130	ST				

131	ST				
132	ST				
133	ST				
134	SP				
135	SP	QT	DO		MAJD
136	SP	QT	B	MINI	MIND
137	SP				
138	SP	QT	DO		MIND
139	SP	QT	B	MINI	MIND
140	SP	QT	DO		MIND
141	WIP	QL	B	MAJI	MIND
142	WIT	QL	DO		MAJD
143	WIT				
144	WIT	QT	B	MAJI	MIND
145	BF	QT	IO	MAJI	
146	ST				
147	BF	QT	IO	MAJI	
148	SP				
149	SP				
150	ST				
151	ST				
152	BF	QT	IO	MINI	
153	ST				
154	ST				
155	BF	QT	IO	MINI	
156	BF	QT	IO	MAJI	
157	SP	QL	B	MINI	MIND
158	SP	QL	DO		MIND
159	BF	QL	B	MINI	MAJD
160	BF				
161	SP	QL	B	MINI	MAJD
162	BF	QT	B	MAJI	MIND
163	BF	QT	IO	MAJI	
164	ST	QL	B	MINI	MAJD
165	BF	QT	B	MAJI	MAJD
166	BF	QT	IO	MAJI	

167	*				
168	*				
169	ST	QT	IO	MAJI	
170	ST	QT	IO	MAJI	
171	ST	QL	B	MAJI	MIND
172	SP	QT	IO	MINI	
173	SP	QT	IO	MINI	
174	ST	QL	IO	MAJI	
175	BF	QL	IO	MAJI	
176	ST	QT	IO	MAJI	
177	SP				
178	SP	QT	IO	MAJI	
179	SP	QT	IO	MAJI	
180	SP	QT	IO	MAJI	
181	SP	QT	IO	MAJI	

*innovations not fitting into six main categories

Table 2.4 - Unit input levels

	OLD INPUTS			NEW INPUTS			SCRAP INPUTS		
	Cwts iron ore/ ton pig iron	Cwts coke /ton pig iron	Cwts solids /ton pig iron	m^3 oxygen/ million tons iron & steel	Cwts sinter /ton pig iron	Gwh elec- tricity/ million tons iron & steel	Cwts iron scrap /ton pig iron	Cwts total scrap /ton iron & steel	Cwts steel scrap /ton crude steel
1920	47.6	28.1	60.6						8.8
21	42.9	26.5	56.4						11.4
22	41.8	26.1	55.3						12.2
23	44.3	26.0	56.4						11.0
24	46.2	25.8	57.5						10.2
25	47.3	25.5	58.8						10.4
26	46.5	25.4	57.8						11.2
27	45.8	24.9	57.5						10.8
28	46.7	24.8	58.3						11.0
29	47.4	24.9	58.9						10.4
30	48.7	24.8	59.8						11.2
31	50.1	24.7	60.9						12.0
32	50.0	24.1	60.6						12.8
33	47.1	23.2	57.4						12.8
34	47.5	23.0	55.6						12.2
35	46.6	22.3	56.3						12.0
36	45.9	22.4	55.9						11.6
37	46.6	22.9	56.7						11.6
38	47.6	22.6	57.2						11.8
39	42.0	22.0	55.0		4.8		0.96		11.2
40	43.5	23.4	59.1		5.9		0.93	9.6	11.0
41	46.3	24.7	62.9		6.5		1.28	9.4	11.2
42	46.0	24.8	62.8		6.3		1.68	10.6	11.8
43	44.8	24.4	61.9		6.5		1.99	10.8	12.4
44	43.8	23.0	60.9		6.7		1.80	9.6	12.2
45	41.2	22.1	56.9		6.5		1.54	9.0	12.2
46	38.2	22.0	53.4		5.9		1.46	9.4	12.2
47	37.3	21.5	51.8		5.6		1.44	9.6	12.2

1948	36.7	21.0	51.2		6.0	152	1.42	11.0	12.2
49	35.5	20.6	50.6		6.4	153	1.67	11.2	12.6
50	34.6	21.3	50.2		6.9	160	1.89	11.2	12.6
51	35.9	21.4	51.8		7.3	168	1.69	9.8	11.6
52	35.9	21.2	52.6		8.1	176	1.41	9.4	11.0
53	35.4	20.0	52.7		8.5	172	1.39	9.2	11.2
54	32.4	19.7	50.7		9.9	177	1.46	9.6	11.2
55	29.3	19.7	49.9		12.4	193	1.34	10.0	11.2
56	30.0	19.0	50.1		11.7	193	1.32	9.4	10.8
57	28.2	17.9	49.3		12.9	199	1.34	9.4	10.6
58	25.2	16.8	47.6	3.8	14.3	196	1.71	9.0	11.4
59	20.9	16.5	46.3	5.5	18.0	204	1.76	8.8	10.6
60	19.1	16.4	45.5	7.5	18.8	230	1.85	10.0	10.4
61	17.9	15.5	45.1	8.2	19.8	222	1.87	9.0	10.4
62	14.0	14.4	43.8	12.7	22.9	223	2.07	8.2	10.2
63	11.3	14.0	41.7	17.2	24.2	249	2.09	8.8	10.4
64	10.8	13.3	40.8	20.7	24.3	272	1.93	9.8	10.2
65	9.8	12.8	39.5	24.5	24.4	282	1.87	9.6	10.2
66	9.3	12.5	38.3	23.6	24.4	259	1.87	9.0	10.4
67	8.4	12.5	37.6	25.2	24.8	253	1.92	8.8	10.6
68	8.9	12.4	37.2	27.6	24.4	271	1.61	9.2	10.6
69	8.9	11.9	36.5	25.8	22.8	288	1.39	9.6	10.6
70	9.0	11.2	36.2	28.1	22.7	306	1.32	10.2	10.8
71	8.5	11.2	35.9	31.0	23.3	266	1.34	9.0	10.6
72	9.3	11.7	35.5	30.6	22.3	262	1.12	9.4	10.8
73	10.6	11.7	35.0	29.2	20.5	308	0.72	9.6	10.4
74	10.4	11.7	34.5	28.2	19.7	293	0.79	9.0	10.4
75	9.0	11.7	35.3	25.8	22.1	295	0.98	8.8	11.2
76	9.9	11.6	35.1	26.6	21.3	353	0.72	10.0	11.0
77	10.0	11.4	35.0	26.4	21.2	360	0.70	9.8	11.6
78	6.6	11.3	34.4	26.3	25.4	378	0.15	11.2	11.6
79	6.4	11.4	34.0	28.0	25.6	378	0.08	11.8	11.0
80	8.8	11.2	32.5	26.1	22.0		0.10		
81	11.0				19.9				

Table 2.5 - Gross consumption levels

	OLD INPUTS			NEW INPUTS			SCRAP INPUTS		
	Million tons iron ore	Million tons BF coke	Million tons BF solids	Million cubic metres oxygen	Million tons BF sinter	Thousand Gwh electricity	Million tons iron scrap	Million tons total scrap	Million tons steel scrap
1920	19.8	11.3	25.1						4.0
21	5.6	3.5	7.3						2.1
22	10.2	6.4	13.6						3.6
23	16.4	9.7	20.9						4.7
24	16.9	9.4	21.0						4.2
25	14.9	8.0	18.5						3.8
26	5.8	3.1	7.2						2.0
27	16.7	9.1	21.0						4.9
28	15.4	8.2	19.3						4.7
29	18.0	9.5	22.4						5.0
30	15.1	7.7	18.5						4.1
31	9.5	4.7	11.6						3.1
32	9.0	4.3	10.9						3.4
33	9.7	4.8	11.8						4.5
34	14.3	6.8	16.7						5.4
35	14.9	7.2	18.0						5.9
36	17.7	8.7	21.6						6.9
37	19.8	9.7	24.1						7.5
38	16.2	7.8	19.4						6.1
39	16.8	9.0	22.0		1.9		0.38		7.4
40	17.9	9.9	24.3		2.4		0.38	9.7	7.2
41	17.2	9.3	23.3		2.4		0.47	9.4	6.9
42	17.7	9.7	26.5		2.4		0.65	10.5	7.6
43	16.1	8.8	22.3		2.4		0.72	10.9	8.0
44	14.7	8.2	20.4		2.3		0.60	9.9	7.4
45	14.6	8.2	20.2		2.3		0.55	9.4	7.2
46	14.9	8.6	20.8		2.3		0.57	10.1	7.7
47	14.6	8.4	20.2		2.2		0.56	10.6	7.7

1948	17.1	10.0	23.8		2.8	3.5	0.66	12.5	9.1
49	16.9	10.0	24.0		3.0	3.7	0.79	13.4	9.8
50	16.6	9.9	24.1		3.3	4.1	0.91	14.1	10.3
51	17.5	10.3	25.1		3.5	4.5	0.82	13.0	9.1
52	19.3	11.3	28.1		4.4	4.9	0.75	13.2	9.1
53	19.8	11.9	29.6		4.7	5.1	0.78	13.6	9.8
54	19.3	11.9	30.2		5.9	5.4	0.87	14.4	10.3
55	18.4	12.3	31.3		7.7	6.0	0.84	15.4	11.1
56	19.8	13.1	33.1		7.7	6.3	0.87	15.5	11.2
57	20.2	13.6	35.3		9.3	6.7	0.96	15.8	11.5
58	16.4	11.4	30.9	132	9.3	6.7	1.11	15.6	11.1
59	13.2	10.5	29.2	194	11.4	7.2	1.11	15.4	10.8
60	14.2	13.0	36.0	274	14.8	8.4	1.46	18.1	12.7
61	13.3	12.1	37.9	309	14.7	8.3	1.38	16.7	11.5
62	9.6	10.6	30.0	481	15.7	8.5	1.42	15.7	10.5
63	8.3	10.5	30.5	655	17.7	9.6	1.53	17.2	11.7
64	9.3	11.8	35.3	821	21.1	10.8	1.67	19.6	13.4
65	8.6	11.9	34.7	981	21.3	11.3	1.64	20.1	13.9
66	7.4	10.6	30.1	966	19.2	10.6	1.47	18.6	12.7
67	6.4	9.9	28.6	1044	20.1	10.5	1.46	18.3	12.6
68	7.4	10.8	30.5	1155	19.3	11.3	1.32	19.2	13.7
69	7.4	10.7	30.0	1079	20.4	12.0	1.14	20.1	14.4
70	7.8	10.6	31.5	1148	18.2	12.5	1.15	20.9	15.1
71	6.5	9.3	27.4	1238	17.4	10.6	1.02	17.8	12.5
72	7.1	8.8	26.9	1204	17.6	10.3	0.85	18.5	13.5
73	8.8	9.9	29.1	1122	14.1	11.8	0.60	18.6	13.6
74	7.1	8.3	23.7	1046	13.6	10.9	0.54	16.6	12.0
75	5.4	7.2	21.1	924	15.0	10.6	0.59	15.8	11.0
76	6.8	8.3	23.9	887	13.2	11.6	0.49	16.8	12.0
77	6.0	7.3	21.0	844	14.8	11.5	0.42	15.5	11.7
78	3.7	6.6	19.4	824	16.8	11.8	0.08	15.3	11.6
79	4.1	7.4	21.6	945	7.0	12.8	0.05	15.2	11.6
80			10.1	451		8.5			6.7
81				814		9.2			8.1
82				694		8.4			

Table 2.6 – Materials inputs variables: data sources and/or computations

	Unit input levels (UI)	Gross consumption level (GC)
Iron ore	Ref: 26, Ref: 8	UI x pig output
Coke	Ref: 26	ref: 4 (1921-80)
BF solids	Ref: 26	UI x pig output
Oxygen	GC/I&S output	Ref: 26
Sinter	Ref: 26, Ref: 8	Ref: 26
Electricity	GC/I&S output	Ref: 26
Iron scrap	Ref: 26	UI x pig output
Total scrap	GC/I&S output	Ref: 26
Steel scrap	GC/steel output	Ref: 26

As we can see, only three outputs were needed in computations - pig iron, crude steel and iron & steel. Annual output levels of pig iron were taken from ref: 8 (pp 346, 366, 429, 484, 596) and ref: 4 (1955, 61, 71, 81). Annual output levels for crude steel were taken from ref: 24 (p 193), ref: 8 (pp 366, 429, 484, 596) and ref: 4 (1971, 82). Where inputs were used in the production of both iron and steel, as well as for some processing operations, and all we have is total industry consumption (eg oxygen), we don't know how much was used in each sector, and so it is not clear what output to use in computing unit input levels. In these cases the aggregate of iron & steel output was used (calculated by simple addition of annual output levels of pig iron and crude steel). Clearly, since some pig iron is used in crude steel production, the output side of the ratio will be overstated in these cases. But we still have a consistent physical ratio with which to pick up any significant variations over time in unit input levels.

Table 2.7 – Analyses of residuals sequences

			Positive residuals	Negative residuals	Runs	Z[1]	Significance level[2]
fIM		Impact potential	11	16	13	-.43	
fQL			12	15	12	-.93	.20
fQT			15	12	9	-2.12	.02
fIO			12	15	10	-1.73	.05
fDO			11	16	14	-.02	
fAI			14	13	15	+.20	
fAD			12	15	13	-.53	
fMAJI			12	15	15	+.27	
fMINI			10	17	8	-2.36	.02
fMAJD			7	20	10	-.71	
fMIND			11	16	7	-2.86	.01
fMAJ			14	13	15	+.21	
fMIN			15	12	9	-2.12	.02
Ore	OLD	Unit input level	33	27	4	-7.02	.01
Coke			24	36	8	-5.92	.01
BF solids			32	28	5	-6.77	.01
Oxygen	NEW		11	11	3	-3.93	.01
Sinter			19	22	4	-5.54	.01
Electricity			16	16	11	-2.16	.05
Iron	SCRAP		19	22	7	-4.58	.01
Total			13	27	14	-1.67	.10
Steel			30	30	15	-4.17	.01

[1] where negative Z scores indicate a tendency towards clustering and positive Z scores indicate a tendency towards dispersion

[2] blank if not significant at .20 level

Ore	OLD	Gross consumption	31	29	8	-5.98	.01
Coke			34	26	14	-4.37	.01
BF solids			34	26	14	-4.37	.01
Oxygen	NEW		12	10	3	-3.93	.01
Sinter			14	27	3	-5.79	.01
Electricity			12	20	5	-4.23	.01
Iron	SCRAP		18	23	5	-5.21	.01
Total			23	17	5	-5.10	.01
Steel			35	25	20	-2.73	.01

Table 2.8 - Period and cycle lengths in various aspects of the potential for environmental change

	High Periods			
	1	2	3	Mean
fAI	31	20	37	29
fAD	26	32	16	25
fIO	22	35	29	29
fDO	26	37	22	28
fQL	33	42	18	31
fQT	23	25	28	25
Mean	27	32	25	28
	Low Periods			
	1	2	3	Mean
fAI	36	17	51	35
fAD	36	22	35	31
fIO	35	13	58	35
fDO	31	17	32	27
fQL	30	22	27	26
fQT	36	31	50	39
Mean	34	20	42	32
Cycle Mean	61	52	67	60

Period lengths based on boundaries given in figures 2.13 to 2.15 in annex 2.

Table 2.9 - Dates of boundaries between periods of high and low impact potential

	A	B	C
fQL	1910	1937	61
fQT	1891	1941	71*
fIO	1884	1942	75*
fDO	1903	1937	70*
fAI	1890	1941	69*
fAD	1903	1938	63*
fMAJ	1902	1943	65*
fMIN	1904	1938	62*
fMAJI	1908	1951	70*
fMINI	1891	1936	65*
fMAJD	1852	1935	62*
fMIND	1910	1948	60
Mean	1896	1941	1966

*Estimated from plots

2G Annex 2: Plotted data

Figure 2.13 - Variations in the potentials for qualitative and quantitative change

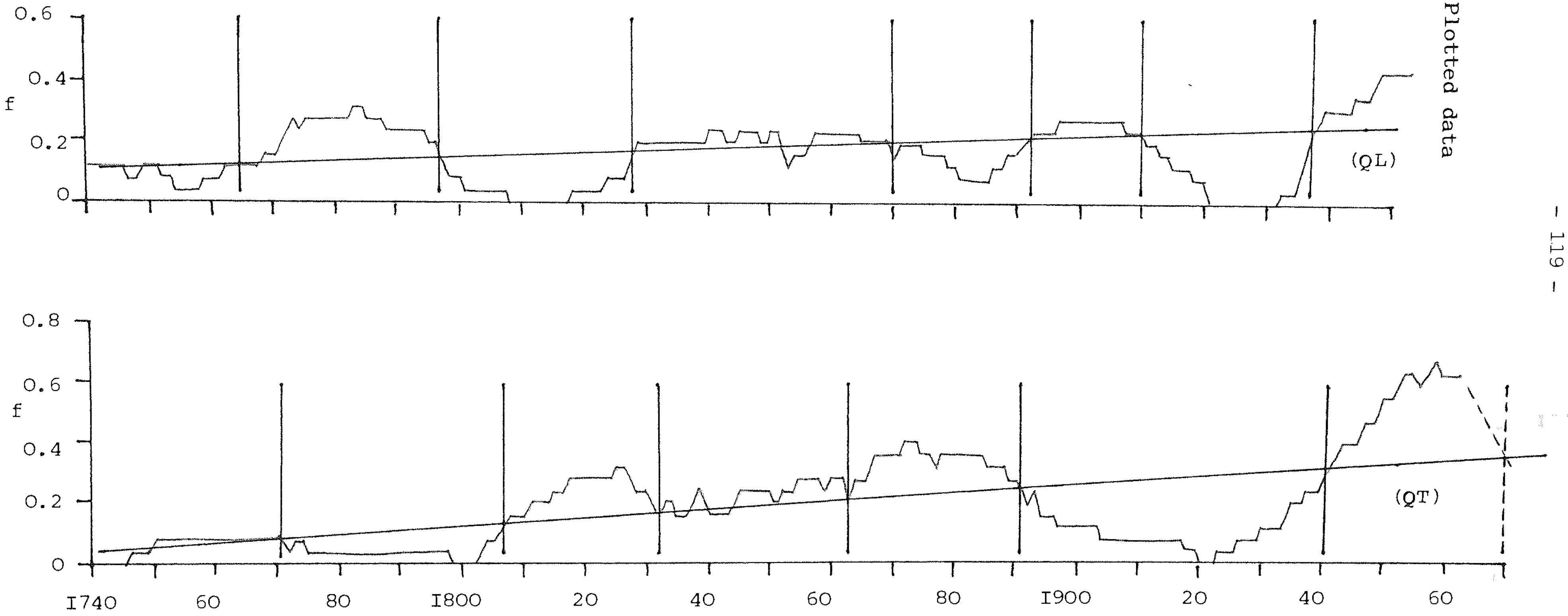


Figure 2.14 – Variations in the potentials for improvement only and deterioration only

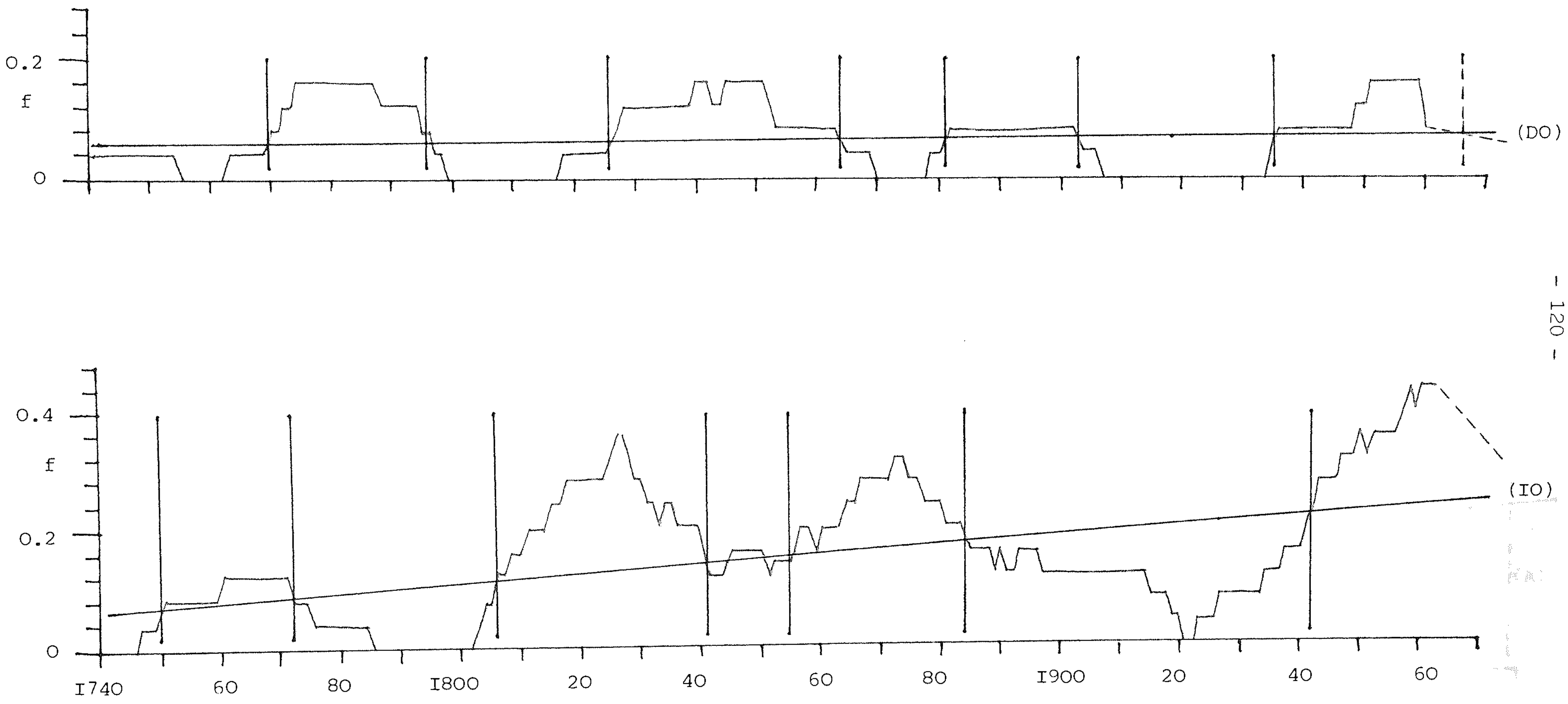


Figure 2.15 - Variations in the potentials for any improvement and any deterioration

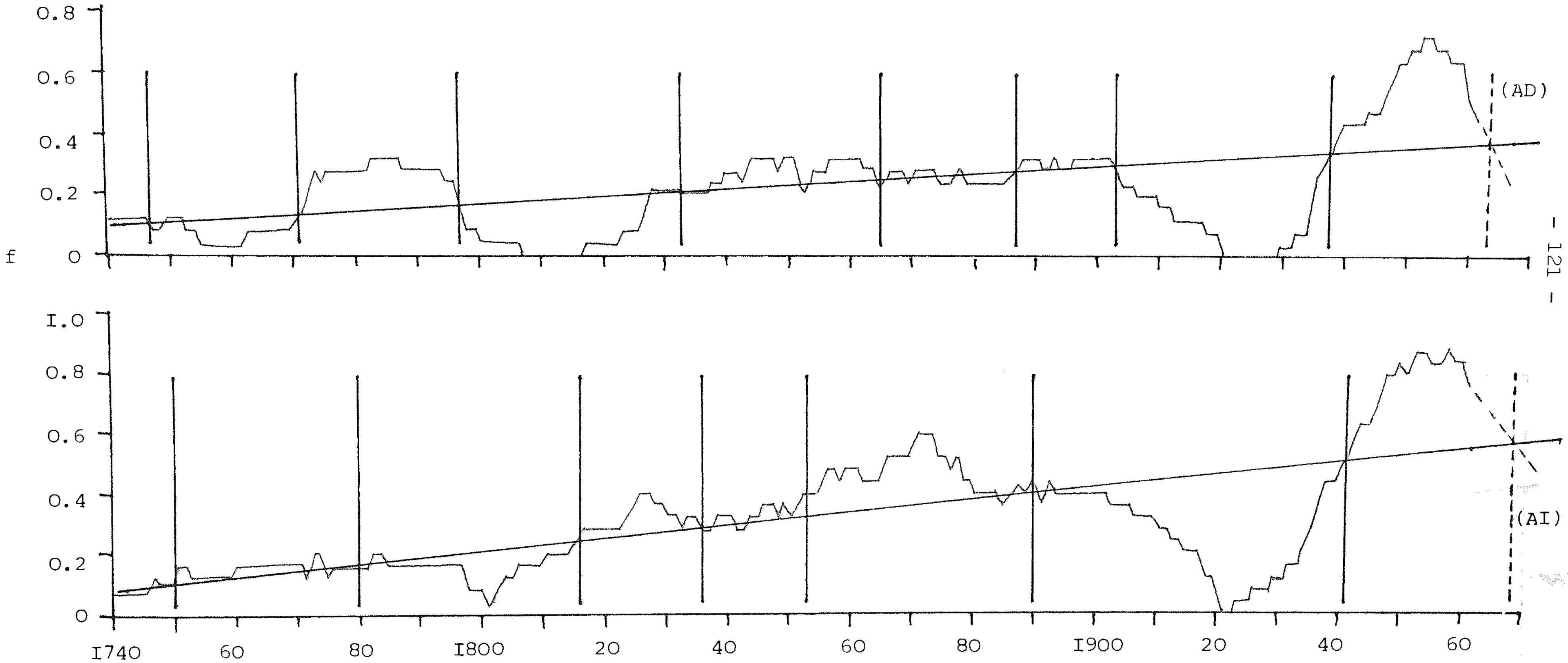


Figure 2.16 - Varations in the potentials for major improvements and minor improvements

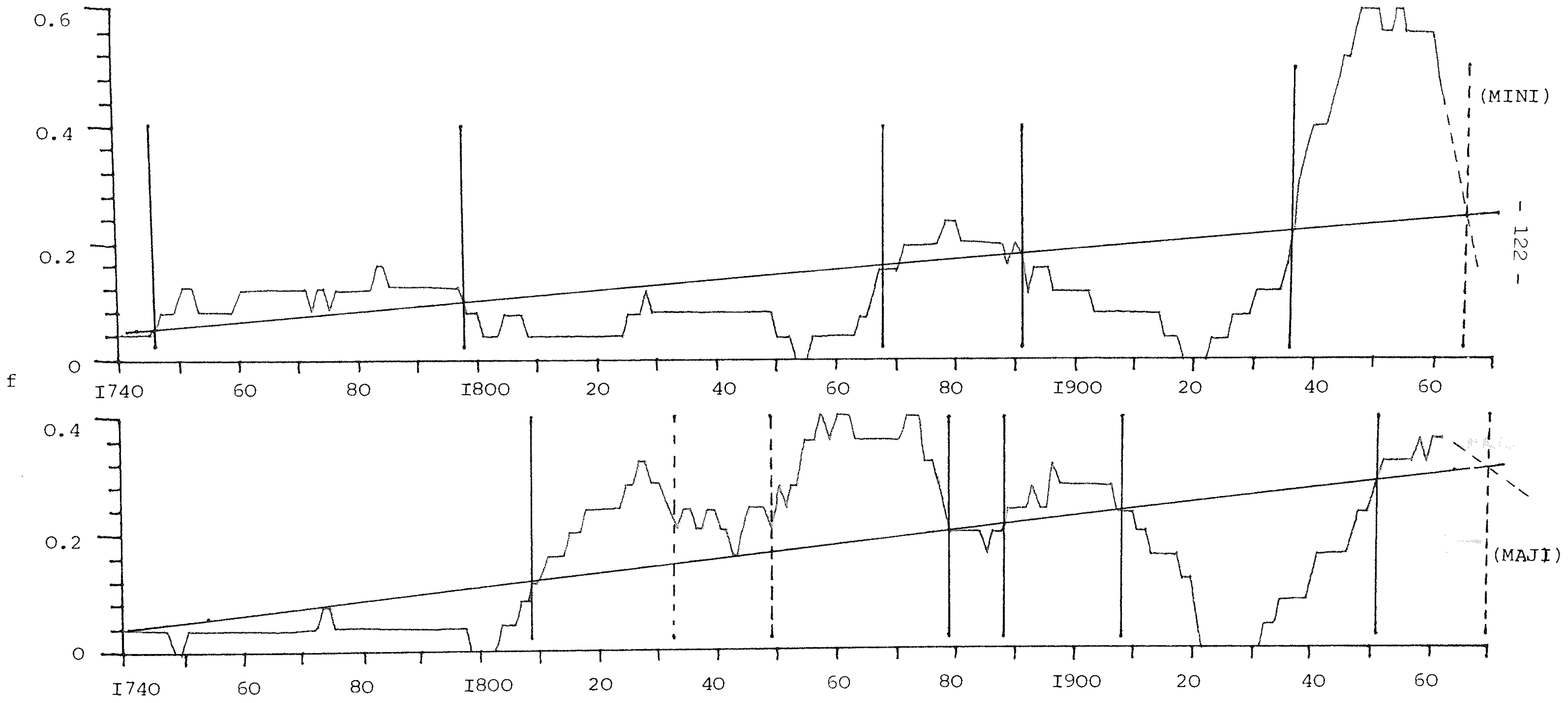


Figure 2.17 - Variations in the potentials for major deterioration and minor deterioration

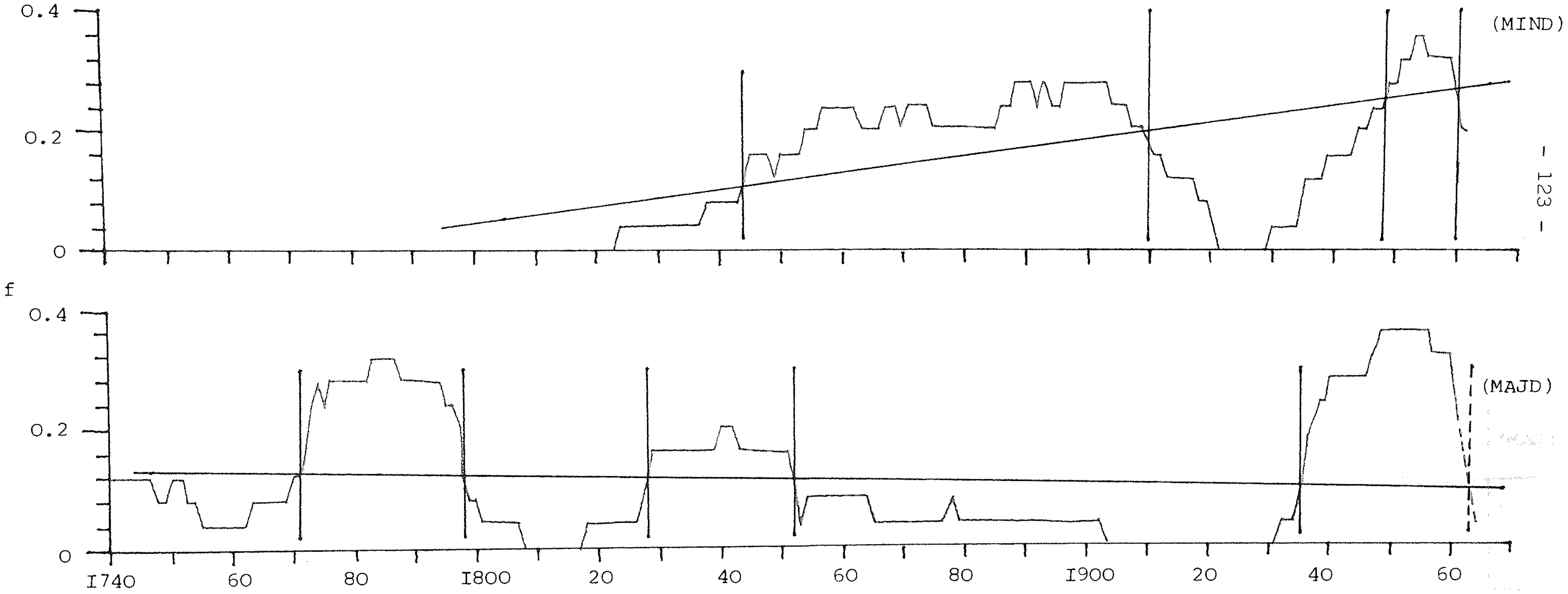
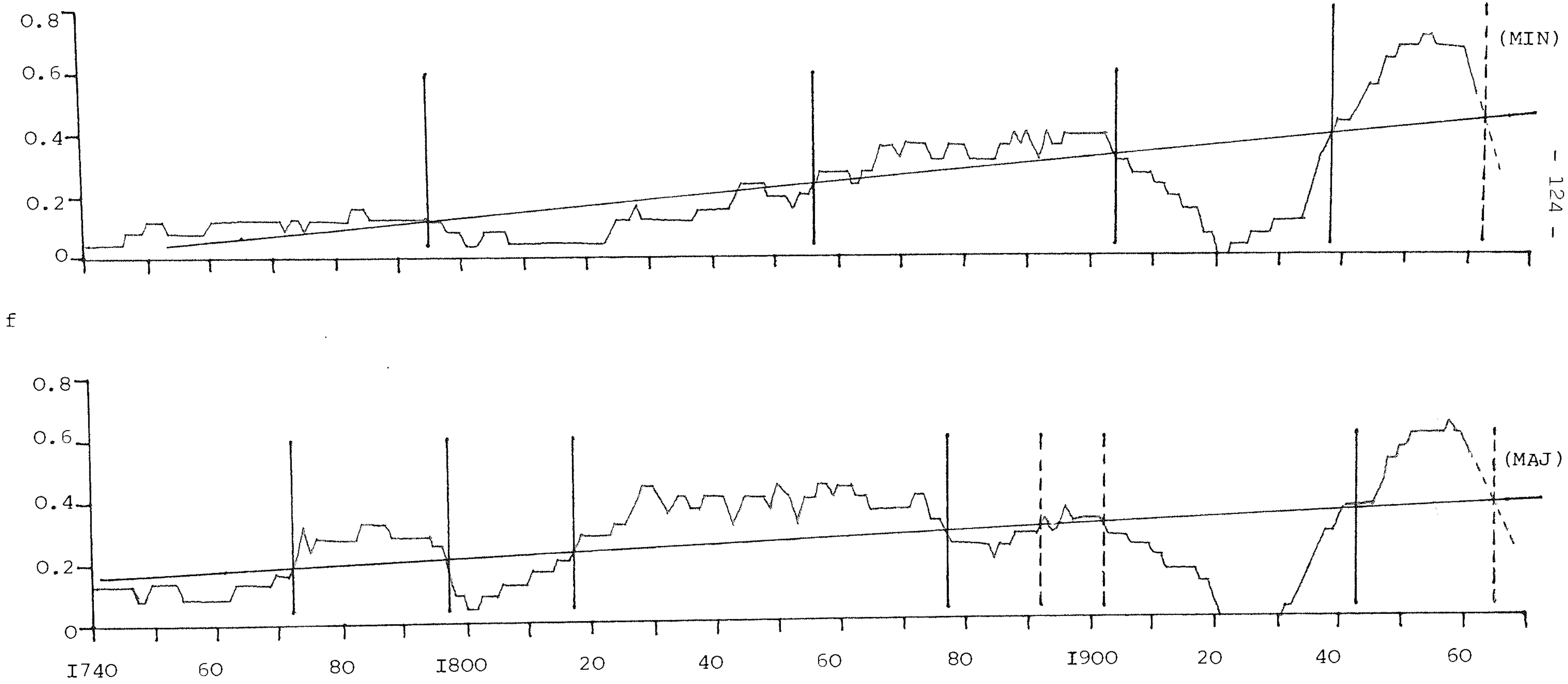


Figure 2.18 - Variations in the potentials for all major and all minor environmental changes



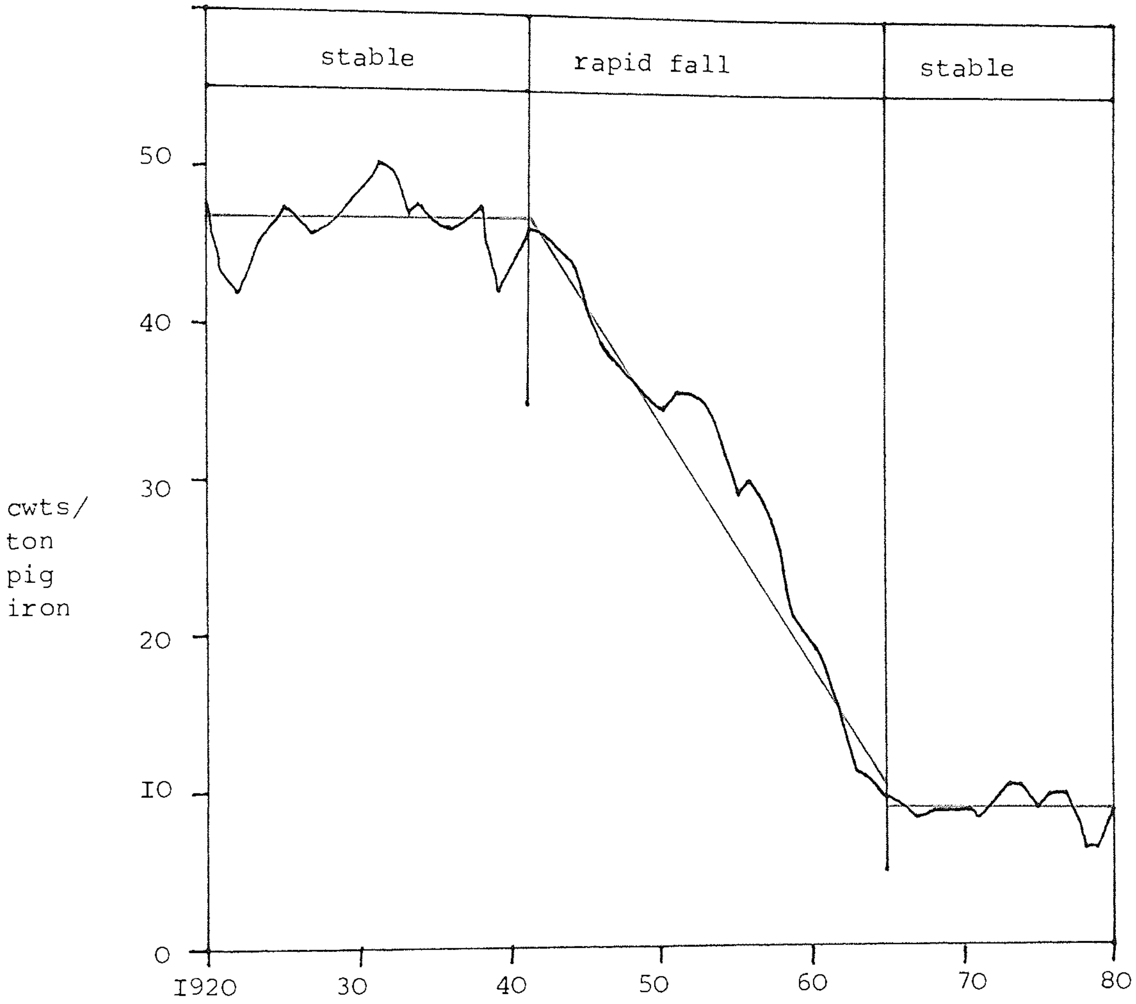


Figure 2.19 - Variations in unit input levels of iron ore

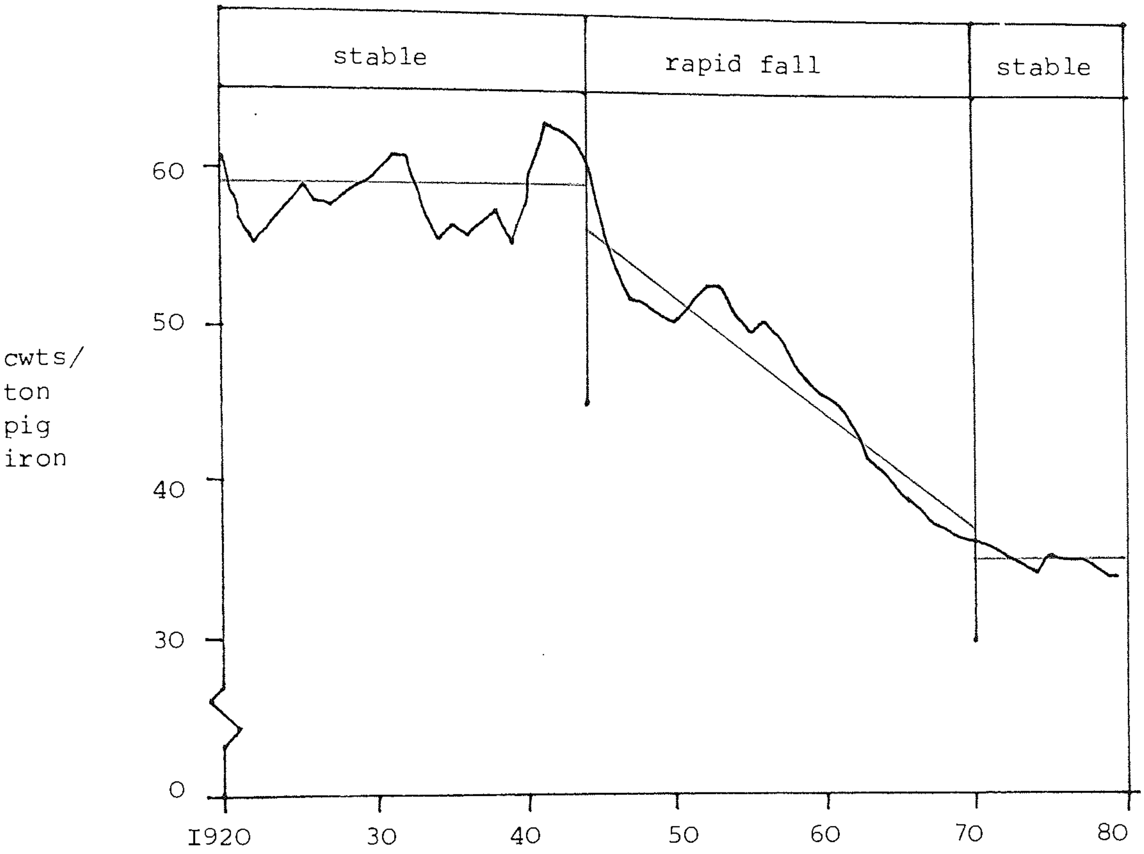


Figure 2.20 - Variations in unit input levels of blast furnace solids

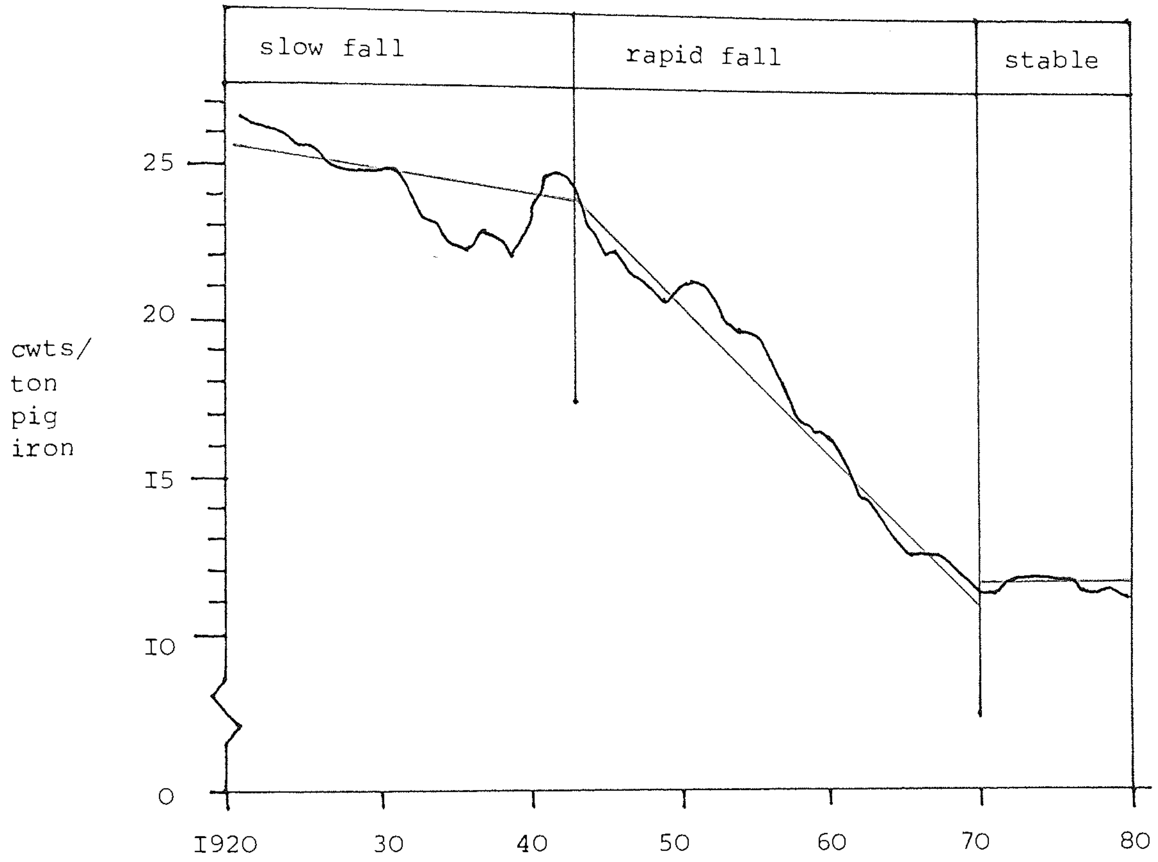


Figure 2.21 - Variations in unit input levels of coke

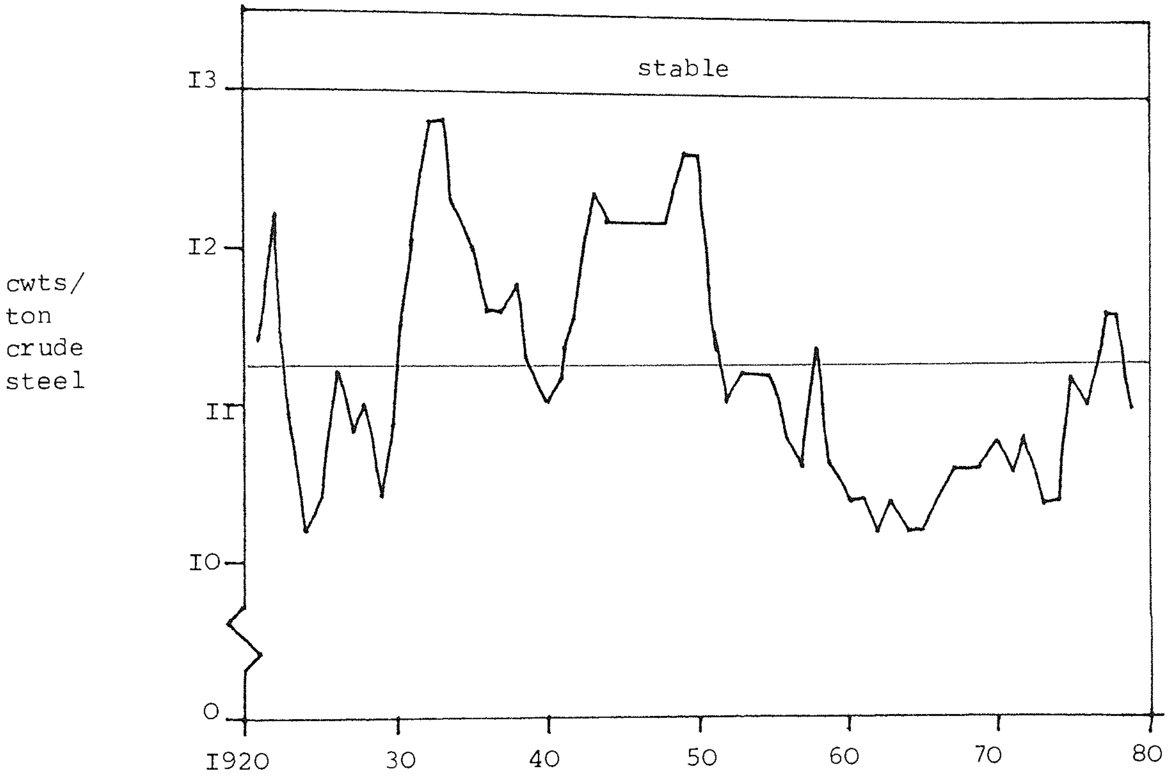


Figure 2.22 - Variations in unit input levels of steel scrap

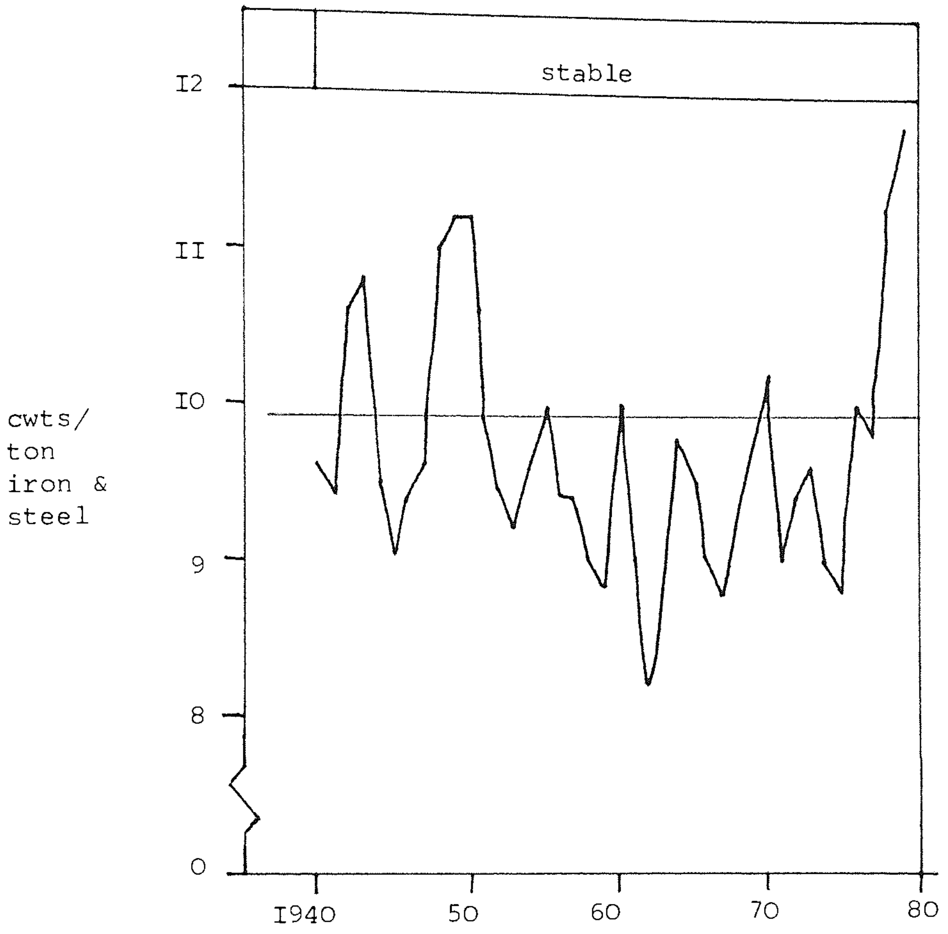


Figure 2.23 - Variations in unit input levels of total scrap

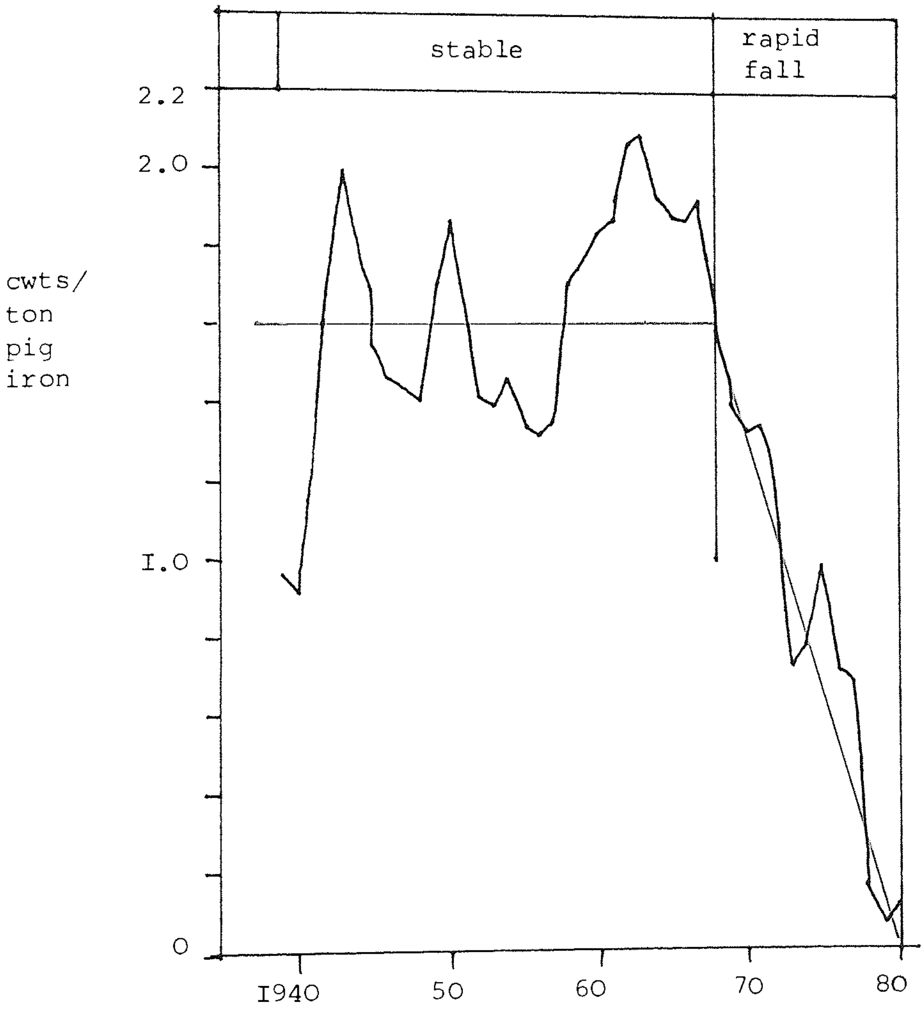


Figure 2.24 - Variations in unit input levels of iron scrap

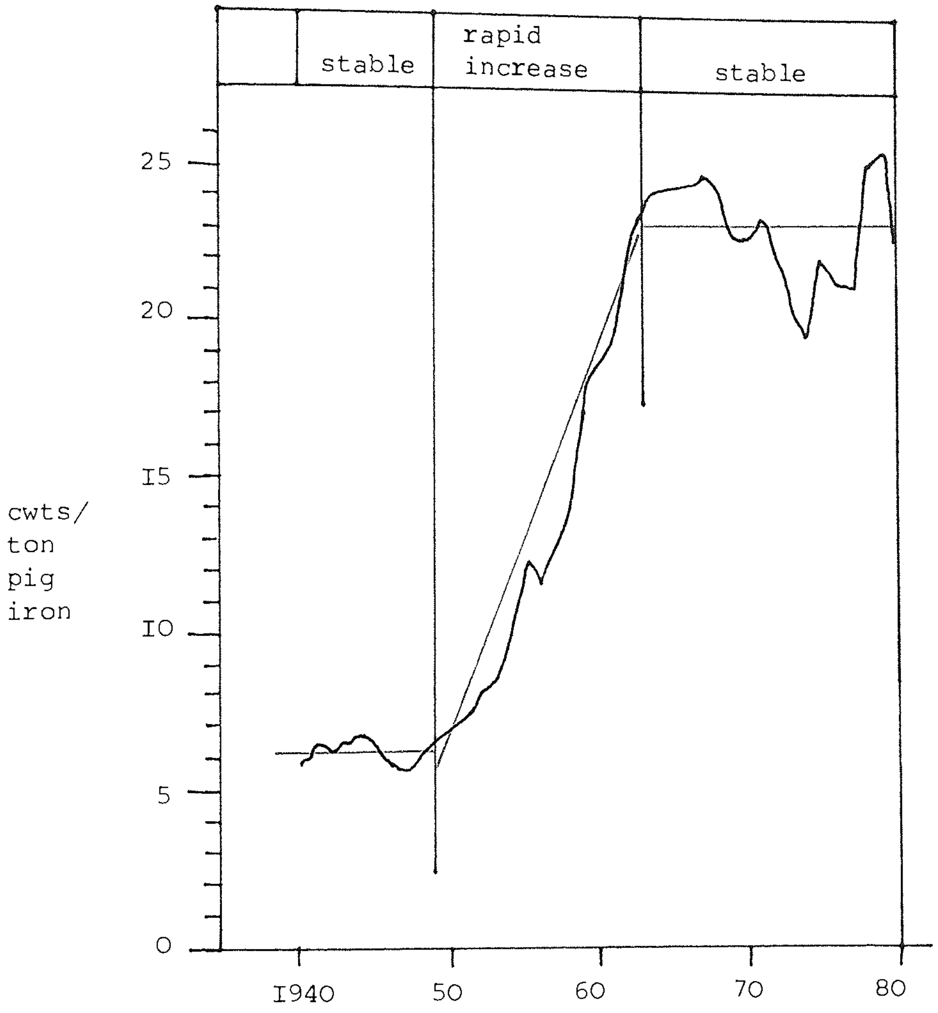


Figure 2.25 - Variations in unit input levels of sinter

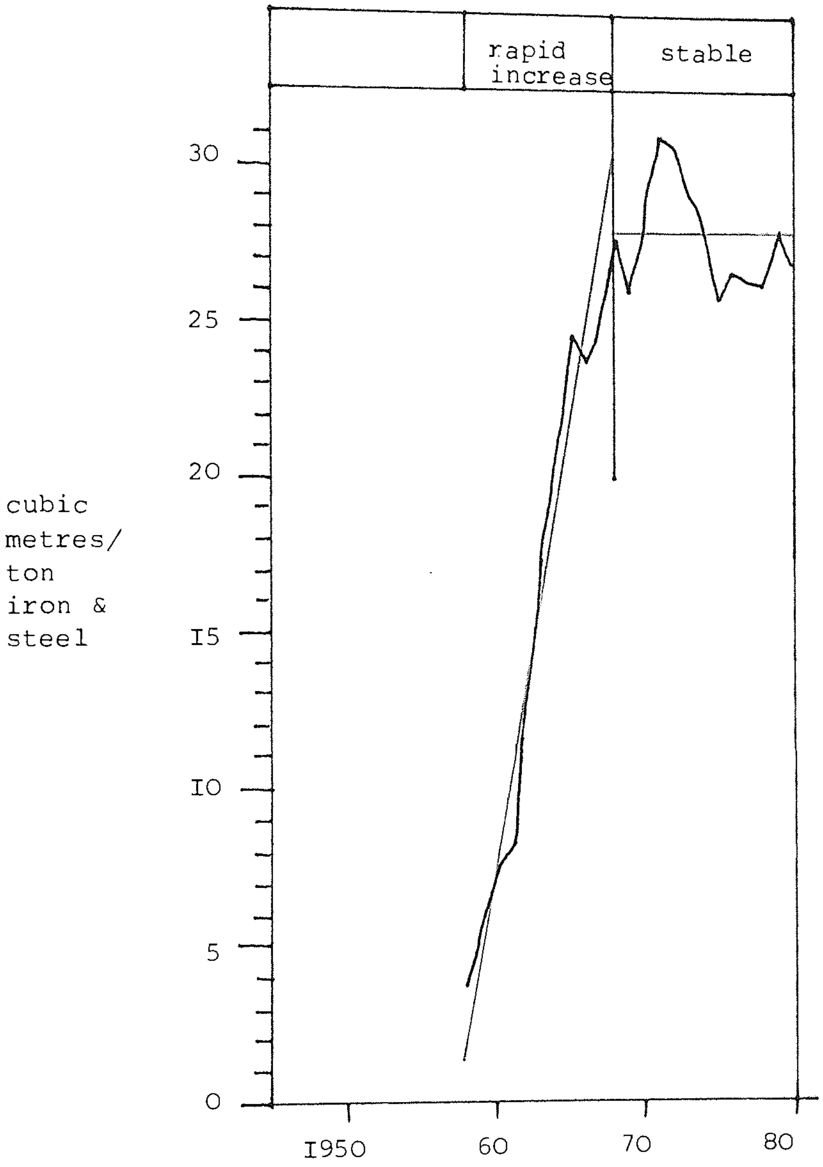


Figure 2.26 - Variations in unit input levels of oxygen

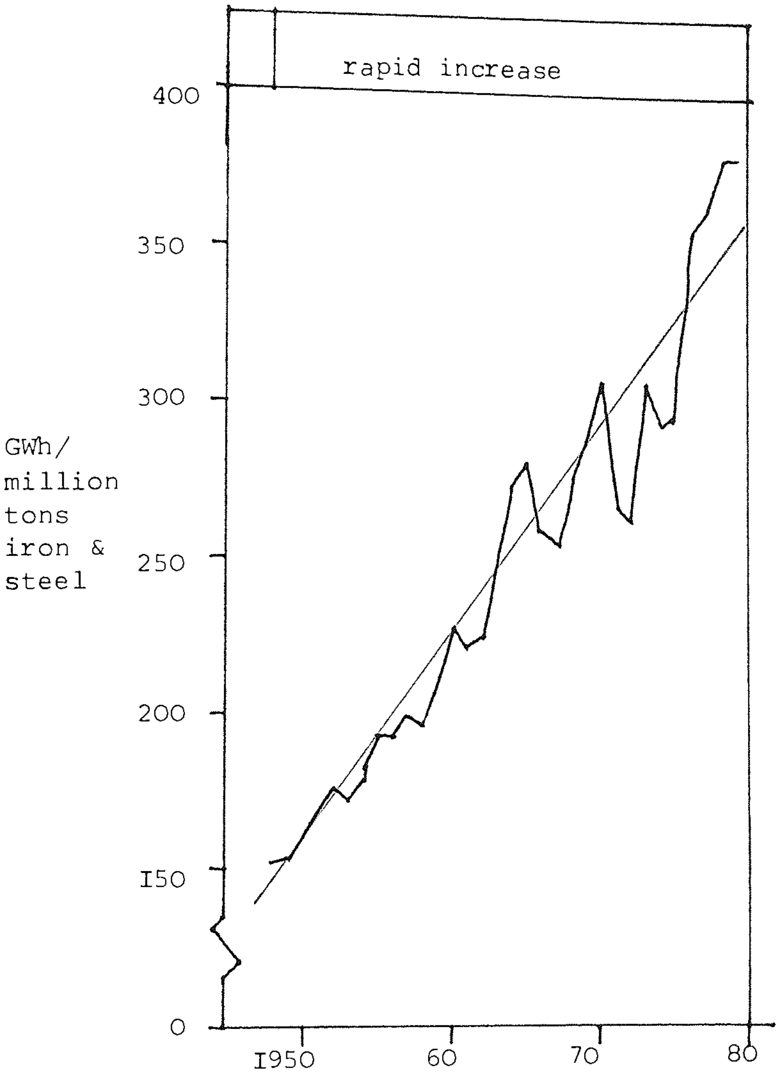


Figure 2.27 - Variations in unit input levels of electricity

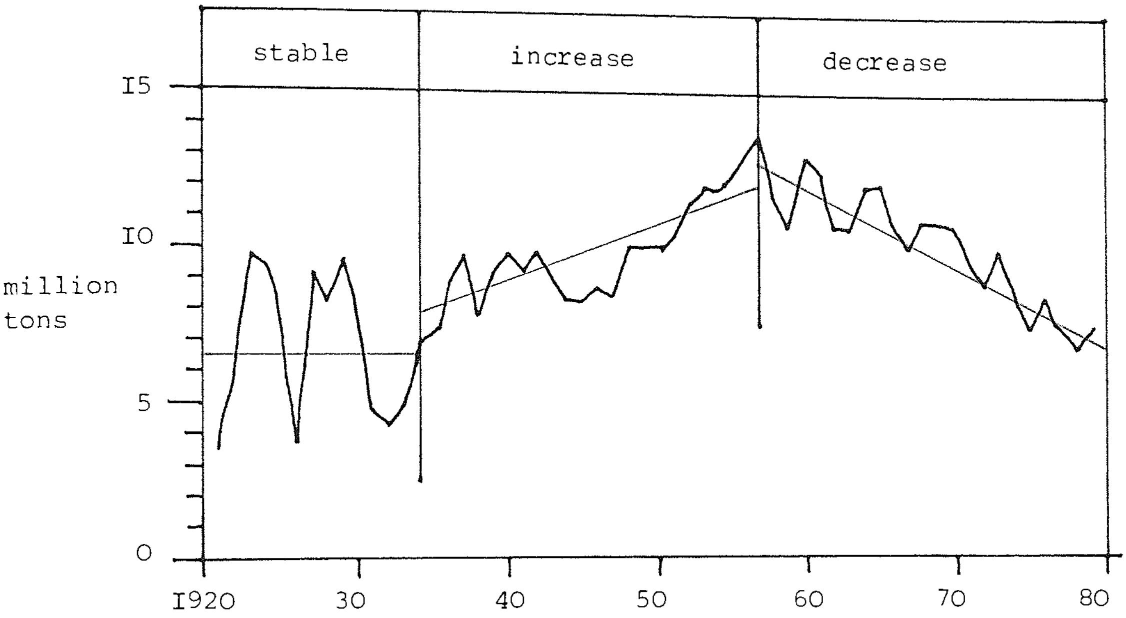


Figure 2.28 - Variations in gross consumption levels of coke

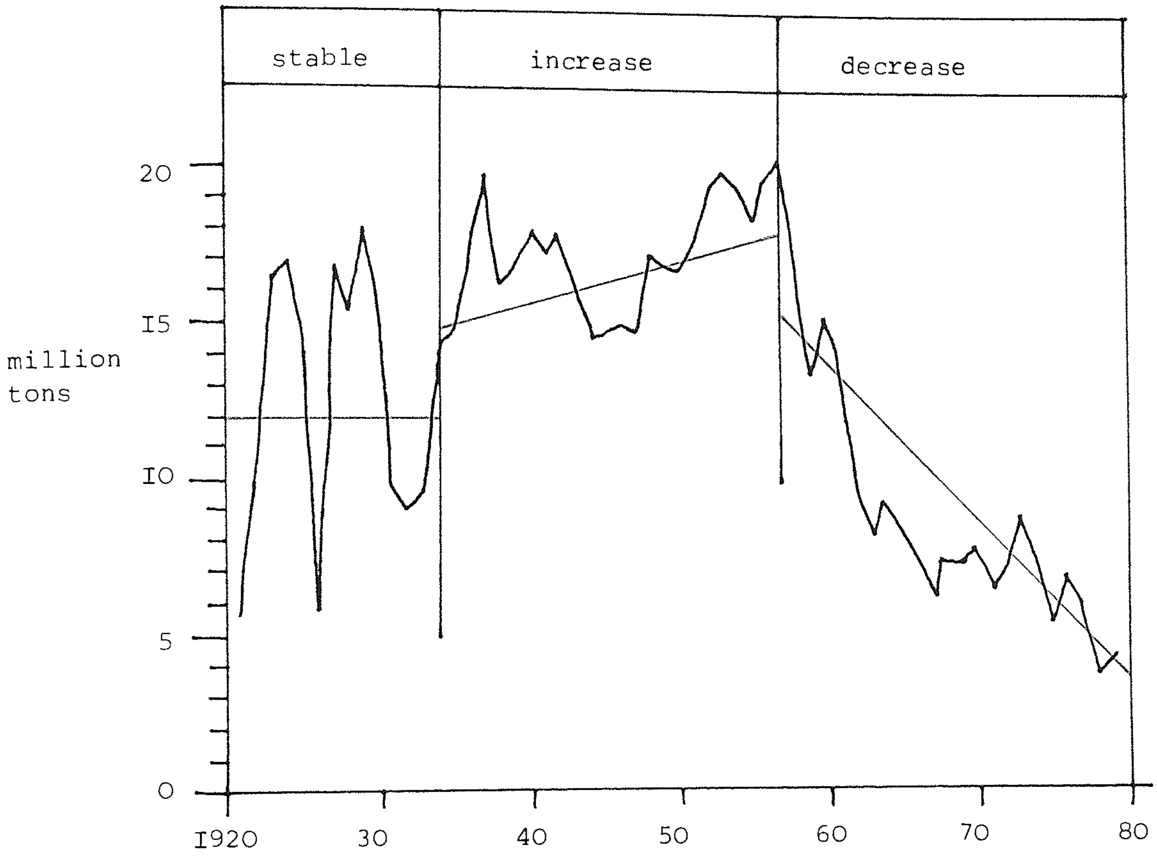


Figure 2.29 - Variations in gross consumption levels of iron ore

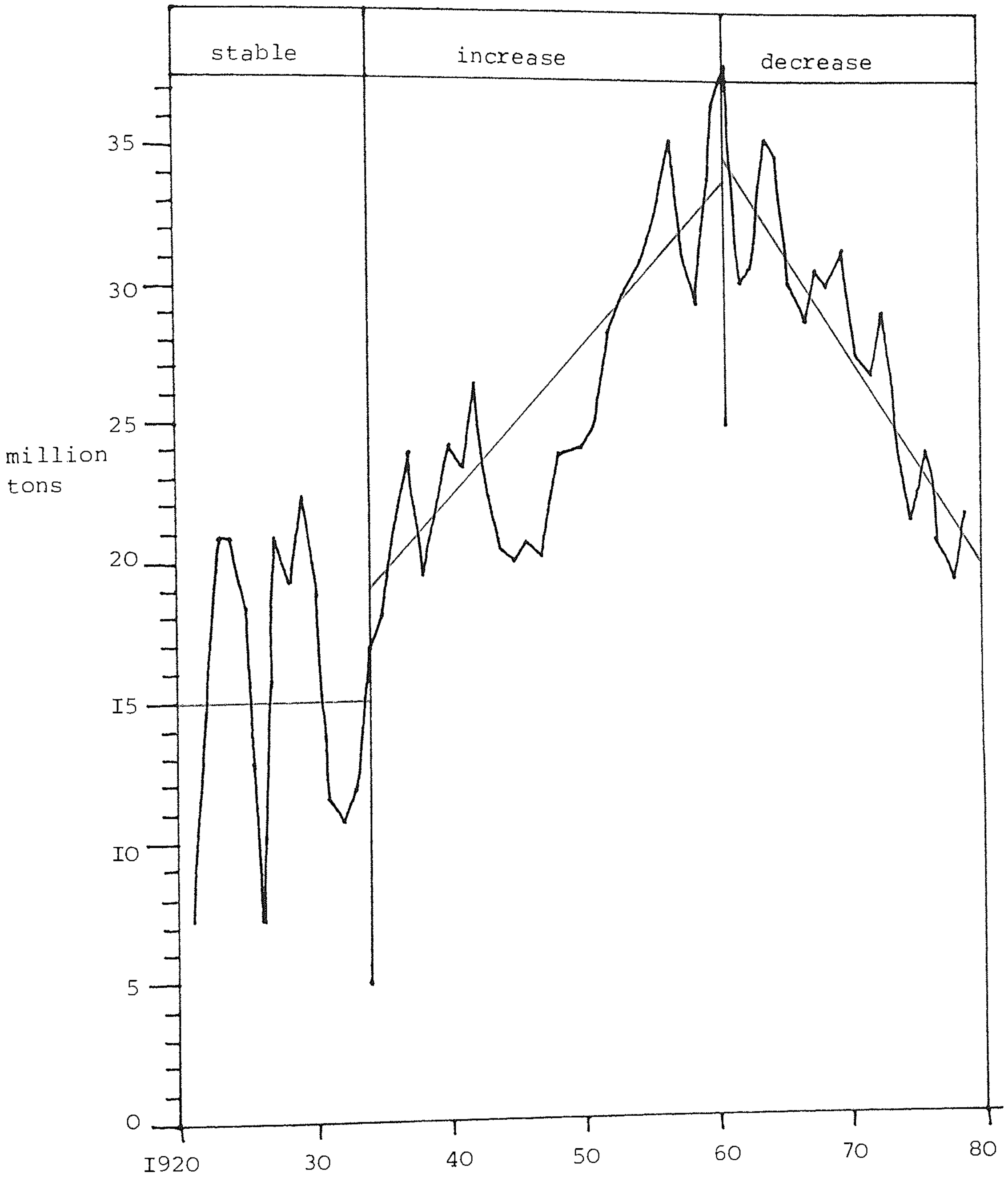


Figure 2.30 – Variations in gross consumption levels of blast furnace solids

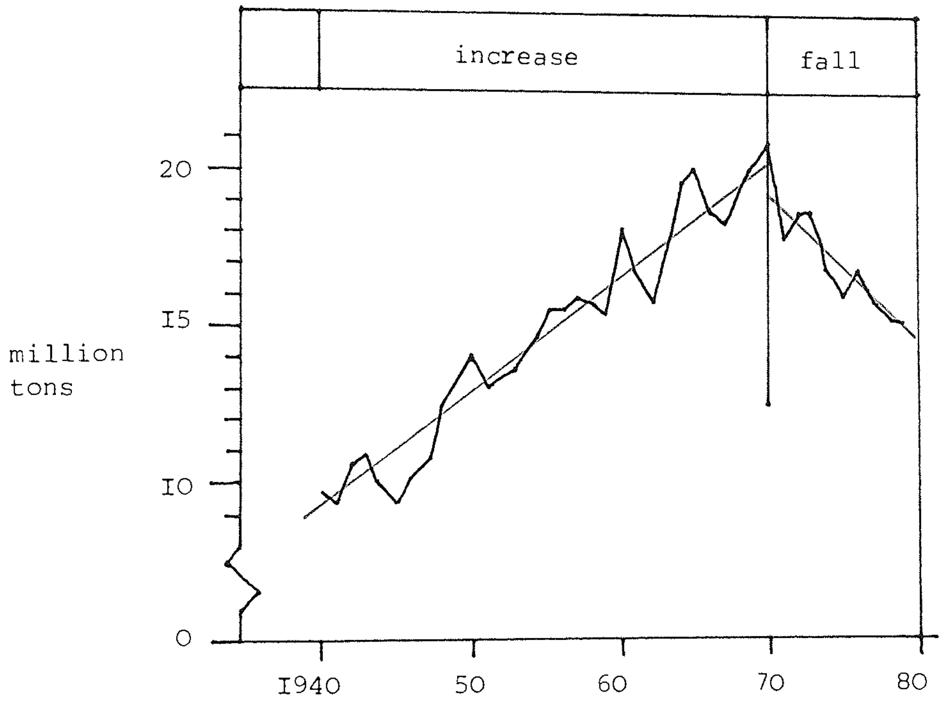


Figure 2.31 - Variations in gross consumption levels of total scrap

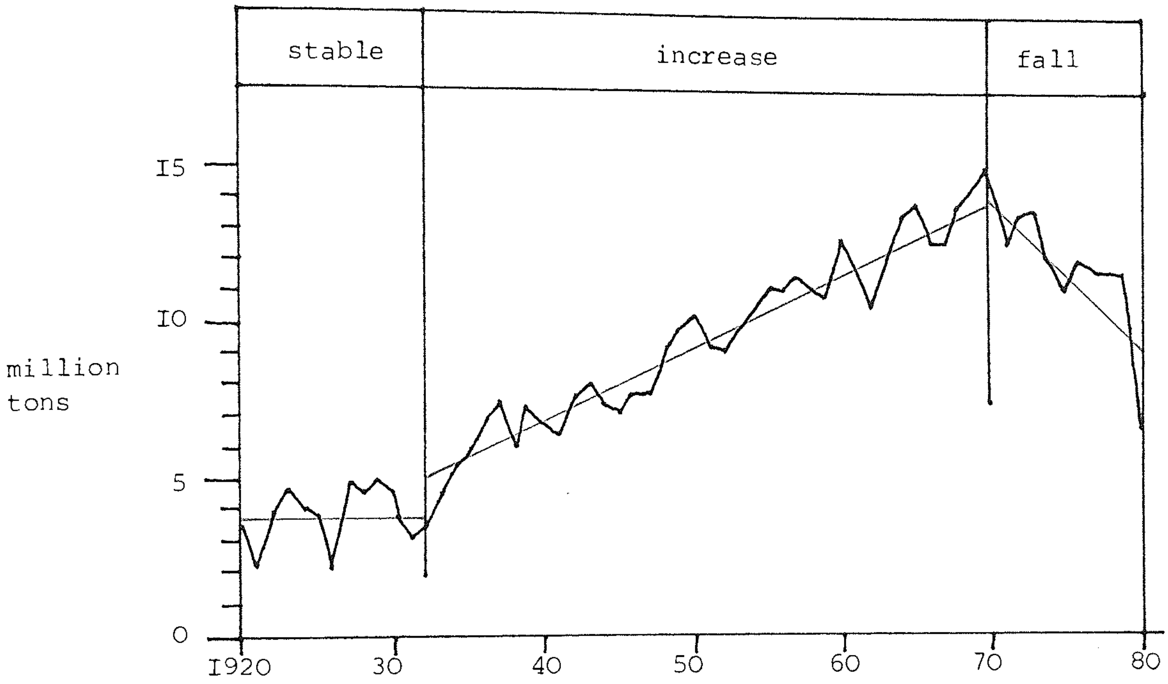


Figure 2.32 - Variations in gross consumption levels of steel scrap

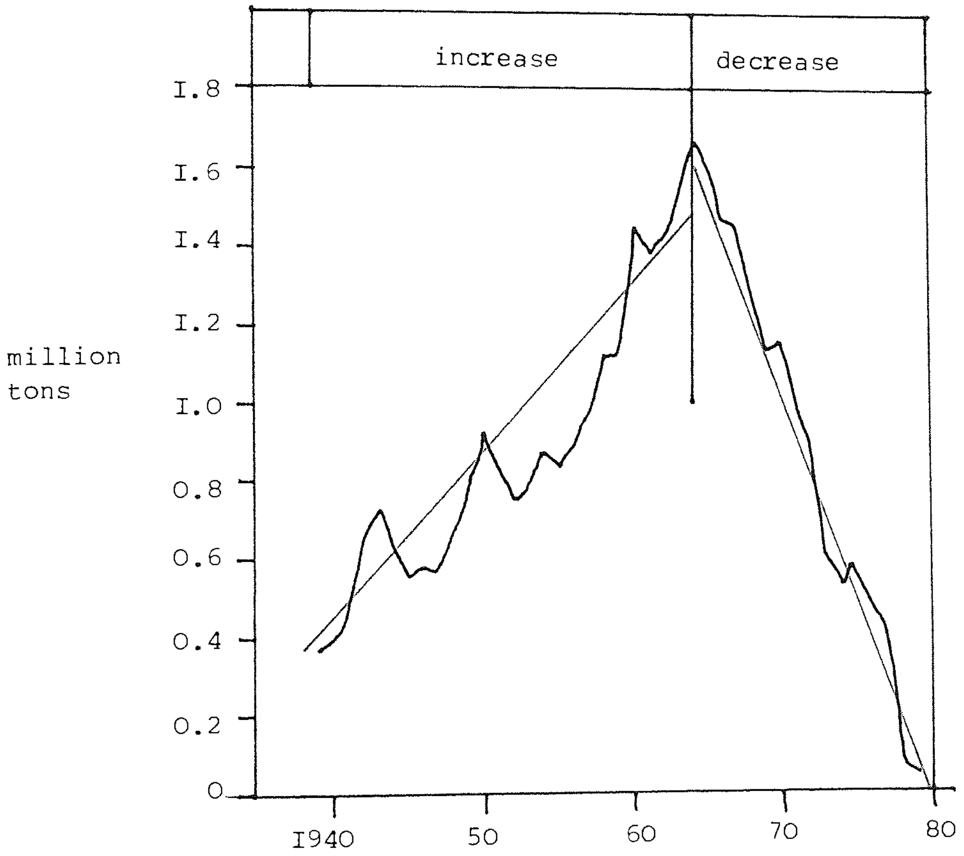


Figure 2.33 - Variations in gross consumption levels of iron scrap

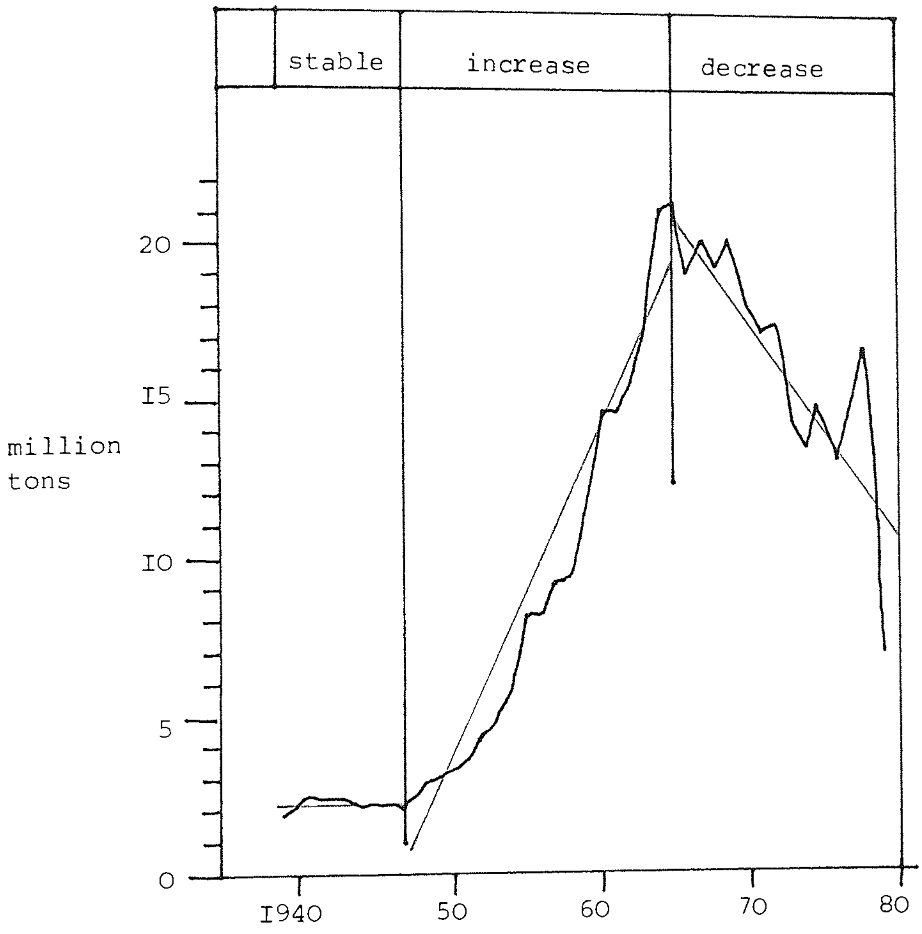


Figure 2.34 - Variations in gross consumption levels of sinter

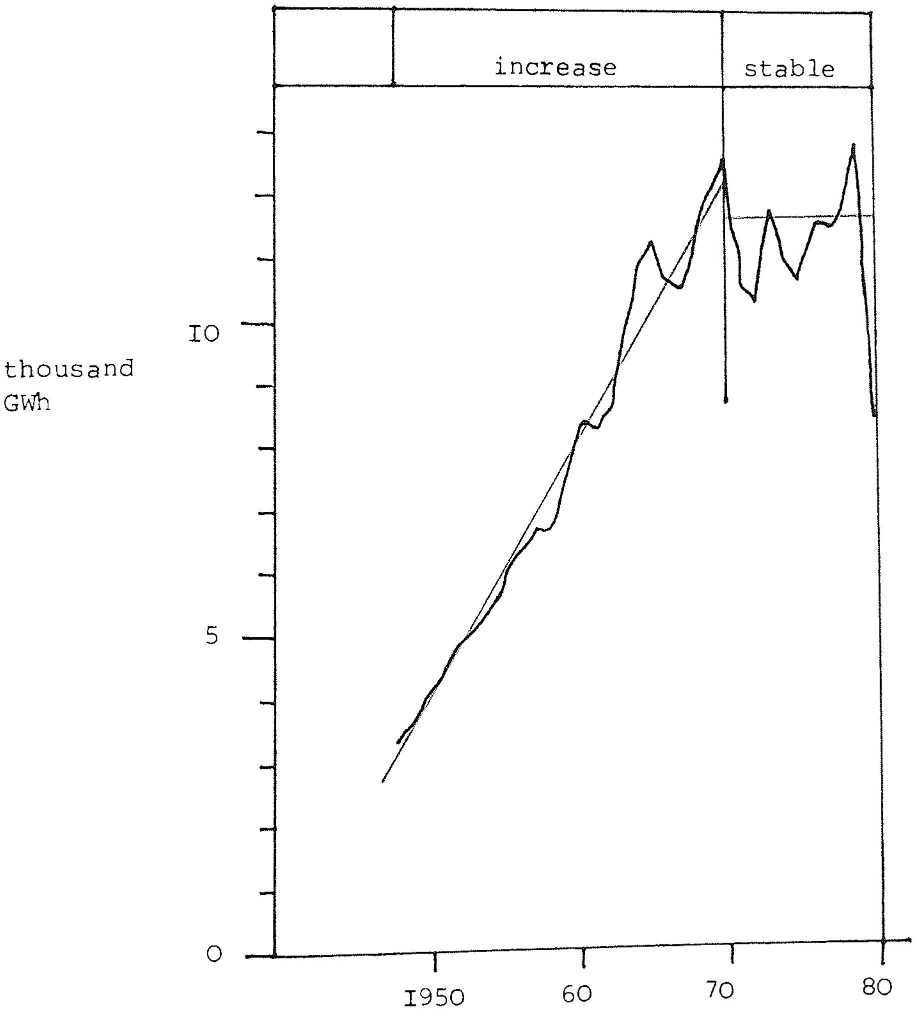


Figure 2.35 - Variations in gross consumption levels of electricity

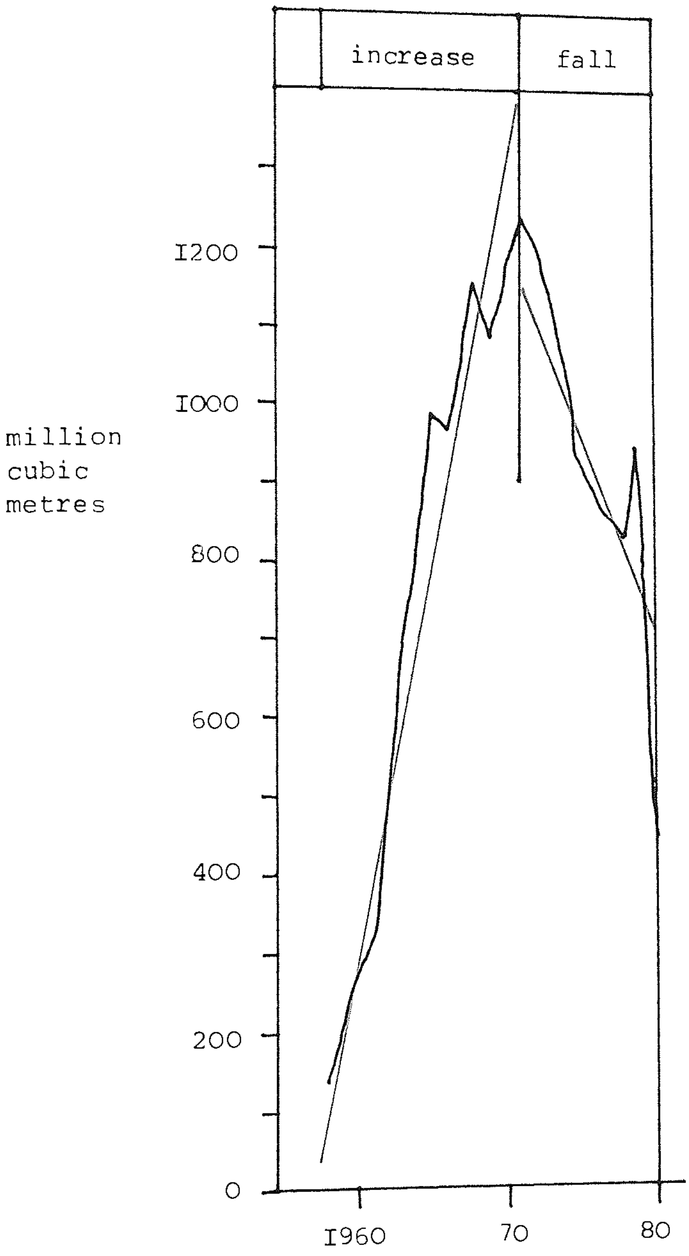


Figure 2.36 - Variations in gross consumption levels of oxygen

Chapter 3: The changing pollution picture in the United Kingdom basic processing sector

3A INTRODUCTION

The general aim of this chapter was to try and deal, as far as possible, with one of the 'loose ends' discussed at the end of Chapter Two - the question of whether pollution changes were periodized in the same way as were changes in inputs to iron and steel production. However, the nature of the available data meant that the particular question addressed had to be more limited. As outlined in greater detail below, the variables used were indicators of improvement in air pollution at the unit level, and no data was available before the mid 1950s. If unit pollution levels were periodized on the same pattern as unit levels of inputs to iron and steel production, we would expect to find that there was rapid improvement until about 1967, and very little change thereafter (see figure 2.10). If such a pattern did exist, it would not prove that unit pollution levels were periodized in the same way as unit input levels as far back as 1920 (though it would be consistent with this proposition). On the other hand, if this pattern did not occur, it would be clear evidence against the proposition.

3B DATA

The data all refers to air pollution in five UK industries - iron and steel, cement, non-ferrous metals, ceramics and electric power generation. The sources for raw data were the annual reports of the Alkali Inspectorate (ref: 2) and the government's 'Digest of Environmental Pollution Statistics' (ref: 11). The Alkali Inspectorate was the statutory body charged with overseeing air pollution in these industries, a responsibility taken over by the Health and Safety Executive in 1976, after which raw data comes from 'Industrial Air Pollution' (ref: 22). Thirty-seven variables were generated from the raw data, all being indicators for change in the rate of pollution improvement. Five different types of variable were used, as outlined in turn below.

1) The least direct of the variables measured changes in the volume of regulatory activity by the Inspectorate. Its claim to be an indicator of improvement lies in the nature of the regulatory 'actions' considered, which were of two types. The first consisted of the initial drawing up, and subsequent tightening of various 'standards'. These included maximum allowed concentrations in discharged air of particular pollutants (such as acids, metals and particulate matter), maximum allowed densities of smoke emitted during different phases of operations (as coded on the 'Ringelmann' scale) and other standards on things such as chimney height and practices of operating plant. The second type of action related to the 'enforcement' of these standards, and consisted of the issuing of orders to the industries concerned, requiring them to comply with particular standards within given time periods or they would be liable to prosectuion. Prosecutions themselves are, of course, an important aspect of enforcement. However, the reports do not give a complete and consistent breakdown of offences and prosecutions by industry, so this aspect could not be pursued. The full, dated list of both types of action is given in table 3.1 (annex 1). This was used to calculate a five year moving average of the annual frequency of all actions, as a measure of the volume of activity (Var 1). Values of this, and all other variables are given in table 3.4 (annex 1).

2) The next variable (Var 2) is a direct measure of changing amounts of a given pollutant per unit of a given output (sulphur dioxide per unit of electricy generated by the CEGB). It was calculated from electric power output data (ref: 4) and estimates of gross sulphur dioxide emissions from power stations (ref: 11, p 5).

3) The third type of variable measured concentrations in discharged air of various pollutants. The data was taken directly from the Inspectorate annual reports, and consists of annual means of samples taken. Table 3.2 (annex 1) gives details of the ten variables of this type (Vars 3 to 12).

4) The next twenty-two variables measured rates of diffusion of aspects of technology especially relevant to air pollution. In most cases they referred to add-on collectors or arrestors, and therefore acted as indicators of changes in amounts and/or concentrations of pollutants emitted. Three variables measured the changing adequacy of chimneys from furnaces, and acted as indicators for improvements in pollution through changes in the degree of dispersal achieved. One variable measured change in process technology particularly relevant to the problem of dark smoke emissions. The raw data in the Inspectorate reports consisted of numbers of plants of given type that were or were not using particular technologies. In all cases except one, total plant numbers were also given, which meant that the better diffusion measure of annual proportions could be calculated and used. Table 3.3 (annex 1) gives details of these variables (Vars 13 to 34).

There are two further points to make about these variables. First of all, eleven of them measured the 'diffusion-in' of technologies seen as being particularly beneficial. In these cases, rapid improvement in pollution is therefore indicated by rapid increases in proportions of plants using those technologies (such as % cement kilns using electrostatic particulate matter arrestors). The other eleven variables measured the 'diffusion-out' of aspects of technology that were seen as positively harmful, or as less beneficial. In these cases, rapid improvement in pollution was therefore indicated by rapid decreases in proportions of plants with those aspects of technology (such as % cement kilns with no arrestment plant for particulate matter).

The second point, as illustrated by the cement kilns example, is that not all the diffusion variables were statistically independent. Other things being equal, % kilns with no arrestment plant will be negatively correlated with % kilns using electrostatic precipitation.[1]

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[1] The negative autocorrelation would only be perfect if the substitution involved only two types of technology. If three or more were involved, and our variables measured the diffusion-in of the 'best' and the diffusion-out of the 'worst', we would still expect a negative relationship, but have no basis for predicting its strength. And this is variables used.

This sort of link exists between other pairs of variables as well, leaving fifteen that are fully mutually independent (and these are indicated in table 3.3). Those variables which were not independent could not provide additional evidence for or against the existence of any particular pattern, but as alternative illustrations, they were used to help in characterising the patterns observed.

5) The thirty-four variables were plotted over time to see whether or not there was any evidence for the proposed pattern of change in the rate of pollution improvement. In the cases of sulphur dioxide from power stations and the volume of regulatory activity, it was easy enough to characterise the patterns of variation since we were looking at single variables over relatively long periods. But for the emission concentration and diffusion variables, the pictures were less clear. The graphs included many variables, covering a variety of timespans, and with differing start and finish dates. Methods were therefore sought for giving simple representations of the pictures painted collectively by each set of variables. And to do this, three summary variables were calculated.

Two of these (Vars 35, 36) were meausres of 'average diffusion rates', calculated by taking simple arithmetic means, across the two sets of diffusion variables, of annual changes in proportions (ie of plants using or not using certain technologies).[2] The same procedure was used to generate the final variable - measuring the 'average change' in emission concentration per year (Var 37). However, the ten individual variables in the set referred to different pollutants. And there was therefore a problem, in that the same absolute change may represent very different degrees of improvement. For example, a reduction of 0.05g/m^3 over a decade would represent

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[2] The calculation of these means included only the independent variables in each set. Also, one of the diffusion-out variables had to be excluded because it had different units of measurement from all the others - absolute plant numbers rather than plant proportions (Var 34). This meant that average rates of diffusion-in and diffusion-out were both based on seven individual variables.

a considerable improvement as regards concentrations of cadmium or flourine, but would represent virtually no improvement in concentrations of dust or sulphur trioxide. To get round this problem, sampled concentrations were indexed before the individual annual changes and the overall mean were calculated.[3]

3C RESULTS

Figure 3.1 below shows the variation over time in the volume of regulatory activity by the Inspectorate, and, as indicated, there was apparently a change in about 1972. Beforehand, there was a slow but steady increase in the volume of activity. After 1972, however, it was pretty stable. The graph does not imply that there was no improvement after 1972. Rather, it suggests that the increase in the rate/degree of improvement was not maintained.

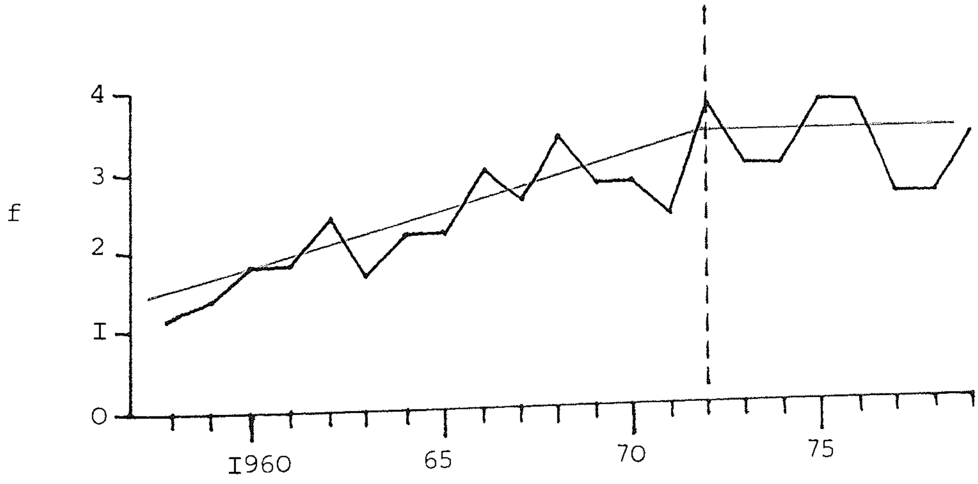

Figure 3.1 – Volume of regulatory activity by the Alkali Inspectorate

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[3] Because of the variation in the time periods covered, there was no base year for the indexing process that would allow the whole set of variables to be included. Whichever year was chosen, we had to lose two. Eight variables were indexed with a base of 1968=100, those excluded being variables 7 and 8.

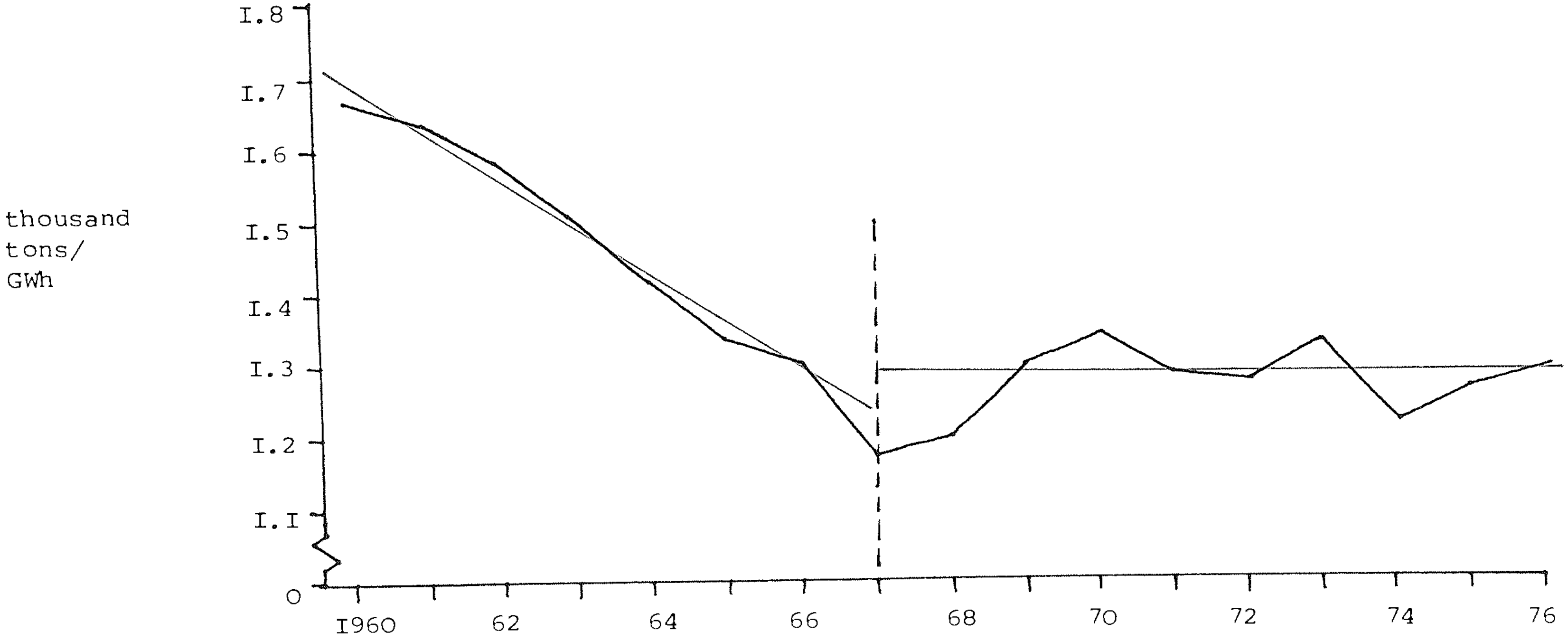
Figure 3.2 below shows the variation over time in sulphur dioxide emitted per unit of electric power generated. And, again, there was a clearly distinguishable change, this time in about 1967. Afterwards, there was very little change in the unit pollution level, whereas beforehand, there was a steady and quite rapid decrease.

Figure 3.6 (annex 2) shows the changes over time in sampled concentrations of pollutants in air discharged. The individual variables display a variety of patterns of change, but we can also make some generalisations. In the first decade or so, there are a few variables which showed little change (3, 6, 9), but most of them showed quite rapid improvements (especially 4, 5, 11, 12). During the rest of the period, some variables again showed little change (6, 7, 8), and some even indicated deterioration (3, 4). At some stage in the middle of the period studied, the balance therefore seems to have shifted - from stability or improvement to stability or deterioration.

Figure 3.3 below illustrates this shift in a different way, showing the average annual change in indexed concentrations. After about 1966, there was very little change. In some years there were slight increases, and in others there were slight decreases, but the period was not generally characterised by either improvement or deterioration. Before 1966, however, the average annual changes were consistently decreases, which, on the whole, were also larger than any changes in the later period. In general, therefore, this early period was one of improvement.

Figure 3.7 (annex 2) shows the diffusion-in of beneficial technologies, and the 1960s seems to have been a decade of quite marked improvement. The independent variables show the rapid diffusion-in of beneficial technologies (14, 16, 17, 18, 22), many being taken up by all plants to which they were potentially applicable (ie 100% diffusion). In the 1970s, the picture was more mixed. One of the independent variables indicates continued improvement (20), a trend

Figure 3.2 - Sulphur dioxide emitted per unit of electric power generated by the CEGB



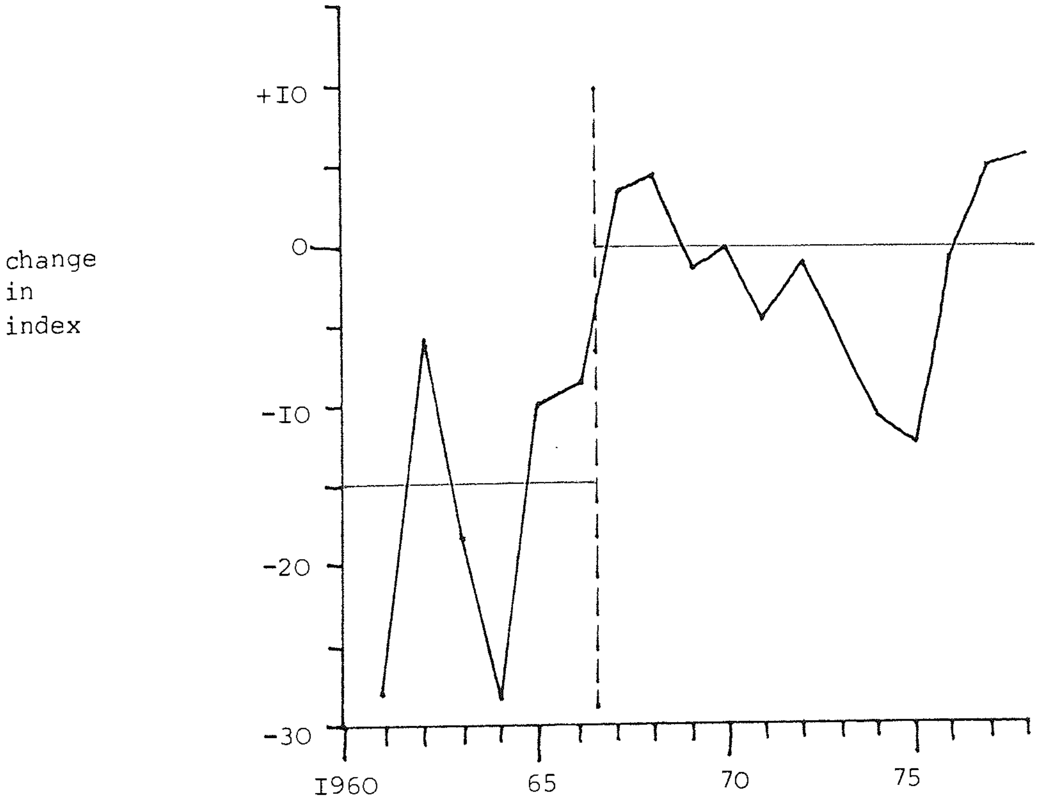


Figure 3.3 – Average annual changes in indexed emission concentrations

also shown by two of the dependent variables (19, 23). Two of the independent variables indicated very little change (15, 22), a trend again reflected by two of the dependent variables (13, 21). So we can apparently distinguish between the early period, which was one of general improvement, and the later period, in which some improvement still occurred, though it was much less widespread.

Figure 3.8 (annex 2) shows the diffusion-out of the badly polluting technologies. After about 1972, there was apparently very little improvement, since all variables indicate very slow diffusion. Beforehand, the picture was more mixed. Some of the independent variables indicate only very slow improvement (25, 28, 29), a pattern also illustrated by one of the dependent variables (27). But most of the independent variables indicate quite rapid improvement (24, 26, 32, 33, 34), a trend that is echoed by two dependent variables (30, 31).

Both sets of individual diffusion variables therefore point to a shift in the general rate of improvement. And this is quite clear in figure 3.4 below, which shows the variation over time in the average rates of diffusion - both in and out. As indicated, the change occurred in about 1973. Beforehand, the diffusion-in of beneficial technologies and the diffusion-out of badly polluting ones were both generally rapid, indicating rapid pollution improvement. Afterwards, average rates of diffusion-out were consistently low, indicating only very slow improvement. And average rates of diffusion-in fell quite sharply, indicating a decrease in the rate of improvement.

In summary, we note that all four types of indicator pointed to a decrease in the rate of pollution improvement at some time in the late 1960s or early 1970s. The similarity in the patterns revealed by these four types of measure allows us to abstract a description that would therefore be generally applicable to the air pollution problems in these industries. As illustrated schematically in

Figure 3.4 - Average annual rates of diffusion-in (35) and out (36)

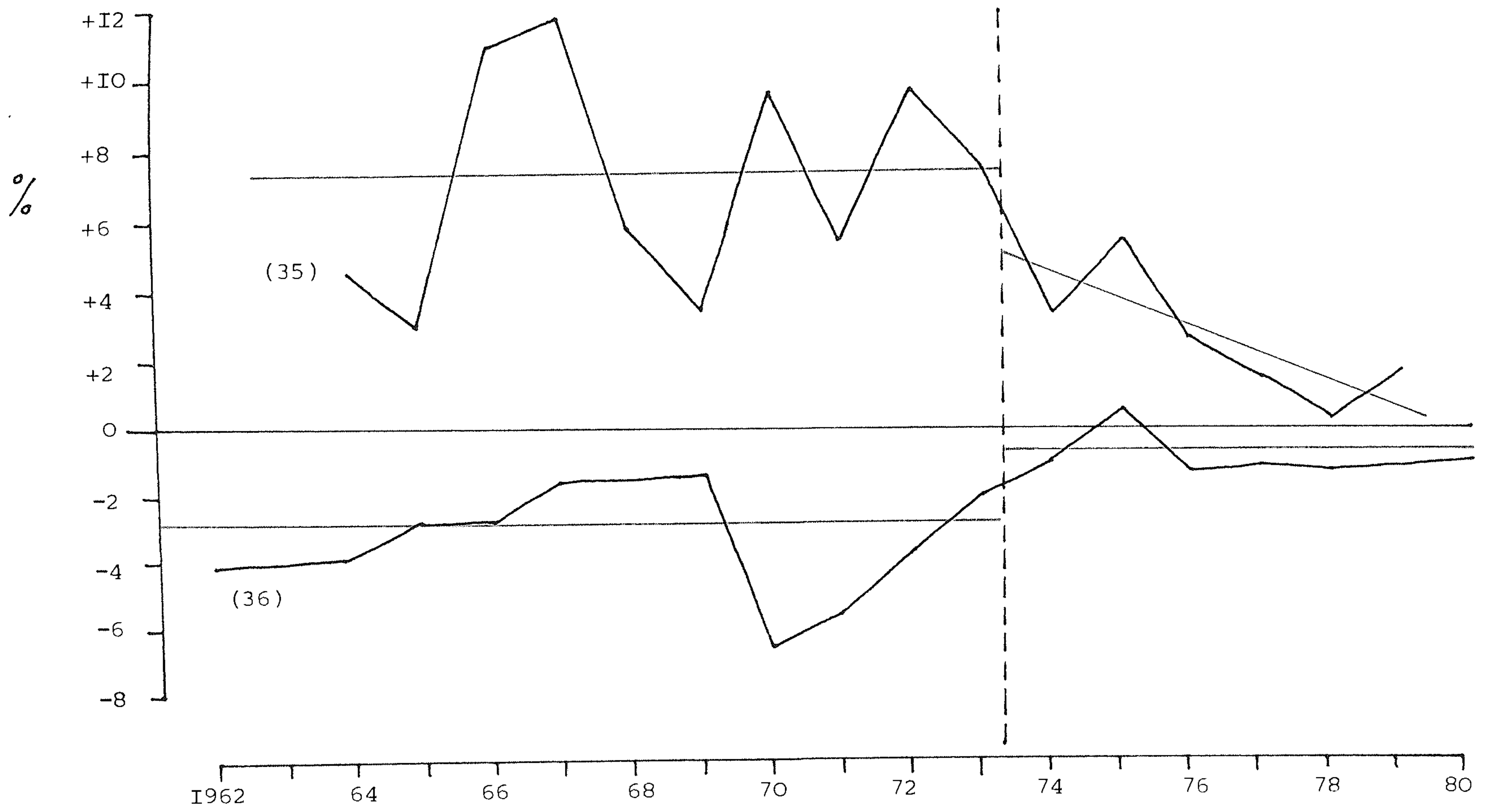
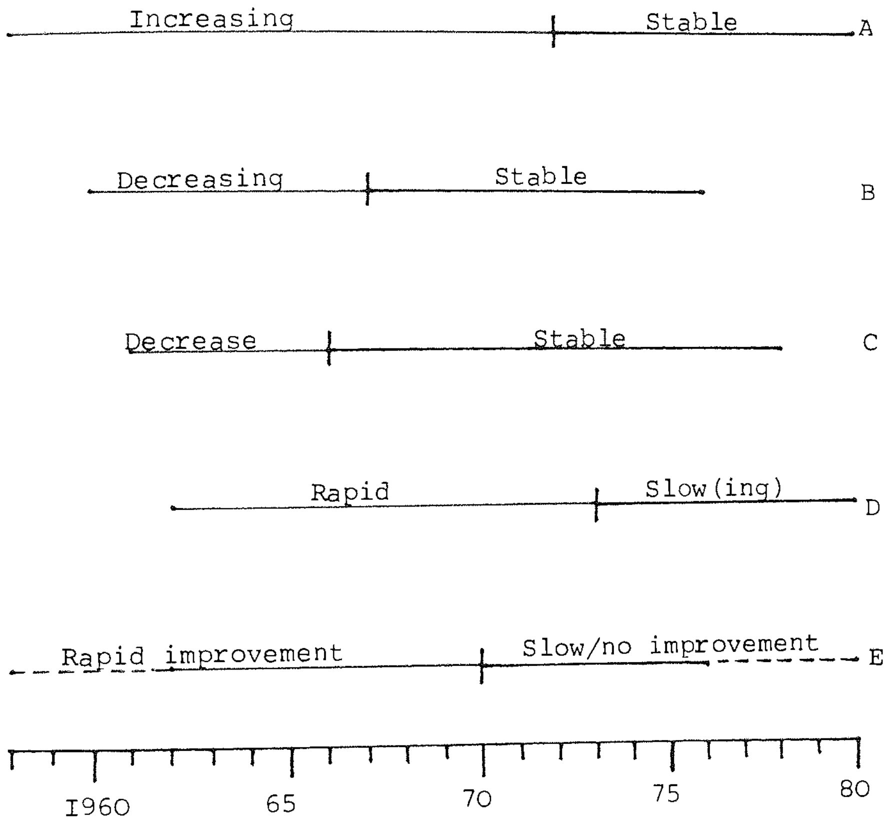


figure 3.5 below, the boundary between the two phases of this general model was 1970.



A - Regulatory activity (figure 3.I)
B - Unit sulphur dioxide (figure 3.2)
C - Emission concentrations (figure 3.3)
D - Diffusion rates (figure 3.4)
E - General pollution model (where boundary date is mean of those above)

Figure 3.5 - Schematic representation of distinctive pollution periods on various indicators

3D DISCUSSION AND CONCLUSION

If the objective of this chapter had been to try and 'prove' that unit pollution levels had the same pattern of change over this period as did unit levels of inputs to iron and steel production, then the analysis presented above would hardly do the trick. There are problems as regards both methods and data. Clearly, as regards methods, the main problem is that the analysis relies on the interpretation of visual evidence, and has no statistical backing.[4]

The data problems are of two types. First of all, although the variables used were all relevant in some way or other to pollution, it is not always clear exactly what they were measuring. For example, a reduction in the weight of particulate matter per cubic metre of air discharged may conflate several influences. It might possibly reflect a greater throughput of air in the production process, in which case the weight of particulate matter emitted per unit of output may be constant, or even rising. Such a reduction is more likely to reflect a drop in the weight of particulate matter emitted per unit of output. But even if it does, the reason is not known. Such a drop could be due to reductions in unit input levels, or to a change to the use of less 'dusty' inputs. It could be due to the introduction of 'cleaner' process technology, so that unit amounts of particulate matter actually evolved were reduced. But equally, unit amounts evolved in process may have been stable, and the drop in unit amounts emitted be due to the introduction of better add-on arrestors.

And this brings us to the second type of data problem - that of data omitted. Add-on cleaners feature prominently in the data, either as the object of diffusion variables, or implicitly, as possible sources of variation in sampled emission concentrations. And, as noted in chapter two, the problem is that we do not know the impact of all these technologies on water and land-based pollution problems.

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[4] The methods used to assess the significance of apparent periodization in the previous chapter would not have been appropriate here, because of the short timespans covered by the data.

The example serves to highlight the fact that the data is far from exhaustive, and there are large areas relevant to 'unit pollution levels' that are left unexplored due to lack of data. For example, until the Pollution Act of 1974, there was no right of access to the data on industrial water pollution held by the Water Authorities. In any such blank area, we can speculate that patterns of change may have been different from those described above.

However, despite these problems, the analysis presented would have been able to deal the proposition a severe blow (had it revealed the existence of other patterns of change). In this context, the fact that the data was not exhaustive is of relatively minor importance. Only a few counter examples would be needed to demonstrate that the proposition had, at best, limited validity. Similarly, it does not matter too much that some of the variables were ambiguous as regards exactly what they were measuring. Counter examples in any of the various senses of the term 'unit pollution levels' would, again, be sufficient to deal a blow to the general validity of the proposition.

The lack of statistical back-up for the visual evidence does remain a problem, but one that is also reduced, given the aim of disproving, rather than proving the proposition. It is one thing to say that the visual evidence supports the proposition although we cannot demonstrate this statistically. Clearly, it is quite another thing to claim that, merely because there is no statistical back-up, the visual evidence could be used to support the existence of some completely different pattern that had been proposed.

We can conclude, then, that although the data is not exhaustive, and some of it is ambiguous, none of it runs counter to the proposition. And, although the methods are imperfect, the visual evidence lends complete support to the proposition that patterns of change in pollution in these five industries were the same, from about 1960, as patterns of change in unit levels of inputs to iron and steel production. And again, although this conclusion does not constitute 'proof', it is consistent with the broader speculation that, since 1920, at least, variations in unit input and unit pollution levels have been periodized on the same pattern.

3E Annex 1: Data tables

Table 3.1 – Regulatory actions by the Alkali Inspectorate

Date	Action	Type[1]	Industry[2]
60	Pb from lead works: range .023 to .23 g/m^3	S	NF
61	Fume from copper works: max .115 g/m^3	S	NF
62	Pb from lead works: range .023 to .115 g/m^3	S	NF
64	Chimney standards for copper works	S	NF
66	Cd from cadmium works: max .04 g/m^3	S	NF
66	Dust from lead works: max .46 g/m^3	S	NF
66	Fume from lead works; max .115 g/m^3	S	NF
71	Total particulate matter (TPM) from secondary aluminium works: range .115 to .23 g/m^3	S	NF
74	Pb from lead works: range .012 to .115 g/m^3	S	NF
75	TPM from lead works: range .23 to .46 g/m^3	S	NF
77	Where PVC cables burnt in metal recovery, chimneys not to be less than 120 ft	S	NF
77	TPM from metal recovery: max .46 g/m^3	S	NF
77	HCL from metal recovery works: max .46 g/m^3	S	NF
77	No smoke to be darker than Ringelmann grade one (R1) at metal recovery works	S	NF
78	Zn from copper works: max .115 g/m^3	S	NF
78	Pb from copper works: range .012 to .115 g/m^3	S	NF
78	Cd from copper works: range .012 to .070 g/m^3	S	NF
81	95% arrestment of total fluoride required in primary aluminium works	S	NF
81	New standards for metal recovery works (not specified)	S	NF
81	TPM from secondary aluminium: max .115 g/m^3	S	NF
81	Max 10 ppm chlorine in discharges from all aluminium processes	S	NF
81	HCL from all aluminium processes: max .46 g/m^3	S	NF
48	TPM from all works: max .92 g/m^3	S	CT
62	TPM from all works: max .46 g/m^3	S	CT
68	TPM from all works: range .23 to .46 g/m^3	S	CT
68	Chimney regulations	S	CT
72	Notice sent to works with only cyclone arrestors that this no longer satisfactory	E	CT

Date	Action	Type[1]	Industry[2]
76	All new kilns, TPM: max .23 g/m^3	S	CT
79	All new kilns to have continuous pollution monitoring equipment	S	CT
59	Standards for bottle ovens (not specified)	S	CS
60	Provisional chimney standards agreed in salt glazing industry	S	CS
64	Salt glazing chimney standards confirmed	S	CS
64	Smoke standards (not specified)	S	CS
67	Salt glazing industry given till 1970 to conform with 1964 chimney standards	E	CS
66	All works given till 1970 to conform to 1964 smoke standards	E	CS
68	Standards on acid soot problems (not specified)	S	CS
72	New blue brick kilns not to emit smoke darker than R1 at any time	S	CS
77	All works, TPM: max .46 g/m^3	S	CS
77	No kilns in industry to emit smoke darker than R2 at any time	S	CS
79	New kilns, TPM: max .10 g/m^3	S	CT
79	New clinker coolers, TPM: max .15 g/m^3	S	CT
64	All boilers, TPM: provisional max .46 g/m^3	S	EY
69	All boilers, provisional chimney standards	S	EY
74	All boilers, chimneys to conform to 1969 standards	S	EY
74	All boilers, smoke and TPM to be monitored continuously	S	EY
74	Coal-fired plant designed before 1958, TPM: max .46 g/m^3	S	EY
74	Coal and oil-fired plant designed after 1958, TPM: range .115 to .46 g/m^3	S	EY
74	All new coal and oil-fired plant, TPM: max .115 g/m^3	S	EY
74	Smoke not normally to be darker than R1, and never darker than R2	S	EY
58	For all oxygen using processes, provisional TPM max .115 g/m^3	S	IS
60	For ore drying, crushing or sintering, TPM: max .46 g/m^3	S	IS
60	Provisional standards for hot-blast cupolas, chimney regulations and use of cyclones	S	IS

Date	Action	Type[1]	Industry[2]
63	Revised standards for hot-blast cupolas (not specified)	S	IS
67	All tropenas furnaces to have fume arrestors by end of year, or face prosectuion	E	IS
68	Further chimney standards for hot-blast cupolas	S	IS
68	Hot-blast cupolas, TPM: range .115 to .46 g/m^3	S	IS
69	Coke ovens, standards reviewed (not specified)	S	IS
70	New ore drying, crushing or sintering plant, TPM: max .115 g/m^3	S	IS
70	Blast furnace exit gases, TPM: max .115 g/m^3	S	IS
70	Non oxygen steelmaking, TPM: max .46 g/m^3	S	IS
70	Oxygen steelmaking, TPM: max confirmed at .115 g/m^3	S	IS
73	Further chimney standards for hot-blast cupolas	S	IS
73	Five year period for all hot-blast cupolas to have 'full' fume arrestment	E	IS
73	All new cupolas, TPM: max .115 g/m^3	S	IS
74	Notice sent to all open hearth steel works to fit fume arrestors	E	IS

1: S = standards, E = enforcement

2: NF = non-ferrous metals
CT = cement
CS = ceramics
EY = electricity
IS = iron and steel

3: Data from annual reports of the Alkali Inspectorate 1948 to 1975 (ref: 2), and 'Industrial Air Pollution' 1976 to 1983, annual reports of the Health and Safety Executive (ref: 22).

Table 3.2 - Emission concentration variables

Variable number	Description
3	g SO_3/m^3 from fletton brick works (5 year moving average)
4	g SO_3/m^3 from other ceramic works (5 year moving average)
5	gFL/m^3 from fletton brick works
6	g Pb/m^3 from lead works
7	$g\times10^{-1}$ Cd/m^3 from cadmium works
8	g particulate matter/m^3 from cement works
9	g dust/m^3 from 'Thameside' cement works
10	g SO_3/m^3 from oil-fired 'Bankside' power station
11	g SO_3/m^3 from ore-sintering works
12	g SO_3/m^3 from steel works

Data source as table 3.1 above

Table 3.3 - Diffusion variables

Variable number	Description
(13)	% of hot-blast cupolas with 'full' fume arrestment plant
14	% of tropenas furnaces with fume arrestment plant
15	% of iron blast furnaces with 'three-stage' arrestment plant
16	% of electric arc furnaces using bulk oxygen that have fume arrestors
17	% of electric arc furnaces using oxygen for light lancing that have fume arrestors
18	% of open hearth furnaces using oxygen for light lancing that have fume arrestors
(19)	% of CEGB boilers with electrostatic or combined particulate matter arrestors
20	% of CEGB boilers with continuous pollution monitoring
(21)	% of industrial boilers with electrostatic or combined particulate matter arrestors
22	% cement kilns with electrostatic dust arrestors
(23)	% of ceramics kilns that are oil-fired (reduces the dark smoke problems associated with coal-firing)
24	% of hot-blast cupolas with only 'provisional' best practical means of pollution control
25	% of CEGB boilers using only cyclone collectors
26	% of industrial boilers using only cyclone collectors
(27)	% of CEGB boilers using only scroll arrestors
28	% of CEGB boilers vented to 'unsatisfactory' chimneys
29	% of industrial boilers vented to 'unsatisfactory' chimneys
(30)	% of cement kilns using only cyclone collectors
(31)	% of cement kilns using no particulate matter arrestment plant
32	% of salt-glazing kilns vented to 'unsatisfactory' chimneys
33	% of ceramics kilns that are coal-fired by hand
34	number of furnaces vented to 'unsatisfactory' chimneys in the copper industry

Data source as table 3.1 above

( ): Variables not fully independent. Pattern of linkages as follows:

Independent variable	Linked variables
24	13
25	(19,27)
22	(30,31)
26	21
33	23

Table 3.4 - Pollution data

	Variable numbers								
	1	2	3	4	6	6	7	8	9
Units of measurement	f	thousand tons/GWh	g/m³				g^{-1}/m^3	g/m³	
1958	1.2								
59	1.4								
60	1.8	1.67							
61	1.8	1.64							
62	2.4	1.59		1.89		.044			
63	1.6	1.51		1.76	.029	.035			.916
64	2.2	1.42		1.59	.029	.046			.687
65	2.2	1.34	1.83	1.45	.016	.025			.687
66	3.0	1.31	1.86	1.39	.016	.025			.687
67	2.6	1.18	1.98	1.43	.011	.028			.687
68	3.4	1.20	2.00	1.39	.017	.032			.730
69	2.8	1.31	2.01	1.39	.014	.032			.782
70	2.8	1.35	2.10	1.48		.031			
71	2.4	1.30	2.08	1.43		.032			
72	3.8	1.29	2.00	1.43		.026			
73	3.0	1.34	1.97	1.55		.026	.027	.39	
74	3.0	1.22	2.03	1.67		.021	.064	.41	
75	3.8	1.27	2.00	1.74		.009	.046	.47	
76	3.8	1.30	2.09	1.86		.011	.046	.55	
77	2.6		2.21	2.00		.015	.014	.18	
78	2.6		2.33	2.11		.011	.053	.34	
79	3.4					.012	.022	.38	
80								.49	

( ): estimated where data coverage was not annual

	10	11	12	13	14	15	16	17	18	19
Measurement units	g/m^3			%						
1958	.059									
59	.082									
60	.087	1.46	1.56							
61	.078	1.33	1.15							
62	.071	1.63	1.26							
63	.080	1.37	1.10		0					
64	.050	1.19	0.57		7.7					
65	.018	1.19	0.92		12.5					
66	.028	0.82	0.84	16.0	37.5	86.8	80.7	58.9		33.5
67	.044	1.21	0.80	18.0	57.1	86.6	89.3	78.6		34.0
68	.044	1.17	0.64	27.0	80.0	87.3	89.3	78.0		36.9
69	.057	1.03	0.62	30.2	87.0	87.3	89.3	87.8	0	39.9
70	.069	0.80	0.55	34.8	87.0	95.1	100	87.2	43.0	41.9
71	.082	0.73	0.39	38.7	100	98.0		87.2	50.0	44.8
72	.087	0.78	0.27	41.9		98.0		100	75.0	38.7
73	.096			50.7		97.9			100	39.9
74	.050			46.3		100				41.4
75	.025			47.7		100				46.8
76	.032			49.2		97.8				53.9
77	.037			55.2		97.6				54.9
78				54.0		97.1				55.4
79						96.6				58.1
80										60.7

	20	21	22	23	24	25	26	27	28	29
Measurement units	%									
1958										
59										
60										
61				9.5						
62				(13.2)						
63			63.0	16.9						
64			64.5	(21.0)						
65			65.9	25.1						
66		20.3	72.9	(29.2)	25.5	28.5	18.7	15.4	29.3	21.4
67		19.9	84.3	33.2	26.0	27.9	22.6	15.3	28.6	21.0
68		18.9	90.2	(38.2)	22.0	26.5	21.5	15.3	27.6	20.0
69		19.7	90.0	43.2	18.8	28.2	36.9	15.0	27.6	19.7
70		16.8	88.5	(54.4)	17.4	26.8	38.0	13.8	26.7	21.2
71	0	13.7	93.3	65.6	14.8	26.6	32.9	11.9	22.6	23.1
72	12.7	5.2	95.2	(71.5)	8.6	30.1	23.1	10.9	23.2	19.1
73	19.5	4.9	95.0	77.4	7.0	28.5	20.0	10.8	22.8	16.8
74	27.2	4.9	95.9	(79.8)	10.4	28.2	15.4	9.2	21.6	15.9
75	42.8	5.8	97.2	(82.2)	9.2	27.3	16.2	6.6	24.9	18.5
76	52.4	5.4	98.0	(84.6)	12.3	21.6	15.1	4.1	22.9	17.2
77	56.6	5.3	98.8	(87.0)	10.3	20.3	13.7	3.2	22.4	16.3
78	58.2	5.5	98.8	89.5	4.0	19.8	15.1	3.4	23.4	15.1
79	62.6	5.2	100	88.8		19.8	12.9	1.3	21.5	14.5
80	67.8	2.9		84.1		17.2	11.6	1.4	20.0	13.4

	30	31	32	33	34	35	36	37
Measurement units	%				f	annual change in... %		index
1958								
59								
60								
61				79.5				-28.0
62				(75.4)			-4.1	-5.3
63	18.7	17.9		71.3			-4.1	-18.5
64	18.2	14.0	82.0	(67.4)		+4.6	-3.9	-28.4
65	17.3	12.3	80.5	63.4		+3.1	-2.8	-10.0
66	15.8	11.3	79.0	(59.5)	132	+11.0	-2.7	-8.4
67	13.4	2.4	77.1	55.5	103	+11.8	-1.6	+3.5
68	7.3	2.4	76.8	(50.7)	91	+5.8	-1.4	+4.4
69	6.6	2.5	58.6	45.8	84	+3.5	-1.3	-1.4
70	8.7	2.9	27.2	(33.0)	54	+9.8	-6.5	-0.2
71	6.7	1.9	10.6	20.2	46	+5.5	-5.6	-4.6
72	6.8	0	6.5	(14.4)	37	+9.9	-3.7	-0.8
73	7.0		6.6	8.5	34	+7.9	-2.1	-5.8
74	4.1			(7.5)	27	+3.5	-0.8	-10.5
75	2.8			(6.5)		+5.6	+0.6	-12.0
76	2.0			(5.5)		+2.7	-1.3	-0.5
77	1.2			(4.5)		+1.6	-1.0	+5.3
78	1.2			3.5		+0.4	-1.1	+5.7
79	0			3.2		+1.7	-1.0	
80				4.0			-1.1	

Figure 3.6 - Sampled emission concentrations

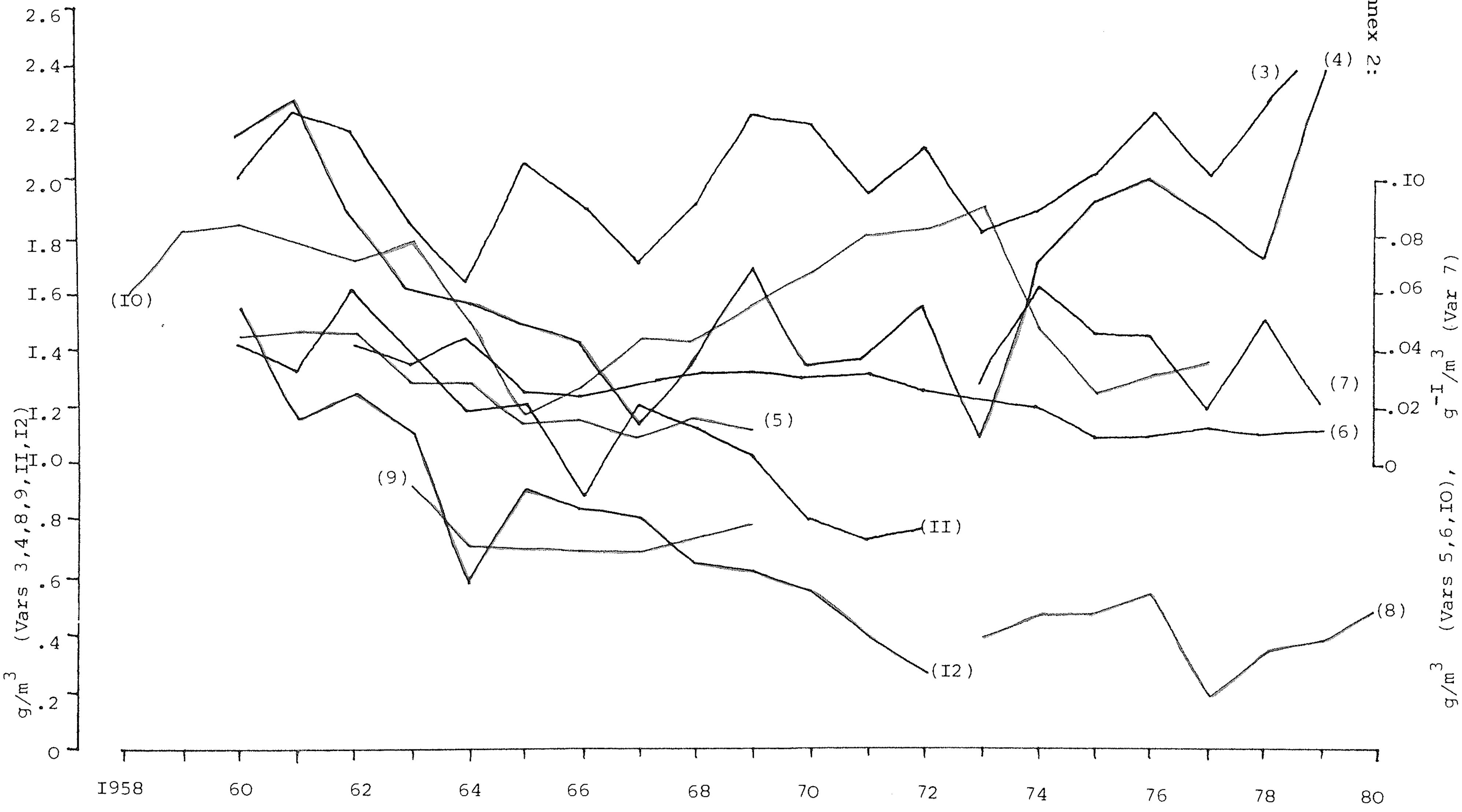


Figure 3.7 - Diffusion-in of beneficial technology

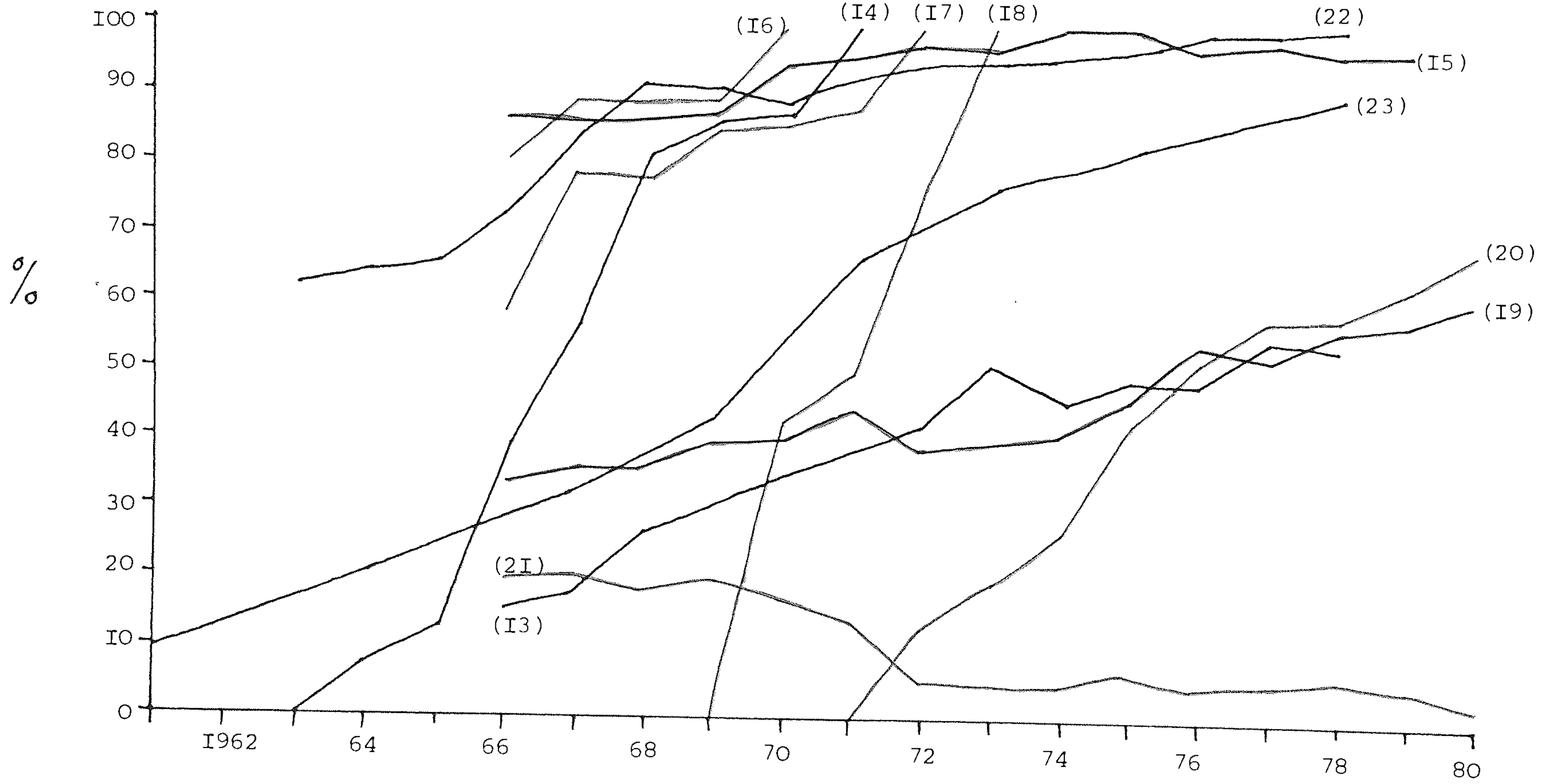
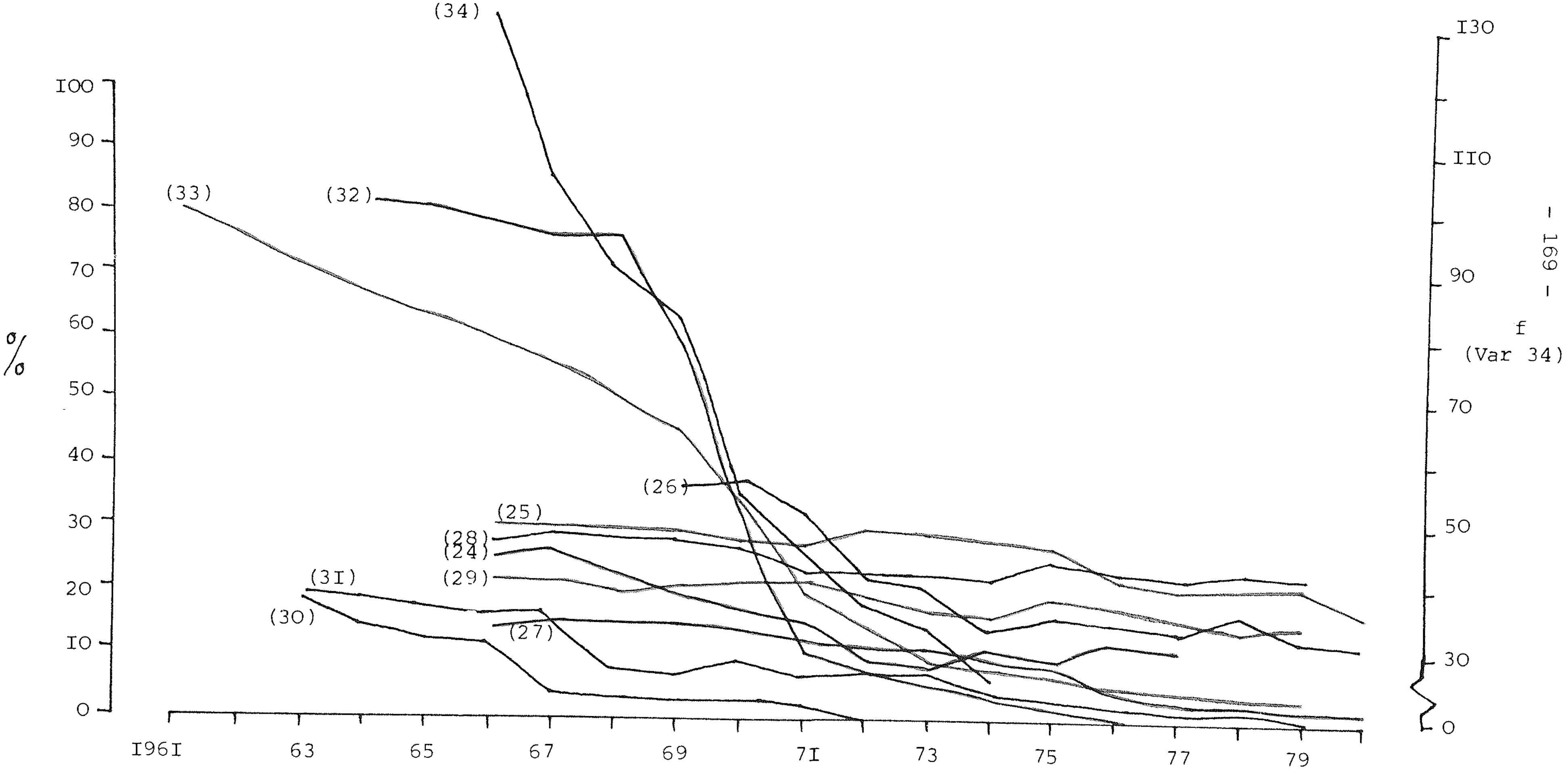


Figure 3.8 - Diffusion-out of badly polluting technology



Chapter 4: Explanation of patterns of enviromental change in the United Kingdom iron and steel industry (1700 to 1980)

4A INTRODUCTION

The broad intention of this chapter is to see whether, and how we can account for the observed patterns of environmental change in the iron and steel industry in terms of aspects of technical change and profitability.

This involved two types of analysis. The first step consisted of empirical work to try and establish whether there actually were links between environmental change, as described, and those technical and profit factors postulated as being likely to have been causally important. Accepted as general evidence for the existence of such links were results showing that these factors were periodized on the same sort of pattern as was environmental change itself. This work therefore involved, first of all, assessing the evidence for or against periodization in aspects of profitability and technical change; and, secondly, characterising the nature of any periodization, in order to see whether or not it was similar to that in relevant aspects of environmental change.

Where such empirical links were established, the second step consisted of trying to account for them in theoretical terms.

4B DATA

(B1) The rate and nature of innovation

It was hypothesised that, in general terms, the periodization observed in impact potential could be explained by reference to variations in the rate and nature of innovation. The first set of variables used to look at these influences were generated by breaking down variations in impact potential into three components, as follows.

The first was simply the overall rate of innovation in the industry (fIN). Moving average and period frequency variables were generated in order to examine patterns of change in this component (in contrast to the others, for which only period frequency variables could be used).

The second component of variation in impact potential is referred to as 'innovation bias' - ie the bias of innovations in terms of whether or not they were recorded as having any environmental impacts at all. This was measured by the proportion of innovations per decade having impacts (%IN).

The third component is referred to as 'impact bias' - ie the bias of those innovations having impacts towards or away from particular impact types. Each of the six impact bias variables measured changes in the proportion of those innovations with impacts that were defined as resulting in a particular type of impact, such as qualitative change (%QL, %QT, %IO, %DO, %AI, %AD).

Using the period frequency variables, the relationships between these variables are therefore as follows:

a) in general: impact potential = innovation rate x innovation bias x impact bias
b) for example: (fIO) = (fIN) x (%IN) x (%IO)

For any given impact potential variable, these three components of variation are independent. But, clearly, there are dependencies between impact bias variables. One of the pair (%QT) and (%QL) is really redundant, because they are perfectly negatively autocorrelated. Both have been used in illustrations, however, to keep in mind the fact that we are dealing with the balance between two classes of impact. There are also links between the other four impact bias variables. But, as with their corresponding impact potential variables, we do not know the direction or strength of autocorrelation, so we need to examine them all in order to characterise the patterns of change in bias towards different impact types.

These variables allowed us to separate out the immediate sources of periodization in impact potential, but do not exhaust the senses in which we might examine the influences of variations in the nature of innovations. In particular, it was postulated that variations in impact bias might themselves result from either of two further aspects of variation in the nature of innovations. First, they may have been due to changes in the balance between categories of technology that had different, and fairly stable types of impact associated. Secondly, they might have been due to changes in the types of impact associated with the innovations within categories of technology (where the balance between such categories remained fairly stable over time). In order to examine these influences, period frequency variables were used to establish whether or not there was any periodization in the proportions of innovations belonging to various categories of technical change (such as % product innovations vs % process innovations).

(B2) The rate of diffusion

It was hypothesised that changes in actual unit input levels reflect two main influences, the first being variation in the potential for such changes, as created by the stream of innovations over time. The general evidence in support of this proposition has already been presented in chapter two, in the sense that, in the period where the data sets overlapped, they were found to have been periodized on a similar pattern. If it is innovation that creates the potential for changes in unit input levels, then it is the diffusion of such innovations that we would expect to influence the rate and extent to which that potential is fulfilled. And in order to investigate this hypothesised link, data was collected on the patterns of diffusion of innovations within the industry.

Fifty-two variables were generated, and they were of three types. The diffusion of individual innovations was mapped using either 'absolute' or 'proportional' measures. Absolute measures were based on total numbers or amounts (for example, of steel furnaces of a given type, or of wrought iron produced in a particular way). Proportional measures, expressed in annual percentages by number or amount, were used to describe diffusion through broader classes of input, output or plant type (for example, the proportion of pig iron output being coke-smelted, the proportion of blast furnace numbers being steam-blown). The third type of measure was used to trace the diffusion of broader classes of technology. For example, all the individual innovations involving electrification will have had their own patterns of diffusion, but each also represents a different, specific application of the more broadly defined technology. The rate of diffusion of electrification as a whole can therefore be described in terms of the speed with which these individual applications follow each other. The variables used in this context were moving averages of the annual frequencies of innovations in the relevant broad classes of technology.

As well as breaking down the total set of variables into these three classes, it should also be noted that there was considerable variation in the absolute and proportional measures, as regards the quality of the data. In the best cases, we had long and continuous sets of annual values. The usefulness of the variables decreased as the data became more intermittent and/or shorter (relative to the whole diffusion 'history' of the innovation).

Not all of the variables were statistically independent and the links between them limited the uses to which some variables could be put. Twenty-one of the variables were mutually independent, and these were used to provide the evidence for or against periodization in diffusion rates. The full set of variables was used in producing a 'best characterisation' of the general pattern of diffusion. In addition, some of the diffusion variables used innovation or unit input level data. In the detailed consideration of the influences of impact potential and diffusion on changes in unit input levels, it was therefore necessary to use only those thirty-eight diffusion variables that were independent of both the innovation and unit input level data sets.

The full set of variables is given in table 4.1 of annex 1, where they are described, and classified according to patterns of dependence within and between data sets. Thirty-five of the variables are based on raw data taken from other published sources - mainly the technical histories of the industry. The remaining seventeen were generated by further calculations. Table 4.2 (annex 1) gives source references or calculations involved, as appropriate.

(B3) Profits

By definition, we know that variations in gross consumption levels must be due to those in unit input levels and/or output levels. Variations in output levels are also one of the main components of variation in total profit volumes. Output level data therefore allows us to test the hypothesis that there was a direct link between the observed periodization in gross consumption levels and periodization in the realm of profits.

The data used to examine this link measured levels of output of pig iron, crude steel and iron and steel in millions of tons per year. For pig iron and for iron and steel, the data was continuous from 1810 to 1981. For crude steel, the data was continuous from 1873 to 1981. In order to iron out the inevitably large year to year variations, the variables used were moving averages of the actual annual output levels (calculated over a seven year period). The sources of raw data are given in table 4.3 of annex 1.

It was also hypothesised that, in general, patterns of environmental change might be indirectly associated with variations in the realm of profits, through the intermediary of technical change. And, in the context of this particular study, it was postulated that variations in the realm of profits might be linked with patterns of change in diffusion rates and in the rate and nature of innovations.

Unfortunately, it was not possible to get hold of direct, monetary data on profits with which to examine these hypothesised links.

However, the output data was again useful in this context. There is a body of work which suggests that there may be systematic links between output and other components of variation in profits. The main empirical studies relating to British industry from 1924 to 73 are reviewed by R Wragg and J Robinson (ref: 54) in conjunction with their own analysis. The following relationships were found in all studies:

a) positive relationship between rates of output growth and rates of growth in labour productivity (ref: 54, p 20)

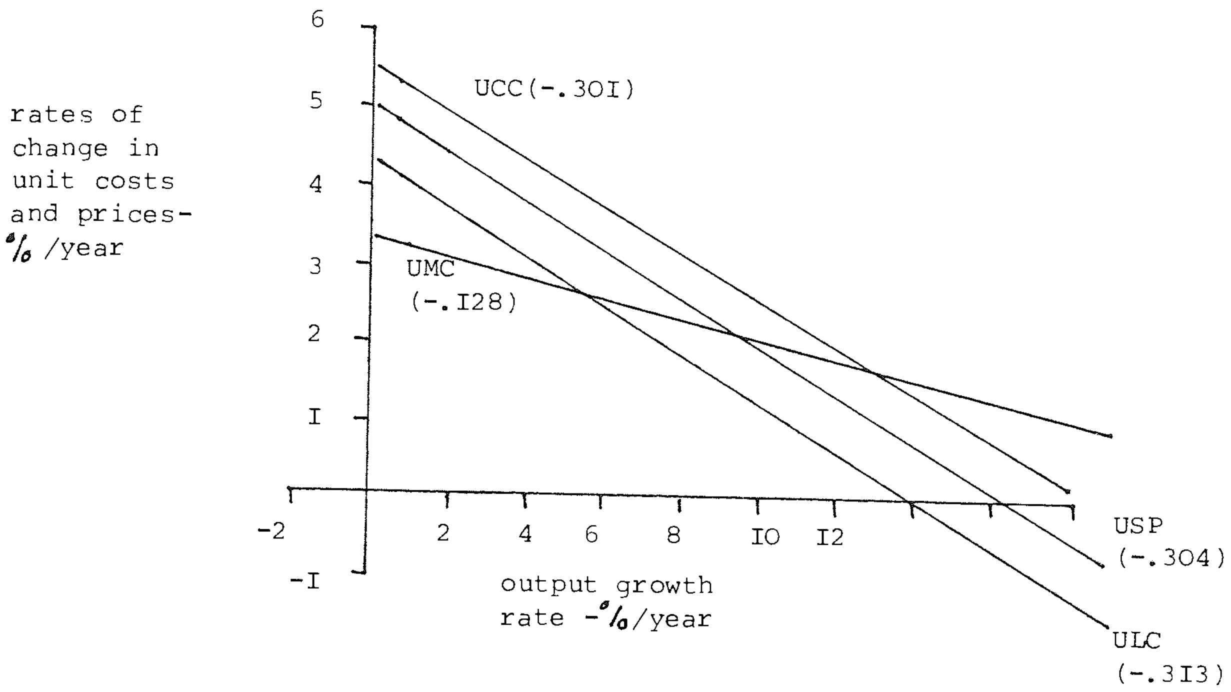
b) negative relationship between rates of growth in labour productivity and rates of change in selling prices (ref: 54, p 32)

c) negative relationships between rates of growth in labour productivity and rates of growth in unit input costs of (1) labour (ref: 54, p 35), (2) materials (ref: 54, p 36), and (3) capital (ref: 54, p 37).

This set of correlations implies that there were negative relationships between rates of output growth and rates of change in unit selling price (USP), unit labour costs (ULC), unit capital costs (UCC) and unit materials costs (UMC). And figure 4.1 below demonstrates that, between 1954 and 73, these relationships were as implied (using the data from the Wragg study, on eighty-two industries defined at the level of minimum list heading).

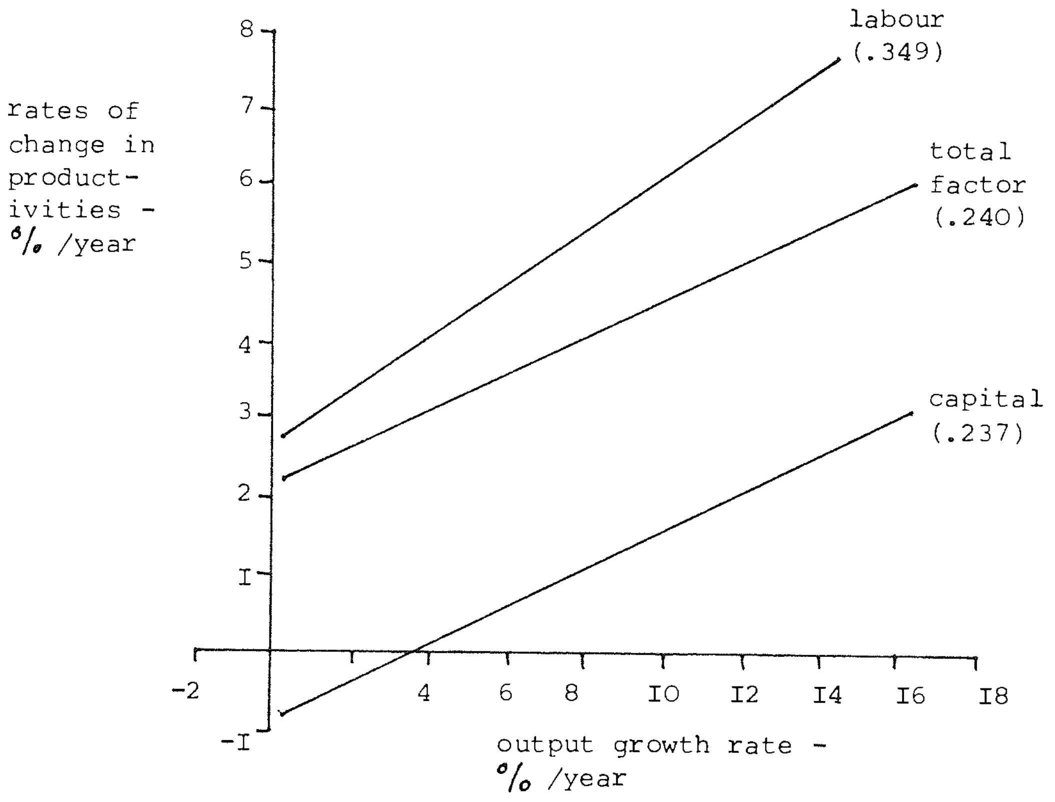
The correlations listed in (a) to (c) above also imply that there were positive relationships between rates of output growth and rates of change in the productivity of factor inputs other than labour - ie materials and capital. Using the Wragg data again, we can show that this was so for capital productivity and for 'total factor productivity' (TFP). These relationships are demonstrated in figure 4.2 below.

So there are certain empirical relationships, between output and other components of variation in profits, over which it seems



( ) regression slope coefficient

Figure 4.1 – Relationships between rates of change in output, price and unit costs (least-squares linear regression)



( ) regression slope coefficient

Figure 4.2 - Relationships between rates of change in output and the productivity of inputs (least-squares linear regression)

that there is general agreement. And these agreed relationships have two important implications for the examination of links between profits and environmental change (via innovation and diffusion). First of all, we can argue that output growth rates provide reasonable surrogate indicators for variations in some of those components of profitability for which we have no monetary data (from 1924 at least. The stability of the relationships before 1924 has to be assumed). And we would therefore expect that any periodization of changes in output growth rates would also be reflected, to some extent, by similar periodization of changes in these other components.

Secondly, therefore, if links between output growth and technical change are empirically demonstrable, we should refer to those other components of variation in profits when trying to account for those associations in theoretical terms.

The variables used to describe changes in rates of output growth were derived from the output level data. Using the raw data on output levels, three 'absolute' growth rate variables were computed. These simply measured annual increases or decreases in millions of tons. Three 'proportional' growth rate variables were then generated. These expressed the absolute annual changes as proportions of the previous year's output level, giving percentage increases or decreases per year. Because one set was derived mathematically from the other, the absolute and proportional variables do not provide independent evidence for or against the periodization of output growth rates. And this limited the uses to which some of the variables could be put. Whilst all six variables were used in trying to characterise patterns of change, only three provided independent evidence about periodization. The value of using both sets lies in the fact that neither gives an unequivocably 'better' indication of output growth rate variations. And if there were links between technical change and output growth, then they may be illustrated better by using one set of growth rate variables rather than the other. Because of the very large year to year variations, particularly in proportional growth rates, seven year moving averages of the actual annual data were again used.

4C EMPIRICAL RESULTS

(C1) The rate and nature of innovation

As represented by the moving average variable, the changes over time in the overall rate of innovation are shown in figure 4.3 below.

It appears to have been periodized, and, as indicated, we can recognise four divisions on the basis of the three major innovation troughs. If we look at the patterns of residual variation around the linear trends in the data within each division, we can see that the periodization was apparently cyclical in nature. This variation is shown in figure 4.4 below, which also demonstrates that the innovation cycles were fairly regular in both form and length, with a 'periodicity' varying between forty-five and seventy-five years.

The proportion of innovations having impacts associated was not periodized on the same pattern as any of the impact potential variables, nor on any other pattern that was at all regular or amenable to simple characterisation. We can therefore argue that the periodizations observed in impact potential were not due to this component of variation.

In contrast, impact bias was found to have been markedly periodized (before 1920, at least). For each pair of variables, those decades were identified in which the bias was shifted one way or the other (where, for example, a bias towards improvement might be given by a positive residual for %IO and a negative residual for %DO). These are shown in figure 4.5 below, where we can see a sequence of periods that was apparently fairly regular, with each period being about twenty-five or thirty years long.

In turn, the periodization of impact bias shown below seems to have been associated with changes in the balance between two categories of technical change. The first category included types of technology whose innovations were all concentrated into particular, and relatively short historical periods, and which were referred

Figure 4.3 - Variations over time in the overall rate of innovation

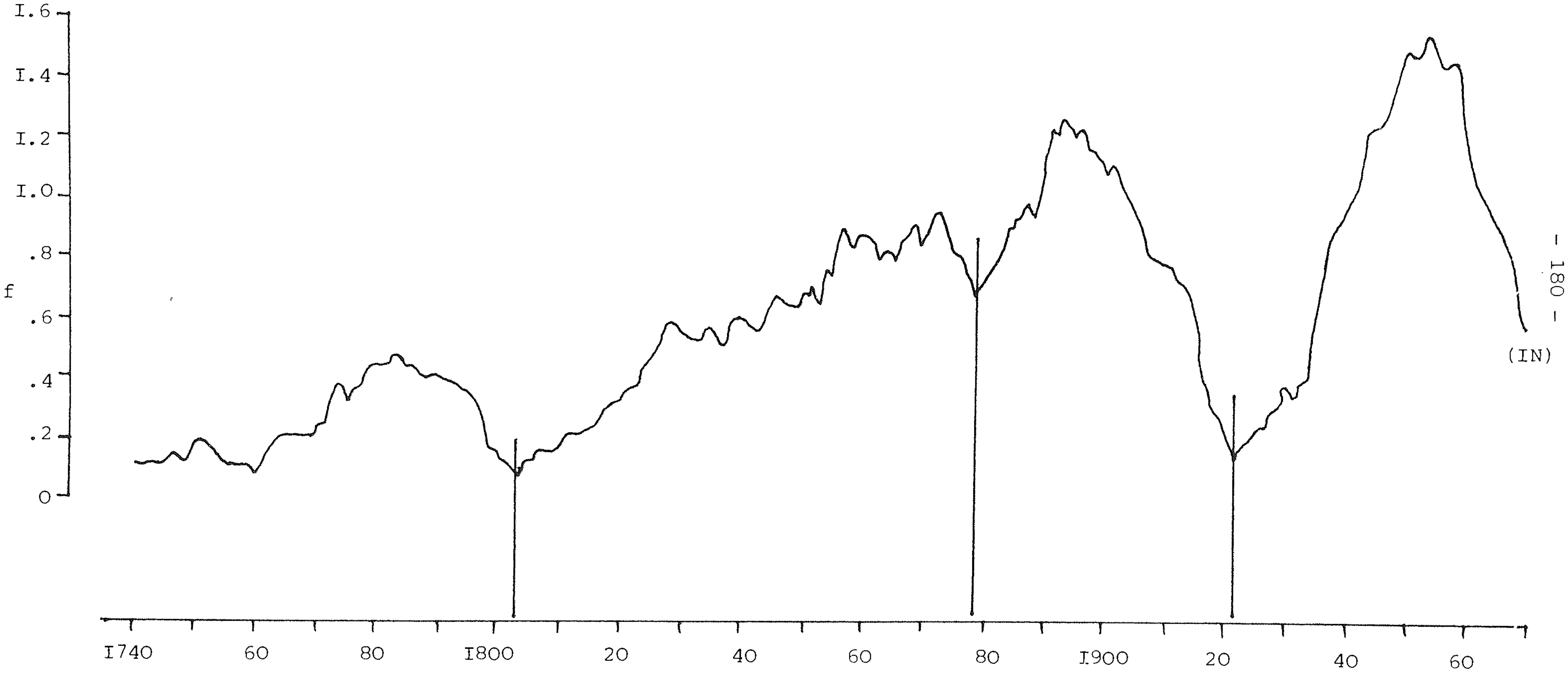


Figure 4.4 - Innovation frequency: residual variation around cycle trends

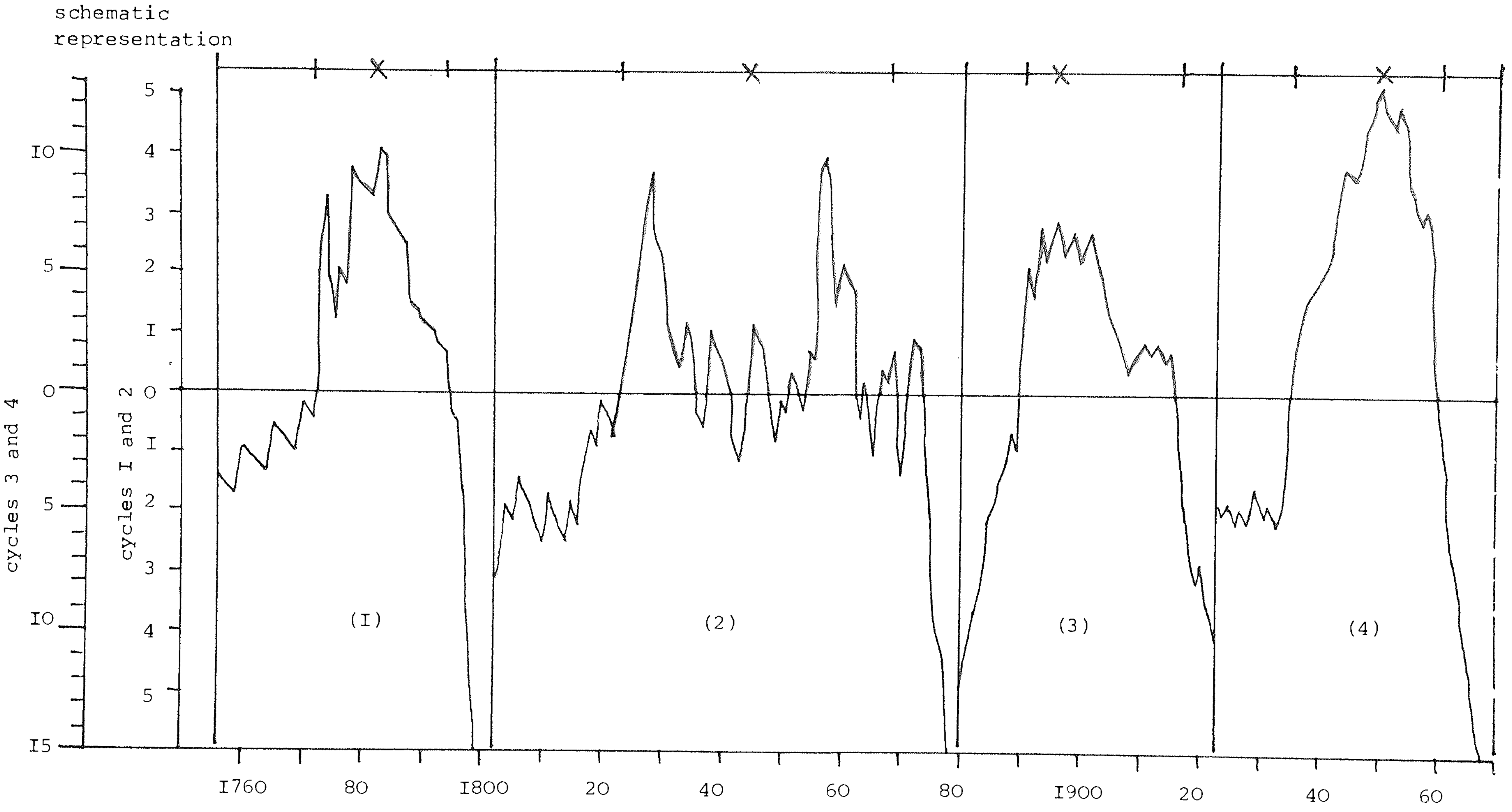
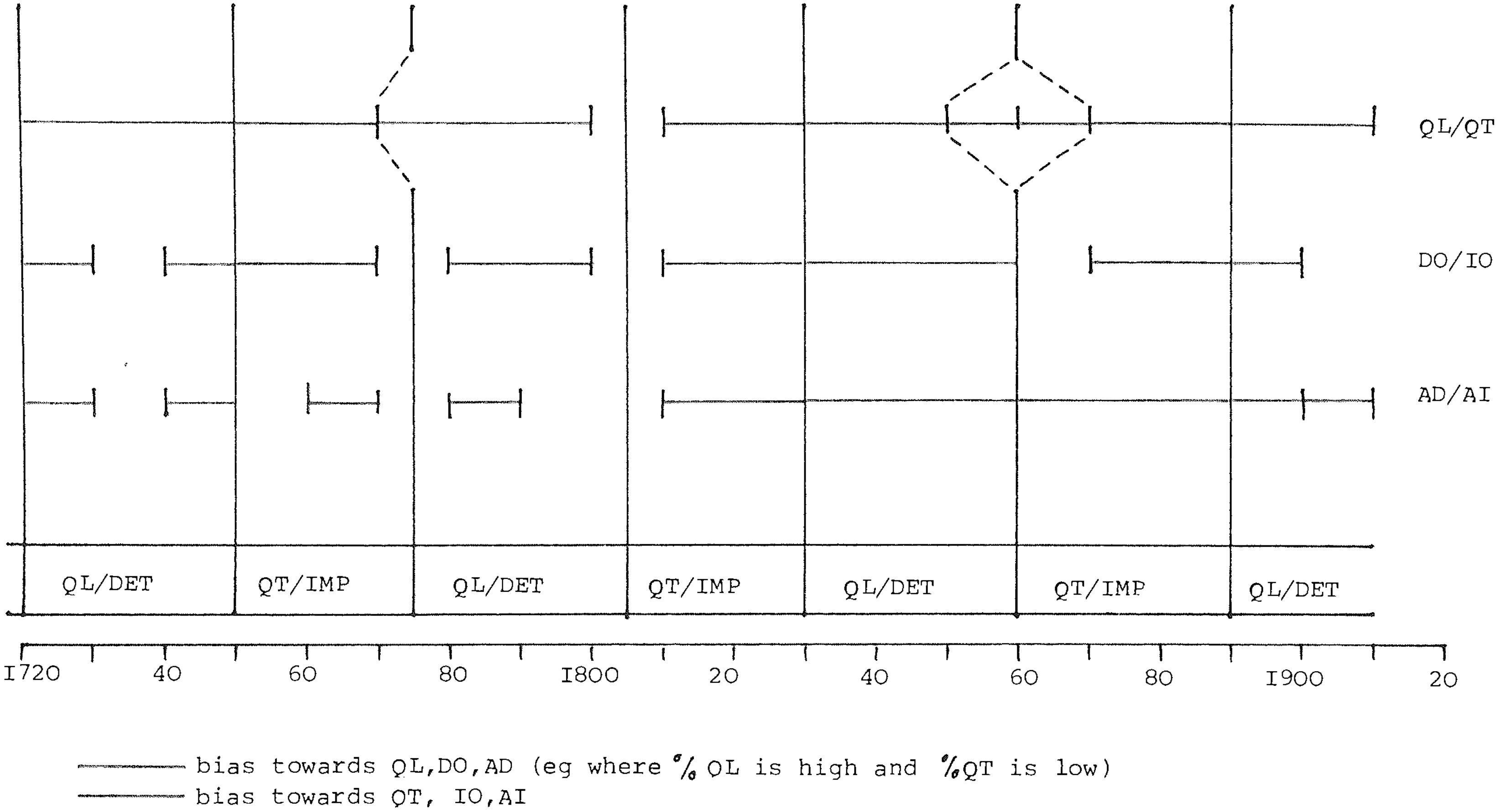


Figure 4.5 - Periodization in the impact bias of innovations



to collectively as 'era' technologies. The first two were largely concerned with power input substitutions. 'Coal-based' technologies included a large number of innovations where steam power was being introduced to replace human labour power, gravity or water power. And 'electrification' consisted mainly of cases where steam power was itself replaced (though it also included innovations which replaced, for example, human labour power for the first time). Coal-based technologies, as a category, also included cases where coal replaced wood - ie a substitution of sources of heat, rather than power. The remaining two era categories were rather different. The third was 'oxygen use', which included not only the introduction of oxygen to steelmaking processes, but also in blast furnaces, in the refining of molten pig iron prior to steelmaking and in the cleaning of steel billets (scarfing). The last era category covered 'add-on cleaners and arrestors', which, again, included innovations in many different sectors of the industry - in the preparation of blast furnace inputs such as coke and sinter, in blast and steelmaking furnaces themselves and in various processing operations such as milling and tinplating.

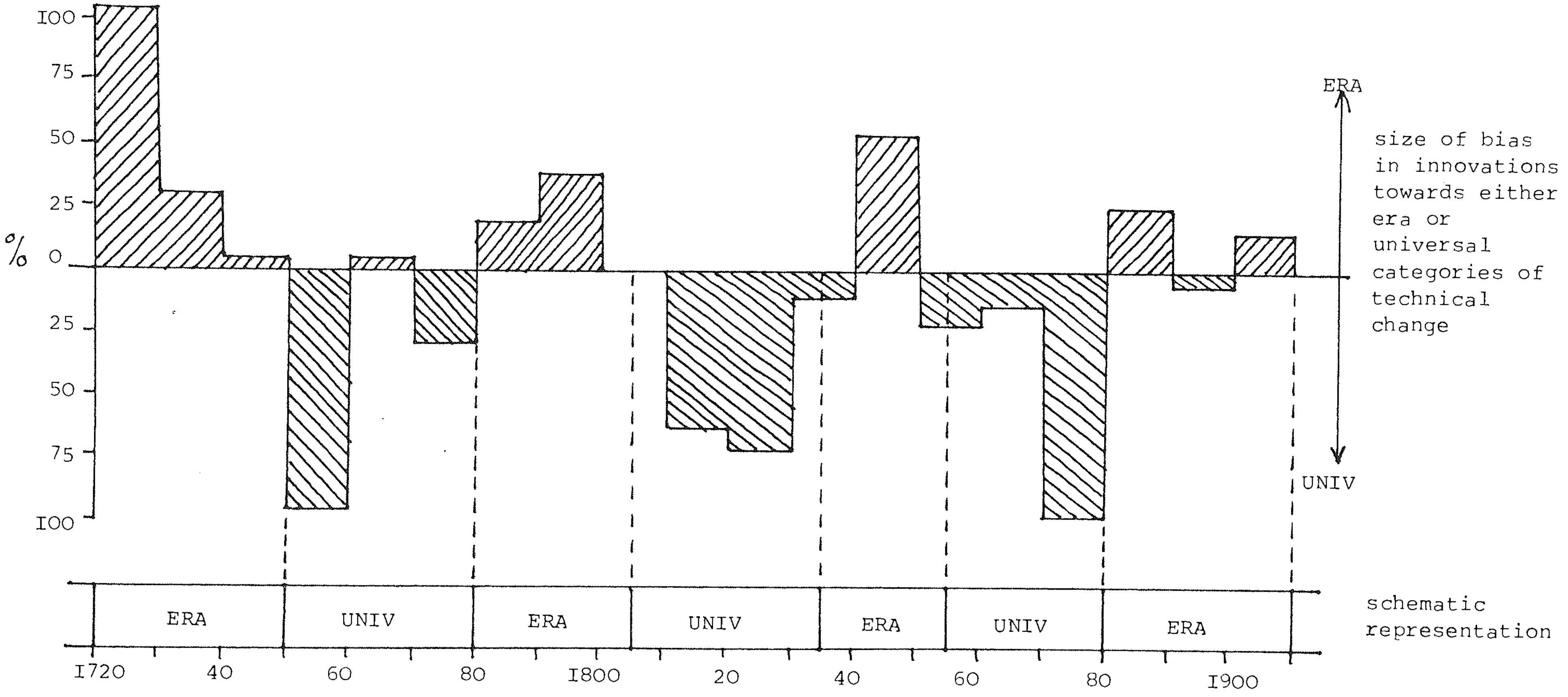
In contrast, the second broad category of technologies covered types of technical change that occurred throughout the study period, rather than in particular eras. Collectively, these were referred to as 'universal' aspects of technical change, and there were four individual categories involved. The first was 'recycling'. This included the reuse of wastes as inputs at a single point in the process chain (such as the use of blast furnace waste heat for blast heating itself) and also the use of wastes from one point in the chain as inputs to another (such as the use of puddling cinder in the blast furnace charge). It also covered cases where iron and steel industry wastes were processed for sale as inputs to other industries (such as the recovery of sulphur from coke oven gases). The second category was 'integration'. This covered cases where the linear process chain was shortened by innovations that allowed steps to be left out (such as the various improvements in wrought iron milling that did away with the need to reheat billets). The third category was 'mechanisation and automation'. This included initial mechanisation - the first time that other power inputs replaced human labour in any given operation, and also those cases where operations already partially mechanised were further mechanised or automated. The last category was a catch-all, covering other increases in 'process efficiency', where improvements were obtained in respect of time taken for a given operation, amounts of inputs used, product quality, etc. Many of these improvements were brought about through changes in plant size or design (such as the use of cast iron bottom plates in puddling furnaces or the introduction of rotating steel furnaces). The classification of innovations according to these categories is given in table 4.4 of annex 1.

The variables (% era and % universal) were regressed on time using least-squares linear regression, and patterns of positive and negative residuals were examined. In both cases, the sequences were found to be significantly clustered (at the .05 level for % era, and at the .10 level of % universal), indicating a periodization.

To characterise the nature of this periodization, the two variables were used to construct a single measure of the extent to which the balance of innovations was shifted towards one or other category. This involved adding or subtracting residual values as appropriate. For example, the size of the bias towards era technologies in a particular decade might be given by adding a positive % era residual to a negative % universal residual (or by subtracting a smaller positive % universal residual from a larger positive % era one). As described by variations in this measure over time, the changing balance between the two categories is shown in figure 4.6 below.

As we can see, between 1720 and 1910, there were four periods when the balance was shifted towards era technologies and three when it was shifted towards the universal aspects. And, as suggested by the schematic representation, the pattern seems to have been fairly rgular, with periods twenty to thirty years long. Figure 4.7 below

Figure 4.6 - The changing balance between era and universal categories of technical change



demonstrates how, through its effect on impact bias, the changing balance between era and universal technologies was associated with the periodization of different types of impact potential.

The observed periodizations of impact potential therefore appear to have been due to periodization in two aspects of variation in the rate and nature of innovations - the overall innovation rate, and the balance between era and universal categories of technical change. And it is these two technical influences that therefore require further explanation by reference to variations in the realm of profits. Before that, however, we go on to look at the other main technical influence hypothesised as being causally important - ie diffusion.

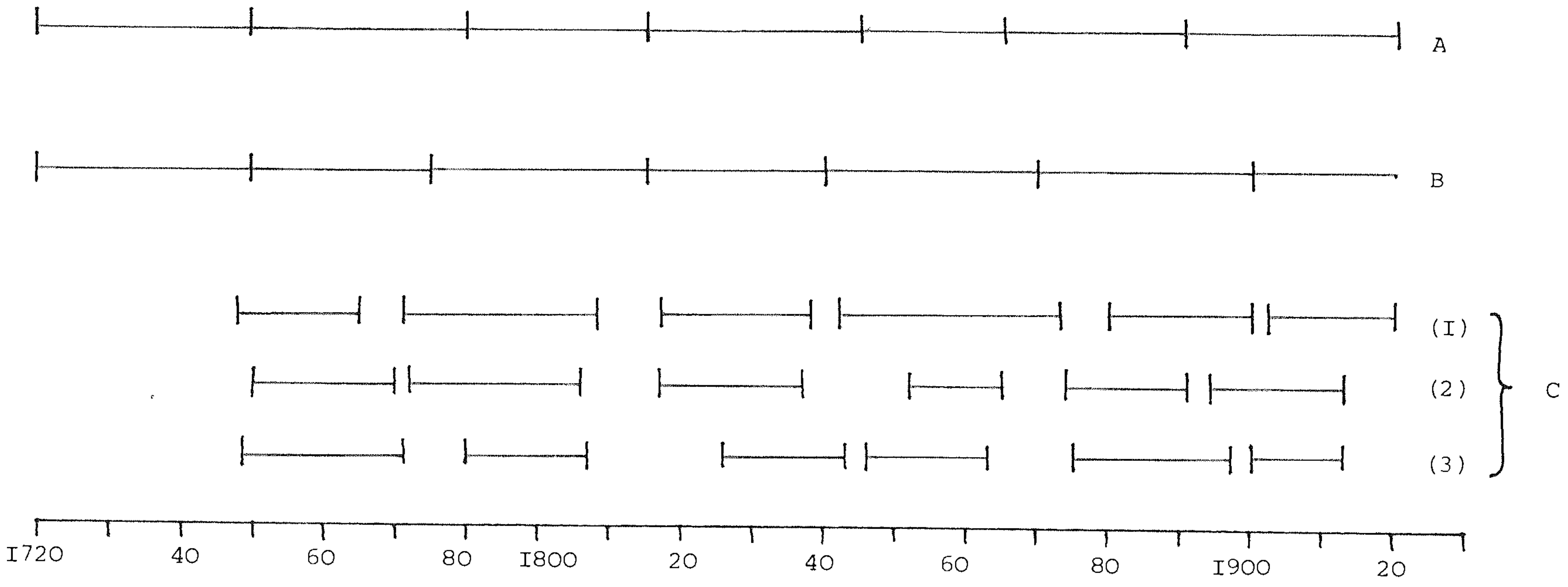
(C2) Diffusion rates

The data for the individual diffusion variables is shown plotted in figures 4.18 to 4.32 of annex 2. For each innovation, the variations in diffusion rates were measured in simple, categorical terms. Where possible, periods of rapid diffusion-in (increase), rapid diffusion-out (decrease) and slow diffusion were identified. As picked out by eye, these periods are indicated on the graphs.

The information given by the twenty-one mutually independent variables was then summarised as follows. For each year between 1740 and 1980, of the total number of variables indicating one or the other, the proportions showing rapid and slow diffusion were calculated. The changes in this ratio over time are shown in figure 4.8 below.

As we can see, there were four distinct periods in which all, or virtually all variables indicated rapid diffusion and three intervening periods in which all variables indicated slow diffusion. Rates of diffusion in general therefore seem to have been markedly

Figure 4.7 – The importance of changes in the balance between categories of technology for the periodization of types of impact potential

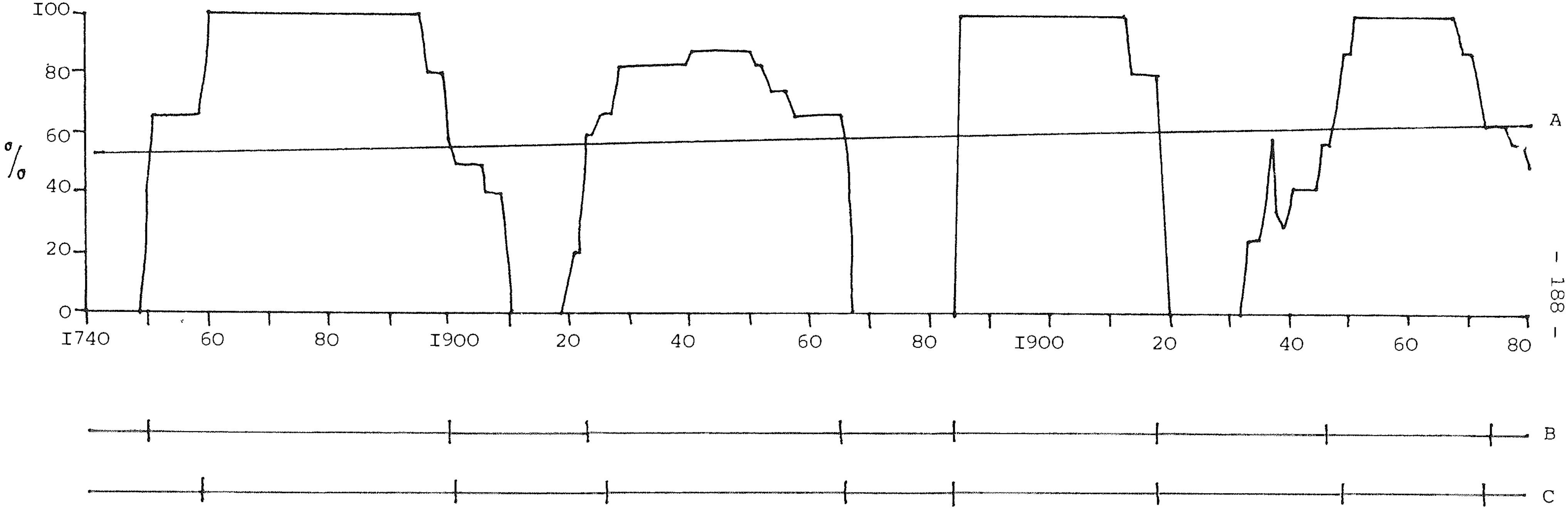


A - balance between categories of technical change towards ——— era ——— universal } (figure 4.6)

B - periodization of impact bias towards ——— %QL, %DO, %AD ——— %QT, %IO, %AI } (figure 4.5)

C - periodization of impact potential towards
(I) ——— fQL, ——— fQT (figure 2.4)
(2) ——— fDO, ——— fIO } (figure 2.5)
(3) ——— fAD, ——— fAI

Figure 4.8 – Variation over time in the proportions of innnovations experiencing rapid and slow diffusion



A - proportion of mutually independent variables indicating rapid diffusion
B - schematic representation of periods of rapid (red) and slow (blue) diffusion
C - as B, using whole set of diffusion variables

periodized.[1] The long run change in the ratio is represented by the semi-averages trend line, which was used to identify the dates of boundaries between periods of rapid and slow diffusion. The resulting schematic representation of the sequence is shown on figure 4.8 immediately below the plotted ratio.

In order to give a best characterisation of the pattern, the same processes of summary and abstraction were applied to the information yielded by the full set of fifty-two variables, and the resulting sequence is shown schematically at the bottom of figure 4.8.

The fact that diffusion rates were periodized on this pattern provides general support for the postulated link between diffusion and unit input levels. And we can now argue, therefore, that the observed periodization in unit input levels was due to periodization of both the technical influences postulated as being causally important - ie the rate and nature of innovations, and the general rate of diffusion. The associations are demonstrated in figure 4.9 below.

(C3) Output growth rates

The six output growth rate variables are shown plotted in figures 4.33 to 4.38 in annex 2, along with the long run linear trends in the data. The statistical evidence for the existence of periodization in output growth rates is given by the fact that, in all six cases, the sequences of positive and negative residuals were found to be markedly clustered, with Z scores significant at the .001 level (see table 4.5, annex 1). As noted, only one set of three variables provides independent evidence, but it doesn't matter whether we consider the absolute or proportional variables as being dependent.

Trying to characterise the nature of periodization was not easy because the variations were far from smooth. As figures 4.33 to 4.38 show, there were frequent peaks and troughs, and these were

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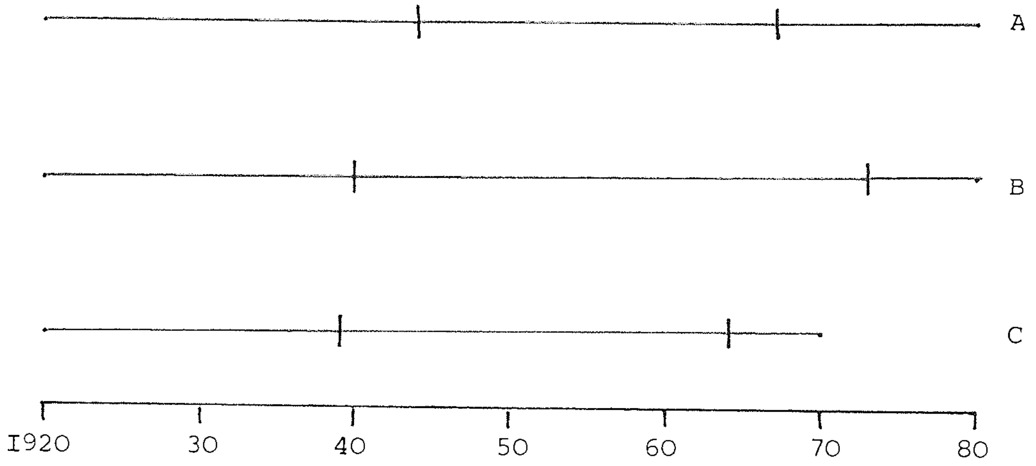
[1] In using these individual variables as the basis for a description of variations in diffusion rates 'in general', it should be noted that the data is not exhaustive, nor does it cover a random sample of innovations within the industry. It simply represents the best data that could be obtained.



A - periods of rapid change (red) and stability (blue) in unit input levels (figure 2.IO)

B - periods of generally rapid (red) and slow (blue) diffusion (derived in the same way as the other schematic representations of diffusion patterns, but using only those variables independent of both innovation and unit input level data sets)

C - periods of high (red) and low (blue) impact potential (table 2.9)

Figure 4.9 - Comparison of periodization in unit input levels, diffusion rates and impact potential

quite major, especially for the proportional growth rate variables. However, many of these peaks and troughs, which occurred at intervals of between five and twenty years, seem to reflect some sort of secondary periodization that was superimposed on to a more fundamental one with a longer periodicity.

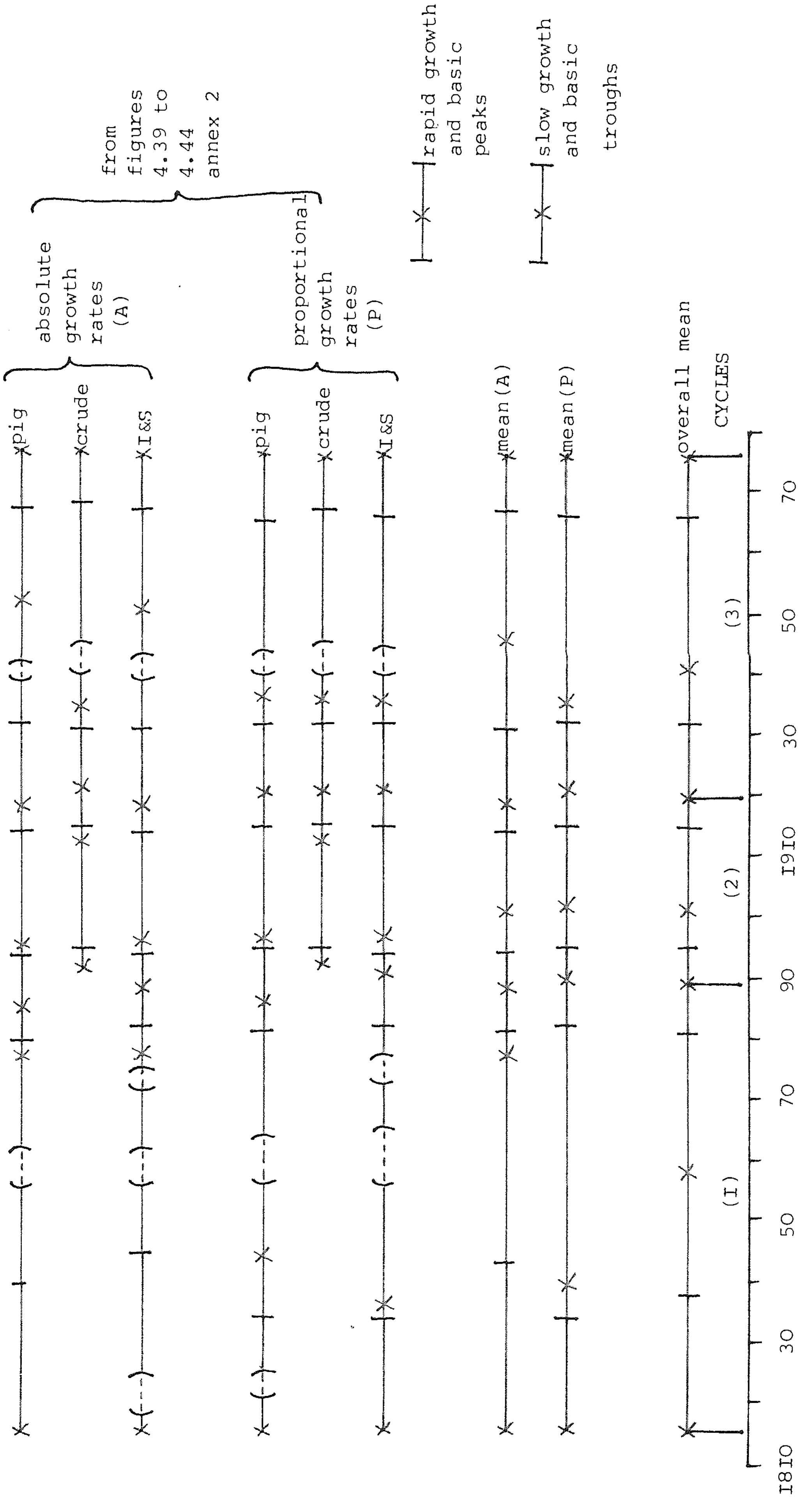
Some peaks appeared to be more basic, in the sense that those either side became progressively less high as we go backwards or forwards in time. And similarly, some of the troughs appeared to be more basic, in that those preceding and following became progressively less low.

Between 1816 and 1976 there were three primary peaks and four primary troughs (including the troughs at the start and end of the period). On the basis of the primary troughs, we could therefore recognise three basic divisions of the period studied. Within each division, there was a common, two-phase pattern. In the first phase, despite the secondary peaks and troughs, we could see that growth rates were basically accelerating until the primary peak. And in the second phase, growth rates were basically decelerating, until the primary trough was reached. This cyclical nature of the underlying periodization is best illustrated by looking at the patterns of residual variation around the linear trends in the data within each of the three divisions. For the six variables, these are shown in figures 4.39 to 4.44 (annex 2).

As we can see, each cycle basically consists of a central period of relatively rapid output growth (positive residuals) surrounded on both sides by periods of slow output growth or decline (negative residuals). The information in figures 4.39 to 4.44 is summarised in schematic form in figure 4.10 below, where a single descriptive model has been abstracted to represent the pattern of variation in output growth rates in general.

The existence and nature of this cyclical variation in output growth rates provides general support for the postulated links between

Figure 4.10 - Generalised description of cyclical variation in output growth rates



profits and technical change. As figure 4.11 below demonstrates, innovation and diffusion rates both tended to be high when output growth was rapid, and vice versa.

In addition, the changing balance between era and universal categories of technology was also found to be associated with variations in output growth. Residual variations in output growth rates were significantly correlated with residual variations in the proportion of innovations classified as belonging to era technologies (see table 4.6, annex 1).

So, all those aspects of technical change which were shown to be associated with the periodization of environmental change have now also been found to be linked to cyclical variations in the realm of profits.

(C4) Output levels

Since the output growth rate variables were computed directly from the output level data, we know that the latter is also periodized. Using the same procedures as were used on the output growth rate data, a general descriptive model of the cyclical variations in output levels was abstracted, and is shown in figure 4.12 below.

As indicated, the output level sequence lags behind that in output growth rates. And, because of the nature of the mathematical linkage, the lag is roughly a quarter of a cycle (though this does not imply a constant number of years).

We can now argue that the observed periodization of changes in gross consumption levels was associated with cyclical variation in the realm of profits in three different ways. First of all, levels of gross consumption are influenced directly by variations in output levels. Secondly, they are influenced by changes in unit input levels, which were shown to be associated with periodization in two aspects of technical change - the rate and nature of innovation and the rate of diffusion. And, in turn, both these aspects of technical change

Figure 4.11 - Comparison of periodization in rates of diffusion, innovation and output growth

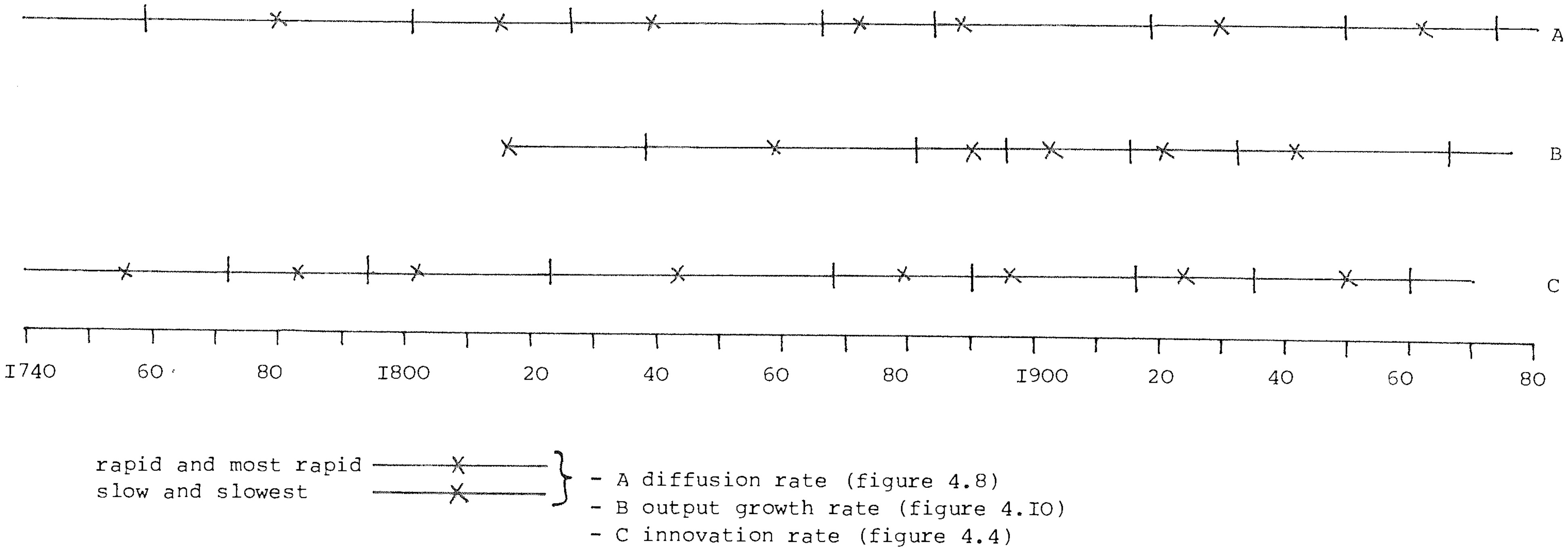
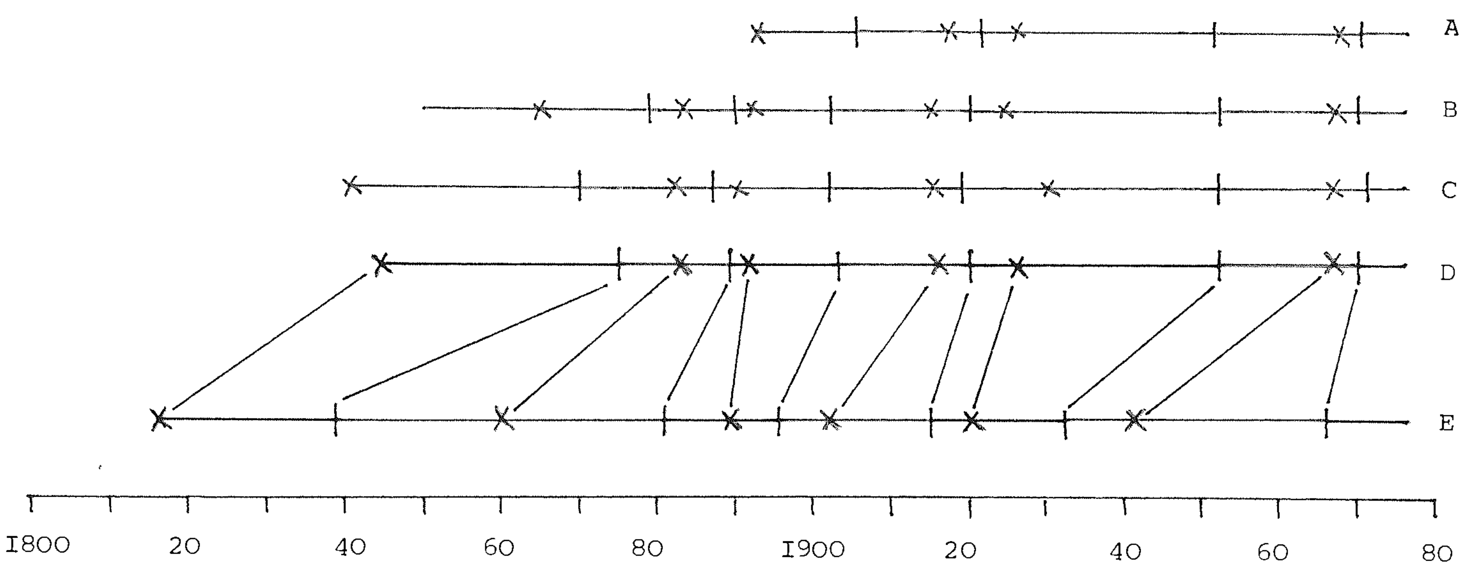


Figure 4.12 - Comparison of periodization in output levels and output growth rates



Output levels - —×— high and peak } - A crude steel
- —×— low and trough } - B iron and steel
- C pig iron
- D in general (where boundary dates are means of those in A to C)

E: Output growth rates - —×— rapid and most rapid } (from figure 4.IO)
- —×— slow and slowest }

were found to be associated with cyclical variations in output growth rates.

(C5) Summary

All those variables representing assumed causal influences were found to have been periodized, and on patterns that provided evidence for the existence of the postulated links. And, as a result, the observed patterns of environmental change could be empirically linked, either directly or via technical change, to the cyclical variations in the realm of profits, as represented by either output level or output growth rate data. The empirical associations are summarised in diagrammatic form in figure 4.13 below.

4D THEORETICAL ACCOUNTS

Of the empirical links detailed in figure 4.13 below, there are a number that require no further explanation. First of all, by definition, changes in gross consumption levels can only be due to variations in output levels and/or unit input levels. Secondly, by mathematical decomposition, changes in impact potential were bound to be due to variations in innovation rate and/or impact bias (and/or innovation bias). And thirdly, although the three were statistically independent, the links from impact potential and from diffusion to unit input levels are really self-explanatory.

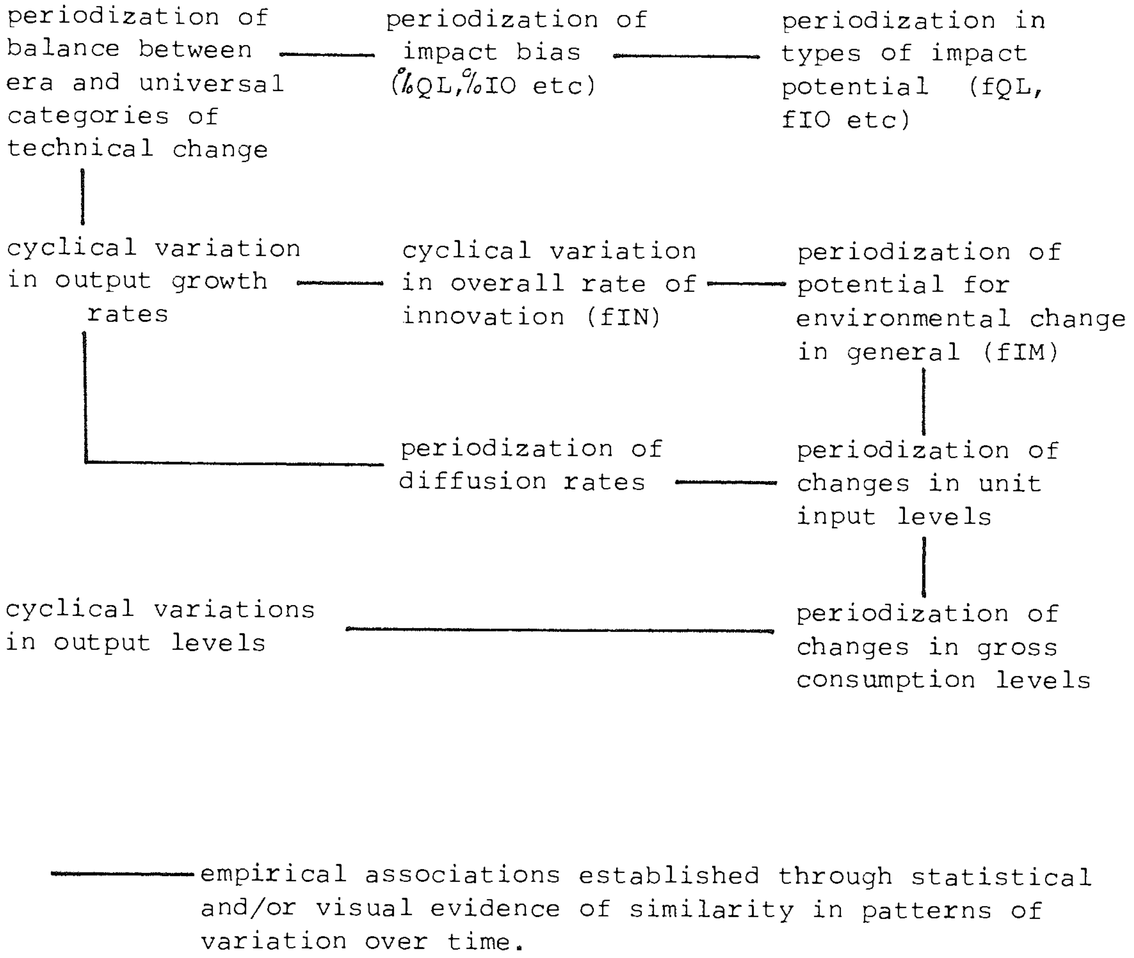
The main empirical results that do need some theoretical explanations are therefore as follows:

1) The links between output growth and the various aspects of technical change - the overall rates of innovation and diffusion, and the changing balance between era and universal categories of technology.

2) The periodization in the output data itself.

(D1) Links between output growth and aspects of technical change

There are two alternative explanations for these links that make use of the relationships between profit components that were



——— empirical associations established through statistical and/or visual evidence of similarity in patterns of variation over time.

Figure 4.13 - Summary of empirical links between environmental change, technical change and profits

discussed when introducing the output data. We consider, first, the positive associations between innovation rates or diffusion rates and rates of output growth. And in using the models to account for these links, we have to subsume both innovation and diffusion under the general label of technical change.

The first of these models, after W E G Salter (ref: 45), can be seen as a 'supply side' linear chain. The form illustrated below gives us an explanation for the association between rapid technical change and rapid output growth, though the model could equally well be used to account for the association between slow technical change and slow output growth.

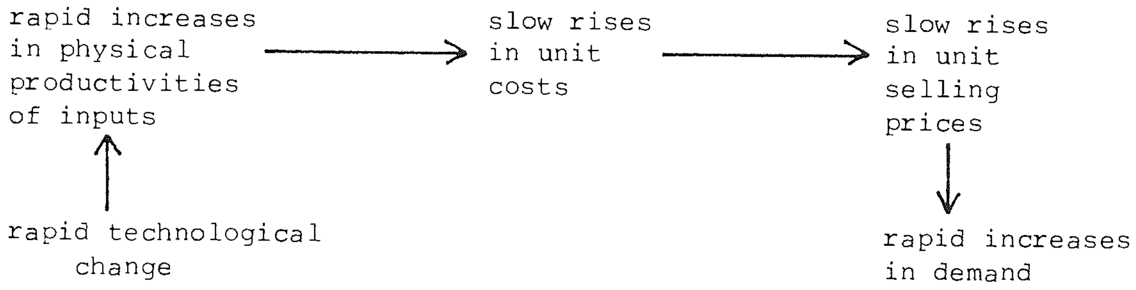


Figure 4.14 - The supply side linear chain

In contrast, the second model, after N Kaldor (ref: 31), can be seen as a 'demand side' linear chain. And, again, its applicability is not limited to the case illustrated below, where the model is used to account for the association between rapid output growth and rapid technological change.

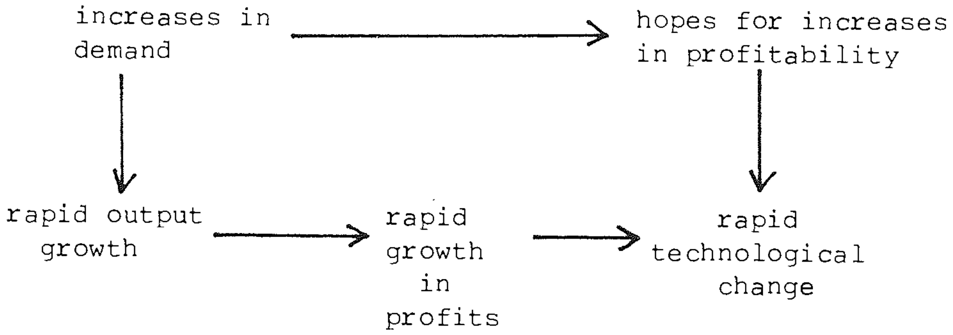


Figure 4.15 - Demand side linear chain

Clearly, each model suggests that the association between output growth and technical change is caused by a different mechanism. In the supply side chain, the crucial mechanism is the response of demand to price reductions brought about by technical change. And in the demand side chain, the crucial mechanism is investment, which is linked back to high demand, both through an increased incentive to invest and through an increased ability to invest.

Both of these mechanisms can also offer explanations for the observed association between rapid output growth and the occurrence of era technologies. The era technologies were characteristically of major significance, not only because of their environmental impacts, but also because, over only a short time period, they found separate applications in many different sectors of the industry. And we can suggest that this is because they incorporated scientific advances which were sufficiently basic to give rise to such a breadth of potential applications. In contrast, the innovations in the universal categories tended to incorporate scientific advances of less far-reaching potential, with only one or two particular applications.

In the supply side model, we would therefore expect the price reductions associated with era technologies to be large, and to result in demand increases that trigger rapid growth in output. In contrast, we would expect that the innovations in universal categories would only affect selling prices marginally, and that any stimulus to output growth would be weak.

In the demand side model, we would only expect to see the sort of major investment program represented by era technologies when demand was very strong, and when both the incentive and the means were available for financing such a program. But the more minor investment represented by innovations in the universal categories could still be undertaken when demand was weaker and when output growth was slow.

The study provided no direct evidence with which to test these models one against the other, and we therefore accept that the links between output and technical change may have either a demand side or a supply side explanation.

(D2) The periodization of output growth

The patterns of variation in output growth could be accounted for in several different ways, in the sense that the results are compatible with a range of models of economic growth. In general, it is the structural change models that seem likely to offer the better accounts, since any balanced growth model would have to cite a series of exogenous factors to account for the demonstrable 'dips' in output growth. And of the structural change models, it is Long Wave Theory that is potentially the most powerful, in that it explicitly leads us to expect the sort of patterns observed. It argues that capitalist development is characteristically discontinuous, and consists of waves of fairly regular periodicity. In order to see how good an account of the case study results is given by the long waves model, we can make rough comparisons on both the length and timing of cycles.

First of all, although there is no single figure for cycle periodicity that is universally accepted by long wave theorists, it is generally put at somewhere between forty and sixty years. The generalised patterns of change in output growth, innovation and diffusion rates shown in figure 4.11 were used to generate comparable cycle length estimates from the case study (and the detailed results are given in table 4.7, annex 1). The diffusion pattern yielded eleven estimates with an average of sixty years. Output growth rates yielded nine estimates with an average of forty-seven years, and innovation rate yielded twelve estimates with an average of fifty-five years. When all thirty-two estimates were considered, the average cycle length was fifty-four years - ie close to the middle of the suggested range.[2]

When comparing the case study with Long Wave Theory on the question of the timing of cycles, we could not refer to a single, and generally agreed long waves chronology. However, a generalised long waves chronology was produced on the basis of the slightly different ones offered by seven authors in the tradition (by procedures discussed in conjunction with the data given in table 4.8, annex 1). And this was compared with a generalised case study chronology produced by taking

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[2] The dispersion around this mean was roughly what we would expect from the normal frequency distribution. 69% of estimates fell within the range mean plus or minus one standard deviation (ie were greater than 41 and less than 67 years).

the means of key dates in the output, diffusion and innovation patterns shown in figure 4.11. The comparison between these two generalised chronologies is shown in figure 4.16 below.

As we can see, the case study results do not conform very closely to the generalised long waves chronology. However, the mismatch in this initial, gross conparison does not necessarily mean that we should reject the long waves model altogether. There are two simple hypotheses which, if they were shown to be correct, would allow us to interpret figure 4.16 as indicating a good match.

First of all, we can see that, after about 1840, the case study chronology leads its long waves counterpart by a fairly consistent amount - fourteen years on average. And we can therefore postulate that the lag was systematic in nature. Such a systematic difference could be a function of real world relations between iron & steel and the rest of the economy, or it may be a statistical artefact, produced by differences in the nature and/or handling of the two sets of data.

Secondly, iron and steel was a 'leading sector' industry in the early waves.[3] And we can postulate that, as engines of national economic change, such industries would be likely to experience cyclical growth before the other, 'trailing sectors' of the economy. If such sectoral differences in timing do exist, then the large amount by which the case study chronology leads in the first wave might well be expected.

If these two hypotheses were demonstrated to be correct, we could then argue that the case study results conformed closely to the long waves model as regards both the length and timing of cyclical variation. In the absence of evidence one way or the other, however, we can only make a cautious and provisional acceptance of Long Wave Theory, on

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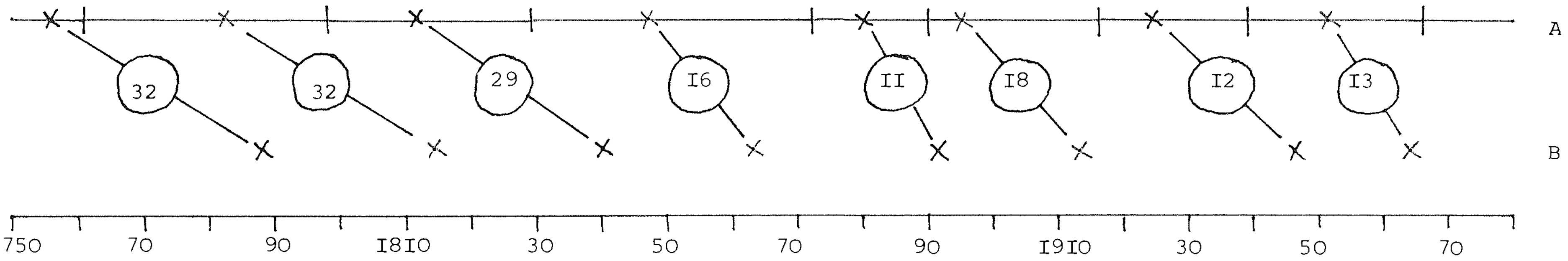
[3] And is very widely accepted as being such, in the sense that it is seen as having been integral to the industrial revolution.

Figure 4.16 - Comparison of periodization in the case study with that described by Long Wave Theory



A - generalised case study chronology - ×— rapid growth and peak } output and technical change
- ×— slow growth and trough

B - generalised long waves chronology - × peaks } (from table 4.8)
- × troughs

○ - number of years by which case study chronology leads the basis of the cycle length comparisons. We can suggest, therefore, that, in general, the periodization of output growth is likely to be well accounted for by structural change models of economic development.[4] And there is some evidence that, of these, Long Wave Theory may be the best single model.

4E DISCUSSION AND CONCLUSIONS

Many of the comments made at the end of chapter two, about the crudeness of data and methods, also apply in evaluating these results. And, indeed, it would not have been appropriate to use very fine data or sophisticated techniques when the patterns we were trying to account for were themselves rather coarse. But despite the crudeness of the empirical analysis, the results do allow us to draw a firm conclusion in relation to the main objective of the chapter. This is that the periodizations of environmental change described in chapter two were not chance observations, but resulted from periodizations in the realms of profit and technical change. Not only was the statistical and/or visual evidence for the existence of the links very clear cut, but it was also possible to give simple theoretical explanations for those links.

As regards the basic aims of the thesis, the broad implication of this conclusion is that it does appear possible to develop a level of analysis of relationships between profit, technology and environmental change that supplements, and lies between those which exist at micro and macro levels. And the results provide two types of input to this meso level analysis.

First of all, they suggest some of the categories of profits and technical change that are likely to be important in explanations at this level of analysis. As regards technical change, the overall rates of innovation and diffusion were found to be particularly important, and are likely to be so for other industries. Equally, we can

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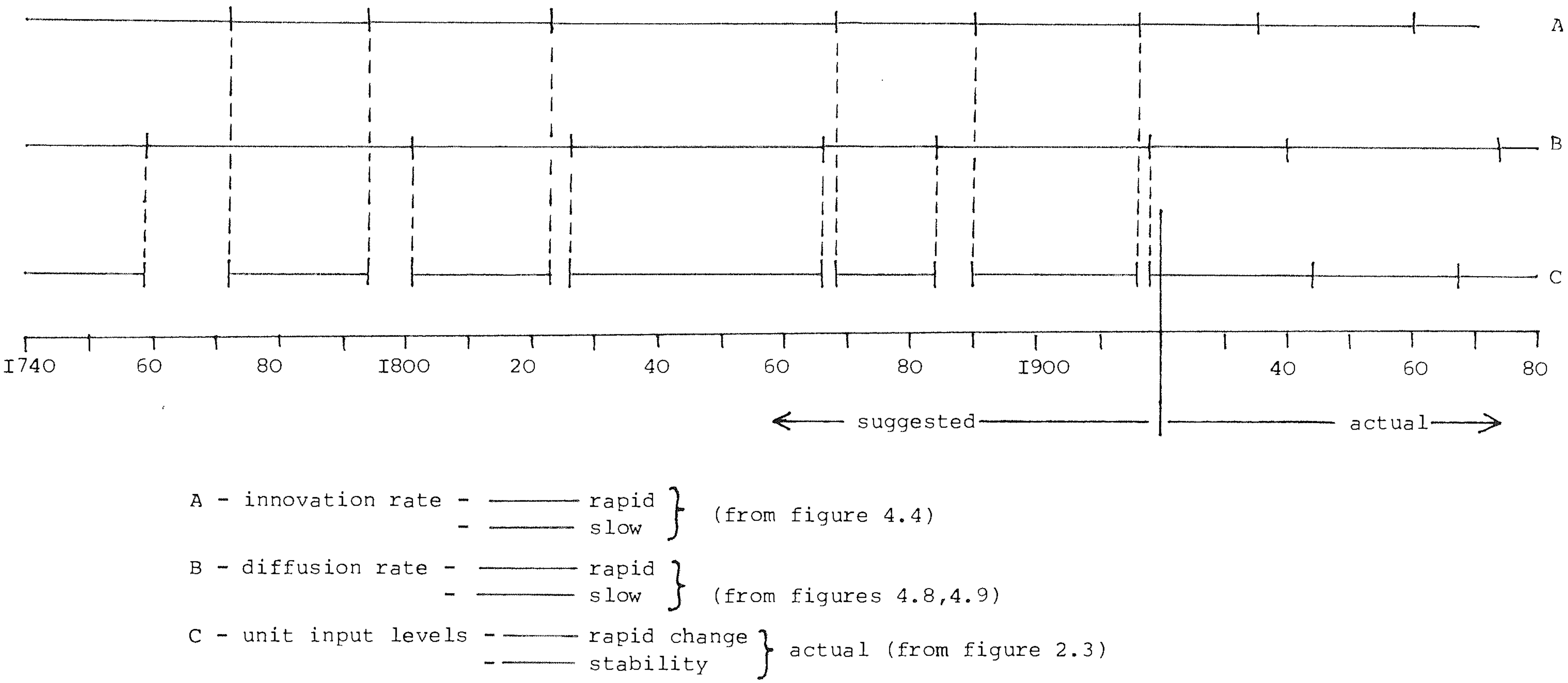
[4] See references 86 to 94.

suggest that many other industries are also likely to exhibit the distinction between major technologies which change the nature of inputs, and minor technological changes which lead to changes in the amounts of existing inputs used. As regards profits, we can clearly point to the importance of variations in outputs, both through their direct influence at the gross consumption level, and through their associations with aspects of technical change. And, to the extent that output data provides a good surrogate indicator, we can argue that the unit costs and productivities of inputs, and unit selling prices are also important explanatory categories.

The second input provided by the results is that they suggest what sort of theory is likely to be useful in bridging the gap between the types of framework traditionally applied at micro and macro levels of analysis. The structural change models in general, and Long Wave Theory in particular, see capitalism as developing in an uneven or discontinuous way. They therefore tend to deal with aspects of capitalism that are neither immutable nor infinitely variable, but which may be generally characteristic of fairly long time periods, in broad sectors of the economy and so on.

As well as giving a clear answer to the basic question of the chapter, and providing these inputs to a more general meso level analysis, the third thing the results do is that they allow us to return better equipped to some of the questions that were posed at the end of chapter two. First of all, it was noted that we could only speculate about whether or not unit input and gross consumption levels were periodized before 1920 (when the hard data started). Since both the technical factors influencing changes in unit input levels were found to have been periodized before 1920, we can now strongly argue that unit input levels themselves were probably periodized as well. Figure 4.17 below shows those periods in which we would expect to find stability and rapid change in unit input levels if we had the data.

Figure 4.17 - Actual and suggested periodization of changes in unit input levels



Similarly, if we had the hard data, we would expect to find that changes in gross consumption levels were periodized before 1920. We have direct evidence of periodization in output levels and strong circumstantial evidence for periodization in unit input levels.

Secondly, it was noted at the end of chapter two that we could only speculate about whether or not environmental change was periodized on the same pattern in other industries, and at the broader, ecological and social levels of description. The structural change models in general, and Long Wave Theory in particular are models of economic change applicable at the level of the national economy (at least). We would therefore expect that many other industries would exhibit discontinuities in patterns of environmental change that were similar to those observed in the iron and steel industry. And, in turn, this would give us the stated precondition for expecting that environmental change was also periodized at ecological and social levels of description.

4F Annex 1: Data and statistical tables

Table 4.1 - Description and classification of diffusion variables

Variable code	Description		Dependence[1]	Figure where plotted
1	% by number of steel furnaces are-	open hearth		4:19
2		Bessemer	B	
3		electric arc	B	
4		oxygen	B	
5		tropenas	B	
6	% by number of blast furnaces are-	charcoal	B	4:20
7		coke	B	
8	% by number of coke blast furnaces are-	water-blown	A B	4:21
9		steam assisted	B	
10		steam-blown	B	
11	% pig iron by weight is-	charcoal-smelted	B	4:22
12		coke-smelted	A B	
13	% wrought iron by weight from-	finery/chafery	B	4:23
14		potting process	A B	
15	% by weight of coke from-	open coking	B	4:24
16		beehive ovens	A B	
17		retort ovens	B	
18		by-product ovens	B	
19	% crude steel by weight from-	cementation	A B	4:25
20		crucible process	B	
21		Bessemer	B	4:26
22		open hearth	B	
23		electric processes	B	
24		oxygen converters	B	
25	sinter as % by weight of ferrous inputs per unit of pig iron		A	4:27
26		open hearth	B	4:28
27		Bessemer	B	
28		electric arc	A B	
29		oxygen converters	B	
30	furnace	tropenas	B	

31	numbers-	charcoal blast		B	4:29,30
32		coke blast	A	B	
33		steam-blown BF	A	B	
34		puddling	A	B	4.31
35	crude steel output from-	open hearth	A	B	4:32
36		Bessemer		B	
37		electric arc		B	
38		oxygen converters		B	
39	input amounts-	gross sinter	A		(2)
40		gross electricity			
41		gross oxygen			
42		unit sinter			
43		unit electricity	A		
44		unit oxygen	A		
45		unit coke	A		
4		unit iron ore			
47	coal-based technologies		A		4:33
48	electrification		A		
49	add-on cleaners and arrestors		A		
50	oxygen applications		A		
51	simple steel alloys		A		
52	wrought iron product diversification		A		

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[1] A: mutually independent within diffusion data set
B: independent of innovation and unit input level data

[2] Chapter two, annex two, figures 2.19 to 2.36.

Table 4.2 - Diffusion variables: sources of raw data and computations

Variables and other data	Sources[1]/Computations[2]
12	Ref: 24, p 67
13, 14	Ref: 24, pp 84, 86, 106. Ref: 8, p 38
15 to 18	Ref: 8, p 210
20	Ref: 24, p 32
26 to 30 total steel furnace numbers	Ref: 8, p 332 (1910-17) Ref: 4 (1936-80)
31, 32 total blast furnace numbers	Ref: 24, pp 12, 21, 113, 219, 243, 249, 252
33	Ref: 24, pp 70, 71
34	Ref: 24, p 106. Ref: 8, p 38
35 to 36	Ref: 8, pp 108, 126, 164, 183, 195, 230, 237, 306, 322, 346, 366, 429, 484, 596 (1870-1960) Ref: 4 (1960-80)
total crude steel output	See table 4.3 below
39 to 46	See chapter two, annex 1, table 2.6
47 to 52	See chapter two, annex 1, table 2.1
1 to 5	(26) to (30)/total steel furnace numbers x 100
6, 7	(31), (32)/total blast furnace numbers x 100
8 to 10	(33)/(32) x 100
11	100 - (12)
19	100 - (20)
21 to 24	(36) to (38)/total crude steel output level x 100
25	(42)/(46+42) x 100

[1] Many of the variables plotted in figures 4.19 to 4.32 also make use of innovation dates given in chapter two, annex 1, table 2.1

[2] Where parenthesised numbers are diffusion variable codes

Table 4.3 - Output level data sources

Dates covered	Reference number	Page number
	PIG IRON	
1810-15	24	228
16-22	24	241
23-30	24	243
31-40	24	248
41-43	24	249
44-46	24	251
47,48	24	249
49,52	24	252
53-73	(1)	
74-77	8	164
78-86	8	106
87-96	8	129
97-1906	8	183
1907-14	8	230
15-18	8	306
19-22	8	346
23-26	8	366
27-32	8	429
33-39	8	484
40-47	8	596
48-50	4: (1955)	141
51-59	4: (1961)	147
60-69	4: (1971)	172
70-80	4: (1982)	217
81	4: (1983)	171
	CRUDE STEEL	
1873,74	49	53
75-77	8	164
78-86	8	108

Dates covered	Reference number	Page number
1887-96	8	126
97-1906	8	183
1907-14	8	230
15-18	8	306
19	8	346
20,21	24	193
22-26	24	366
27-32	24	429
33-39	24	484
40-60	24	596
61-69	4: (1971)	170
70-80	4: (1982)	218
81	4: (1983)	170

[1] Data during this period was estimated, as follows: W G Hoffman (ref: 23) provides an output level series for iron and steel, which runs from 1800 to 1933, and is indexed 1913=100. For each of the fifteen years either side of our data gap, the ratio between the pig iron data and the Hoffman index was calculated. The ratio was found to increase over time - probably reflecting the fact that steel became an increasingly important output during the period. The increase in the size of the ratio over time was represented by a linear, least squares regression equation, and the line was used to estimate pig iron output levels from 1853 to 1873.

[2] From 1873 to 1981, iron and steel output levels were given by addition of pig iron and crude steel values. From 1810 to 1872, iron and steel output levels were estimated from the Hoffman index as follows: the added pig iron and crude steel data overlaps the Hoffman index from 1873 till 1933. The ratio between the two values was calculated for each year in this overlap period, and was found to be very consistent. The average value of the ratio was used to estimate iron and steel output levels in millions of tons from the index in the period before 1873.

[3] These links between the output level variables mean that different variables were independent at different times. From 1810-52, pig iron and iron & steel were mutually independent. From 1853-72, one, but not both of pig iron and iron & steel were independent. From 1873 to 1981, pig iron and crude steel were mutually independent, but both linked to iron & steel.

Table 4.4 - Classification of innovations by era and universal categories of technical change

Era technologies:
coal-based = C
electrification = E
oxygen use = O
add-on cleaners/arrestors = A

Universal aspects:
recycling = R
efficiency increases = E
function integration = I
initial mechanisation = M
further mechanisation/automation = A

Collective categories:
UO = universal only
EO = era only
B = both universal and era

Innovation code	Era category	Universal category	Collective
6	C		EO
7	C	E	B
8	C	I	B
9	C	EIA	B
10	C		EO
11		A	UO
12	C		EO
13	C	E	B
16		E	UO
17		R	UO
18		EI	UO
20		R	UO
21		R	UO
22		IM	UO
23	C		EO
24		EI	UO
30		R	UO
32		A	UO
33		R	UO
35		I	UO
36	E	M	B

Innovation code	Era category	Universal category	Collective
37	E	IM	B
38	E	M	B
39		A	UO
40	E		EO
41		A	UO
42	E	A	B
51	E		EO
53	E	R	B
54		I	UO
55	E	E	B
56	E	EIA	B
57		E	UO
58	O		EO
59	E	IA	B
60		I	UO
61	C	M	B
62	C	M	B
65	E	IA	B
66		IM	UO
67	E		EO
68	E		EO
69	E		EO
70		I	UO
72	C	A	B
74	C		EO
76		E	UO
77	E	IA	B
78	C	I	B
79			
80	C	I	B
81		I	UO
84	C	M	B
85	C	I	B
86	C	I	B
92		A	UO

Innovation code	Era category	Universal category	Collective
94	C		EO
95	C	I	B
97	E		EO
98		E	UO
100		I	UO
101	O	R	B
103	C		EO
105	C	E	B
106	C	A	B
107	C	E	B
108	C	E	B
109	C	E	B
112		E	UO
113		I	UO
114	C	E	B
115		R	UO
117	A		EO
118	A		EO
119	A		EO
121	A		EO
123	A		EO
124	O		EO
125	O		EO
127	EA		EO
128	EA		EO
131		I	UO
135	O		EO
136	O		EO
137	O		EO
138	O		EO
139	O		EO
140	O		EO
141	C	M	B
142	C		EO
143	C		EO

Innovation code	Era category	Universal category	Collective
144	C	M	B
145		R	UO
146		IA	UO
147	E	E	B
149	E	I	B
152		R	UO
155		E	UO
156		E	UO
157	O		EO
158	O		EO
159	O		EO
161	O		EO
162	A		EO
163	A	R	B
164	O		EO
165	A		EO
166	A		EO
169	A	R	B
170	A		EO
171	E		EO
172		EA	UO
173	A		EO
174	A		EO
175	A		EO
176	EA		EO
177	E		EO
178	A		EO
179	EA		EO
180	A		EO
181	A		EO

Total frequencies:

coal-based	30
electrification	24
oxygen use	15
add-on cleaners	21
recycling	12
efficiency increases	21
function integration	26
initial mechanisation	10
further mechanisation/automation	15

universal only	34
era only	50
both	36
neither	55
all universal	70
all era	86

Table 4.5 – Analysis of sequences of positive and negative residuals around long run linear trends in output growth rates

		Pig iron	Crude steel	Iron and steel
Absolute Growth Rates	Positive	78	63	78
	Negative	83	35	83
	Runs	11	10	15
	Z(1)	-11.1	-8.0	-10.5
	Significance(2)	.001	.001	.001
Proportional Growth Rates	Positive	80	48	77
	Negative	81	50	84
	Runs	15	10	17
	Z	-10.5	-8.1	-10.2
	Significance	.001	.001	.001

[1] Negative Z scores indicate clustering tendencies

[2] The very high significance levels partly reflect the use of moving averages in figures 4.33 to 4.38 in annex 2, from which the frequencies were taken.

Table 4.6 – Relationships between output growth rates and the balance between era and universal categories of technical change (Spearman's rank correlation coefficients – 1820 to 1960)

	X_1	X_2	X_3	X_4
Y_1	+.495 (.05)	+.544 (.05)	+.504 (.05)	+.593 (.05)
Y_2	+.170 ($<$.10)	+.099 ($<$.10)	−.018 ($<$.10)	−.214 ($<$.10)

Y_1: residual variation in %era, values ranked 1 = largest positive to 15 = largest negative

Y_2: as Y_1 for % universal

X: decennial means of annual residual variation in output growth rates around cycle trends, ranked 1 = largest positive to 15 = largest negative:

X_1 absolute growth of pig iron

X_2 absolute growth of iron and steel

X_3 proportional growth of pig iron

X_4 proportional growth of iron and steel

( ): significance levels of Rs coefficients

Table 4.7 - Estimates of cycle lengths in case study data (from figure 4.11)

Estimator types*	Diffusion rate	Output growth rate	Innovation rate
A	57 57	74 30 56	46 77 44
B	59 49 73	43 39	60 53 54
C	67 58 65	57 37	51 67 45
D	65 52 55	34 51	74 48 44
Mean	60	47	55

*A: Trough to trough interval

B: Peak to peak interval

C: Interval between start dates for periods of rapid diffusion, output growth, innovation

D: Interval between start dates for periods of slow diffusion, output growth, innovation

Table 4.8 – Construction of generalised long waves chronology

	Dates of peaks				Dates of troughs			
Authors	1	2	3	4	1	2	3	4
A		1850	1905			1821	1878	1932
B		1857	1903	1958		1832	1880	1934
C	1805	1873	1920	1973	1780	1850	1896	1945
D	1813	1874	1914		1790	1844	1895	
E	1814	1869	1917		1790	1848	1896	1933
F	1825	1845	1912	1964	1790	1835	1893	1933
G	1813	1873	1920	1970	1789	1849	1896	1940
Mean	1814	1863	1913	1966	1788	1840	1891	1936

[1] Mean peak and trough dates are those appearing in figure 4.16

[2] Authors:
A S Kuznets (ref: 17, p 293)
B J J Van Duijn (ref: 51, pp 223-233)
C E Hobsbawm (ref: 1, p 152)
D J Schumpeter (ref: 41, p 10)
E N Kondratiev (ref: 20, p 47)
F W W Rostow (ref: 42, tables 2 to 7)
G R S Hartman (ref: 20, pp 66, 67)

[3] In some cases, individual authors gave chronologies in terms of upswing and downturn phases, so that peak and trough dates were known. Other authors followed the original formulation given by N Kondratiev, of four phases – depression, recovery, prosperity and recession. In these cases, peaks were assumed to occur midway through periods of prosperity, and troughs were assumed to occur midway through periods of depression.

4G Annex 2: Plotted data

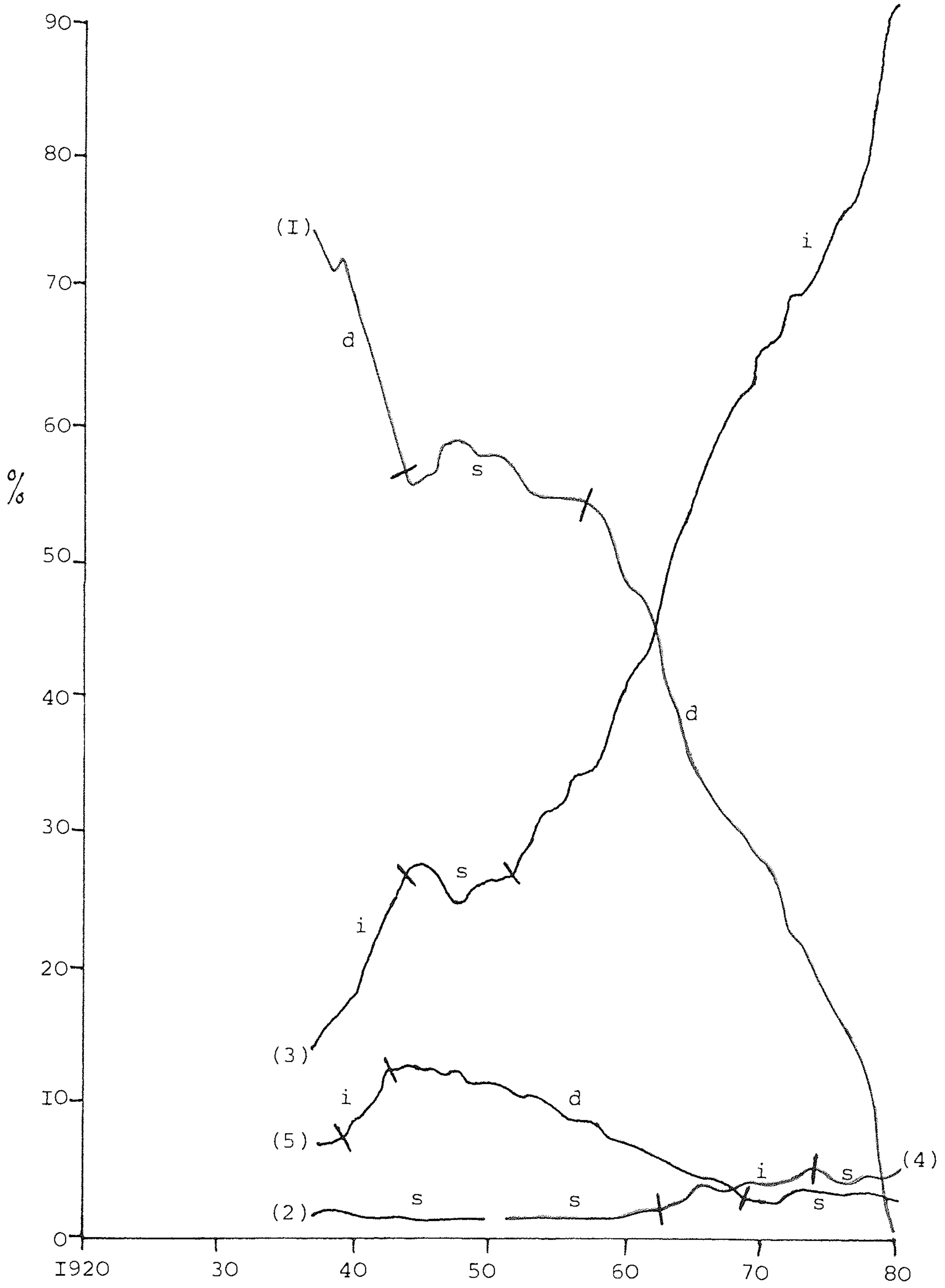
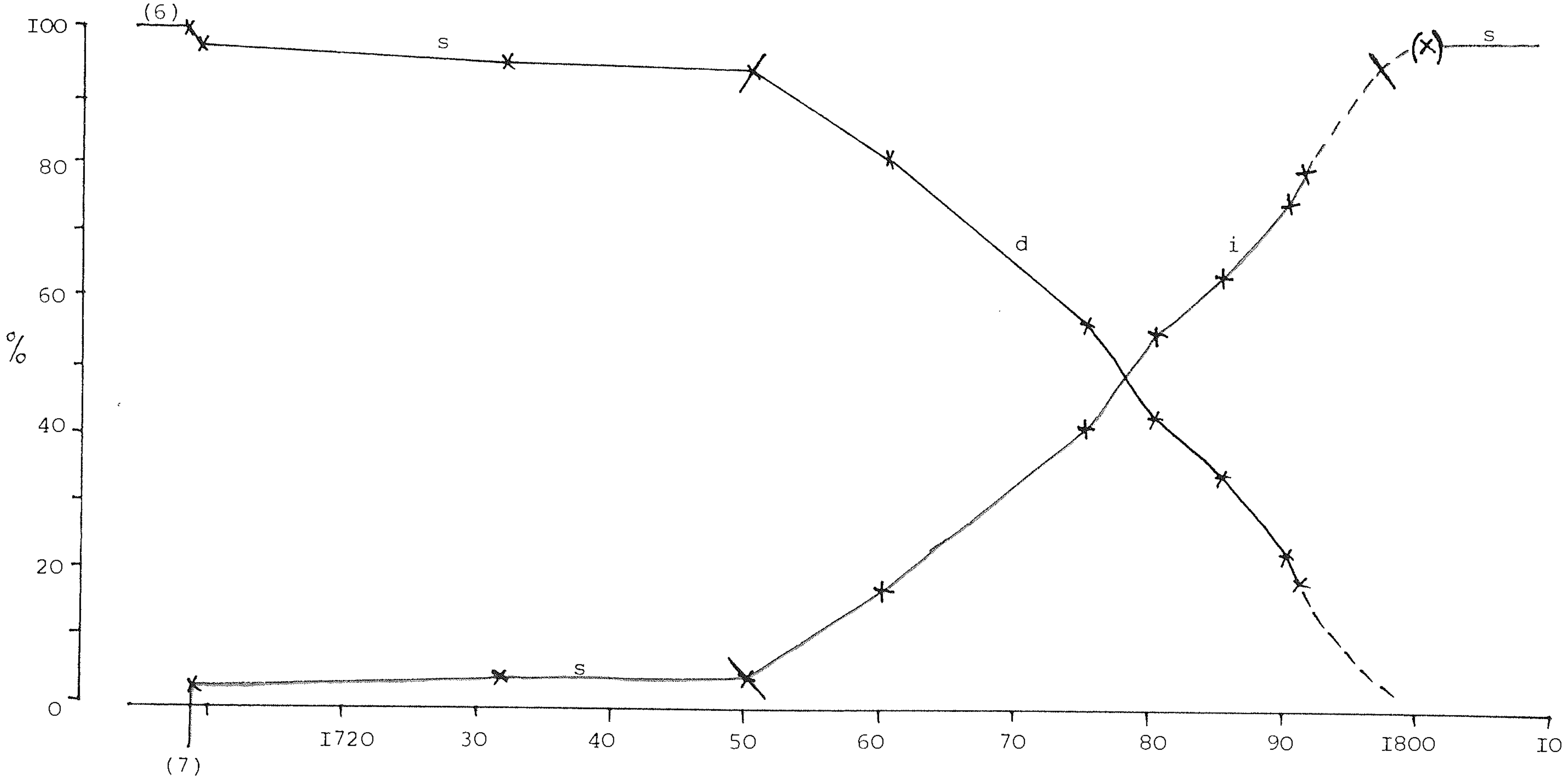


Figure 4.18 – Diffusion of steel production processes (proportions of furnaces)

Figure 4.19 - Diffusion of coke-fired blast furnaces (proportion of furnaces)



(X) = estimated in figures 4.I9 to 4.3I

Figure 4.20 - Diffusion of steam blowing in coke blast furnaces (proportion of furnaces)

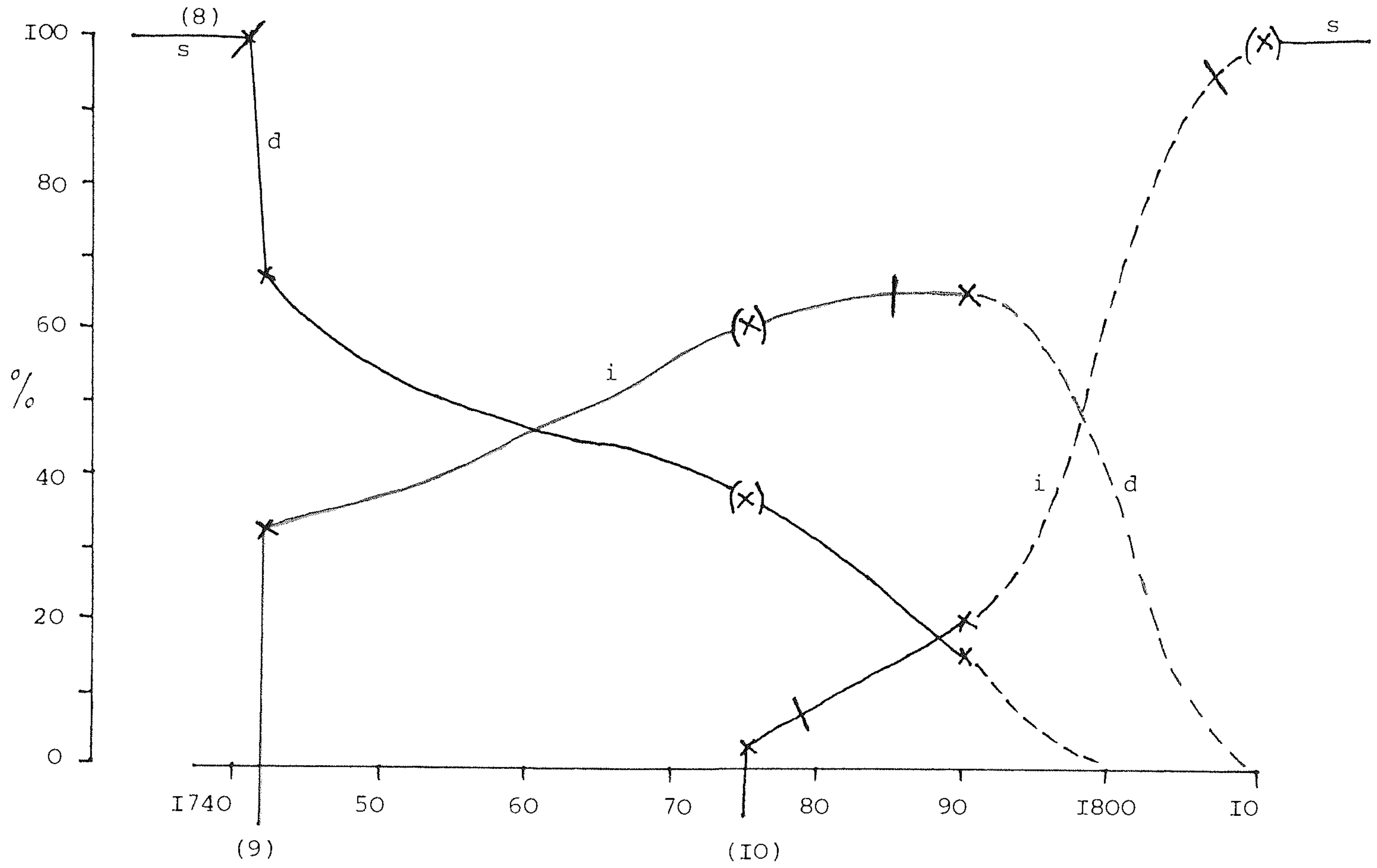
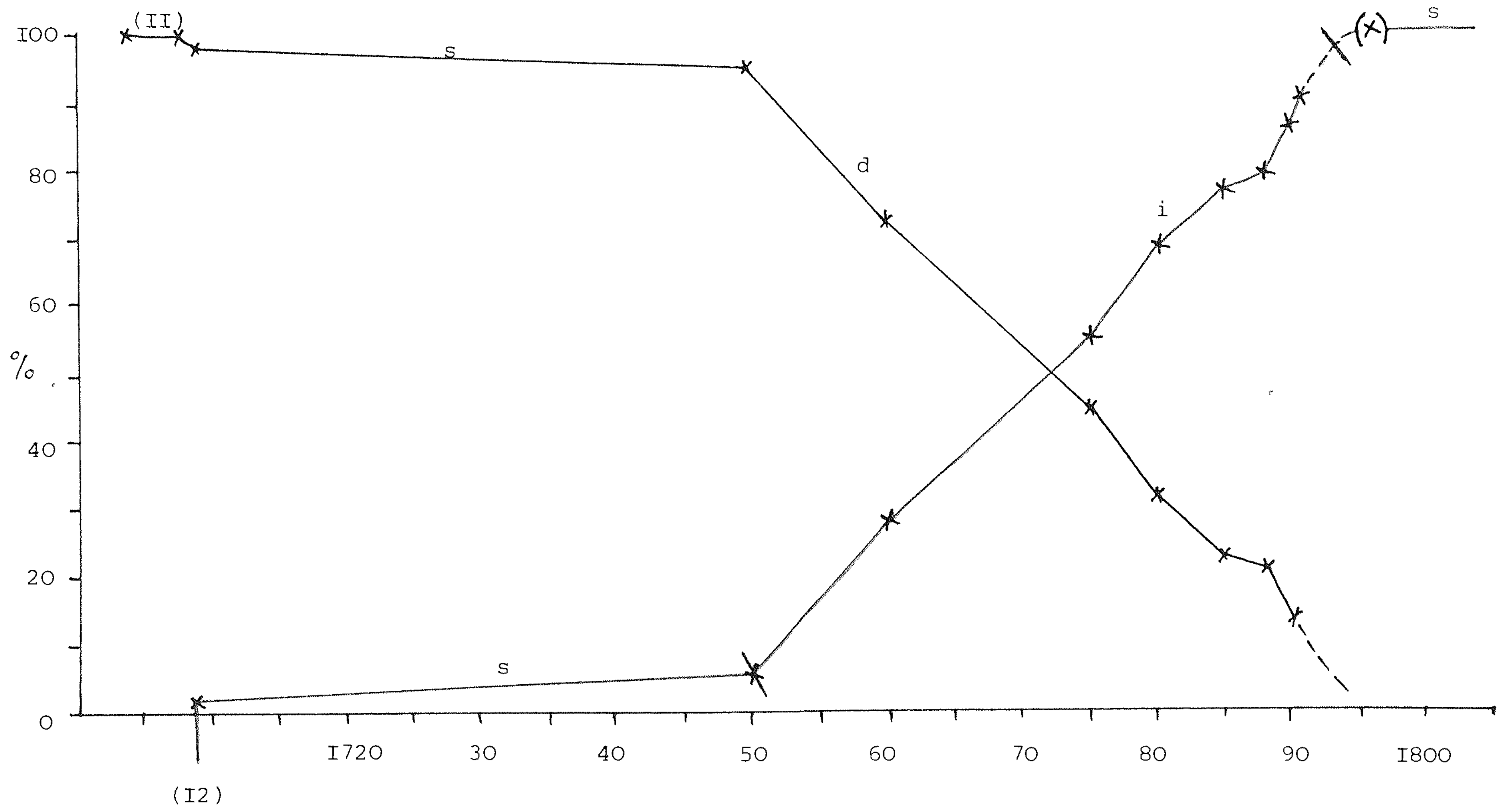


Figure 4.21 - Diffusion of coke-fired blast furnaces (proportion by output weight)



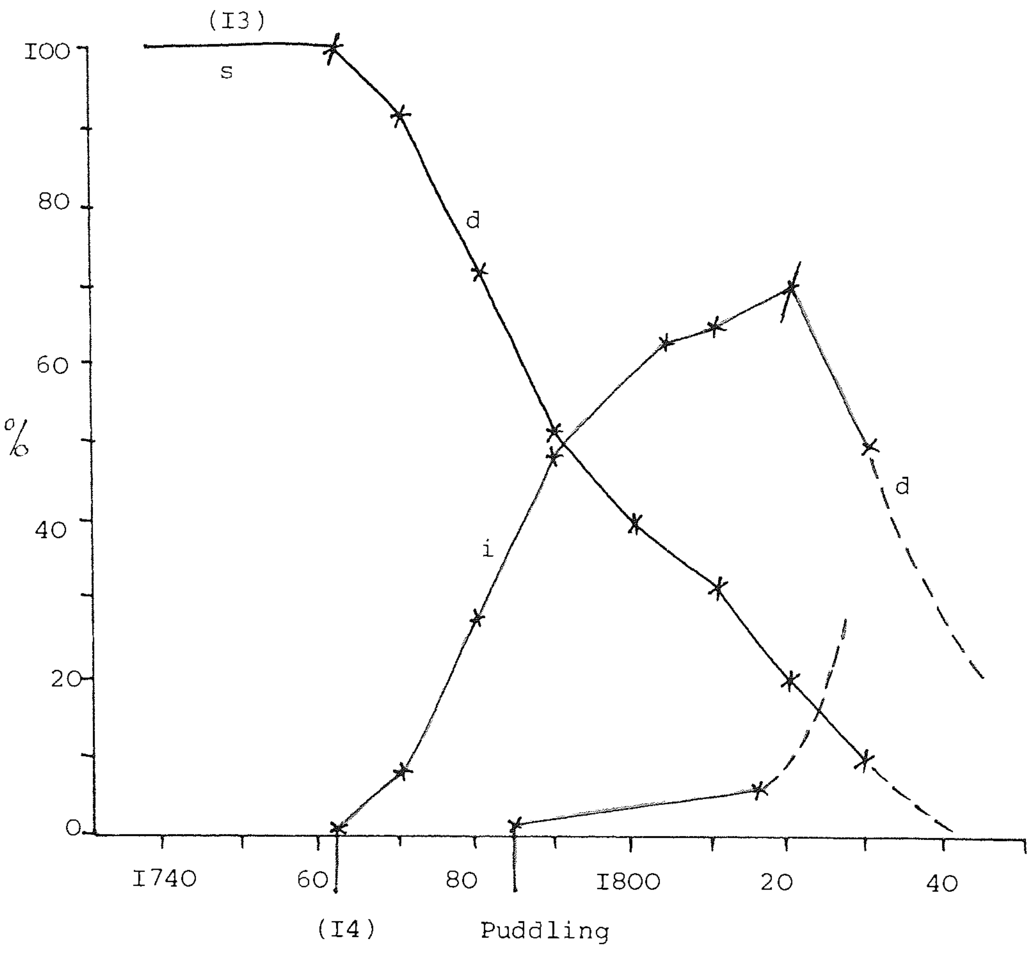


Figure 4.22 - Diffusion of wrought iron production technologies
(proportions by output weight)

Figure 4.23 - Diffusion of coking technologies (proportions by output weight)

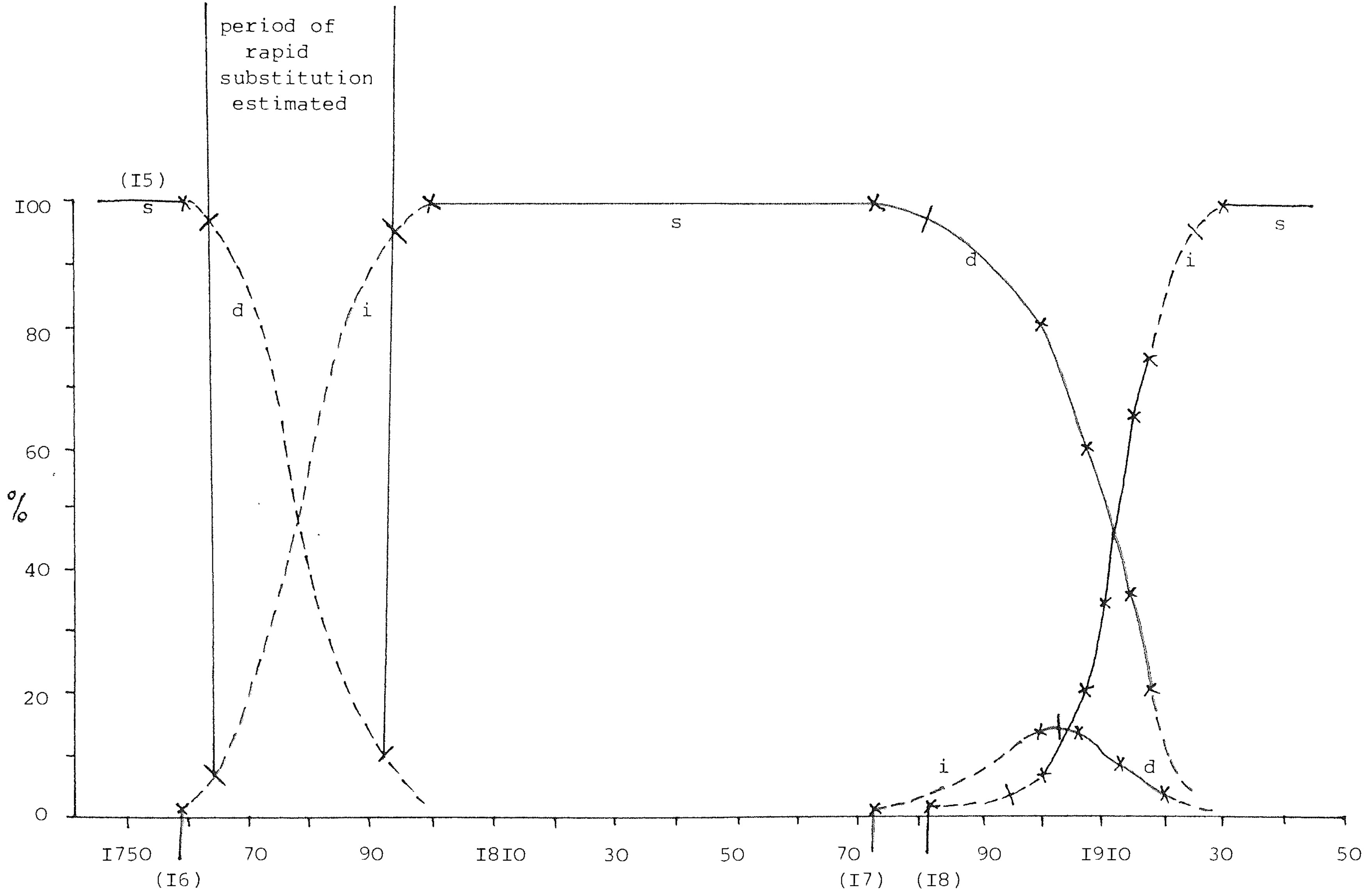


Figure 4.24 - Diffusion of early steel production technologies (proportion by output weight)

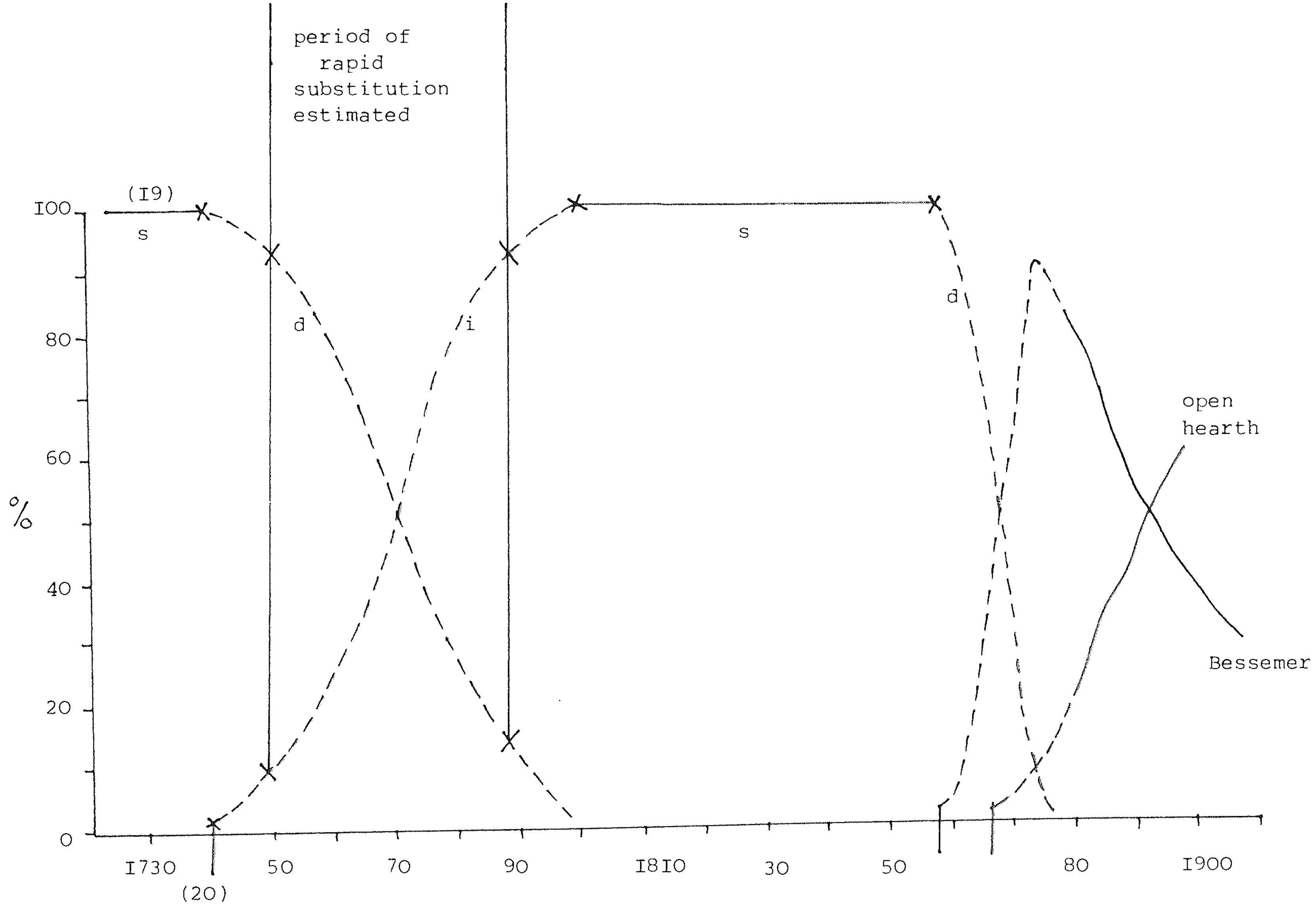
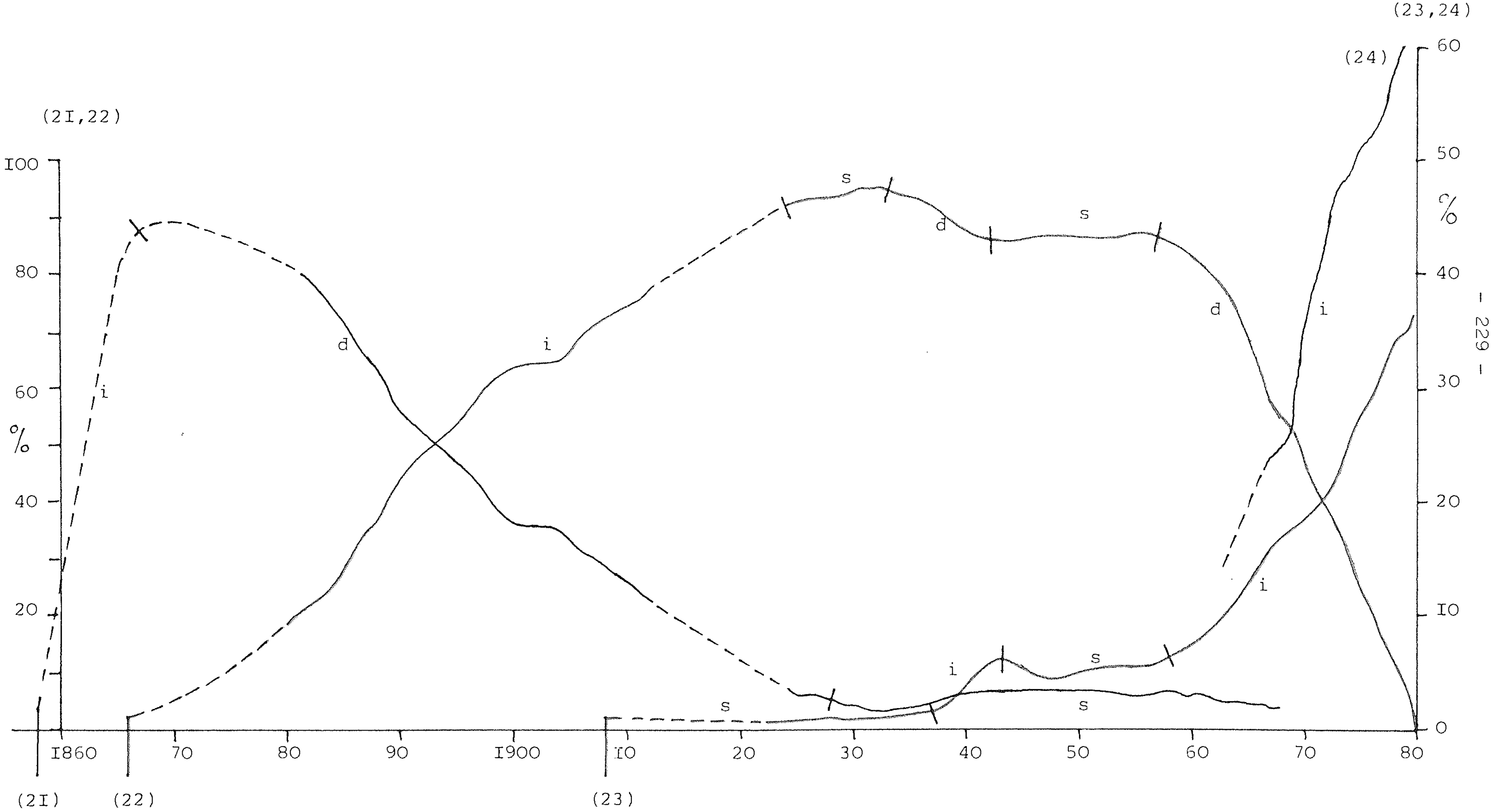


Figure 4.25 - Diffusion of later steel production technologies (proportions by output weight)



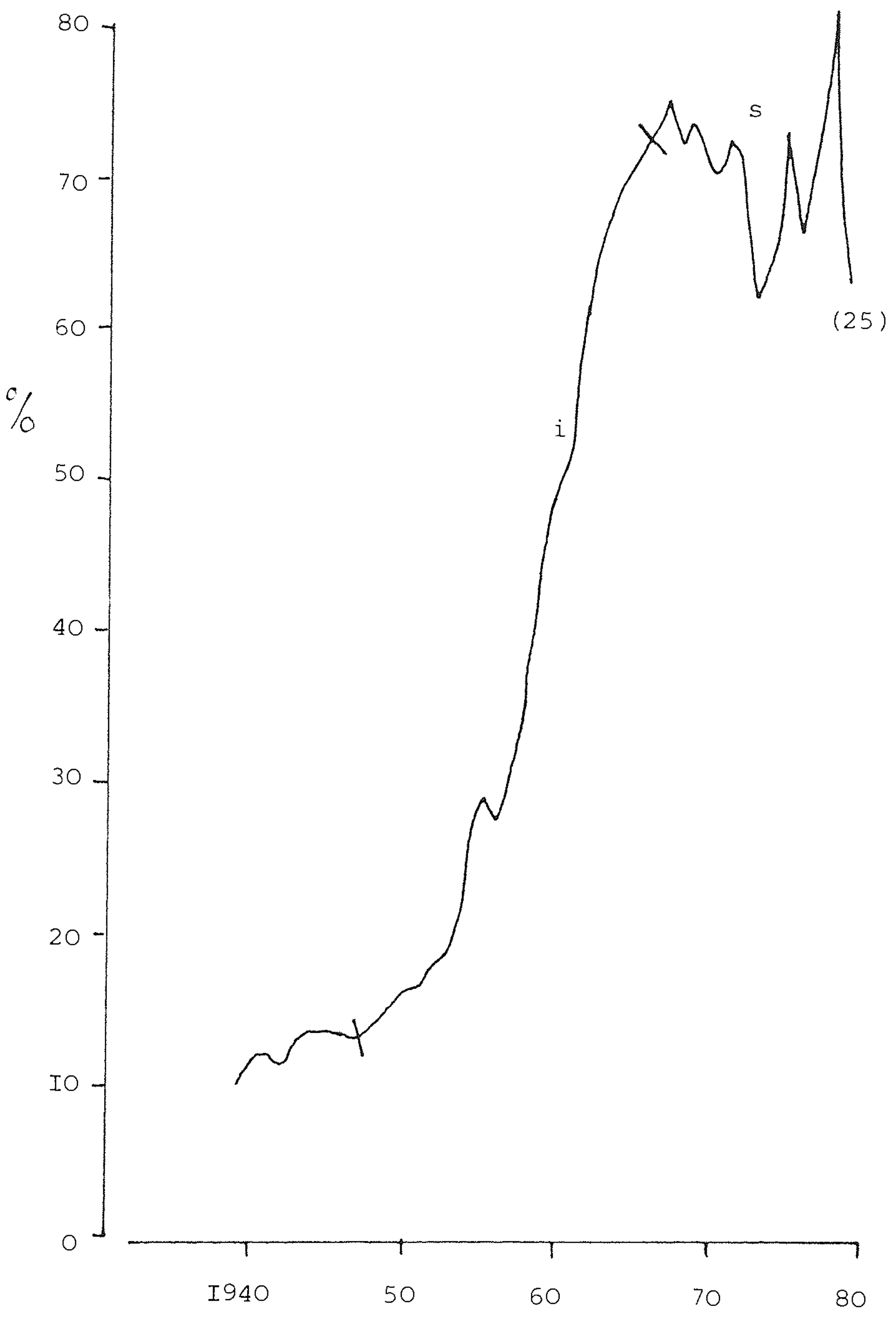


Figure 4.26 - Diffusion of sintering (proportion by input weight)

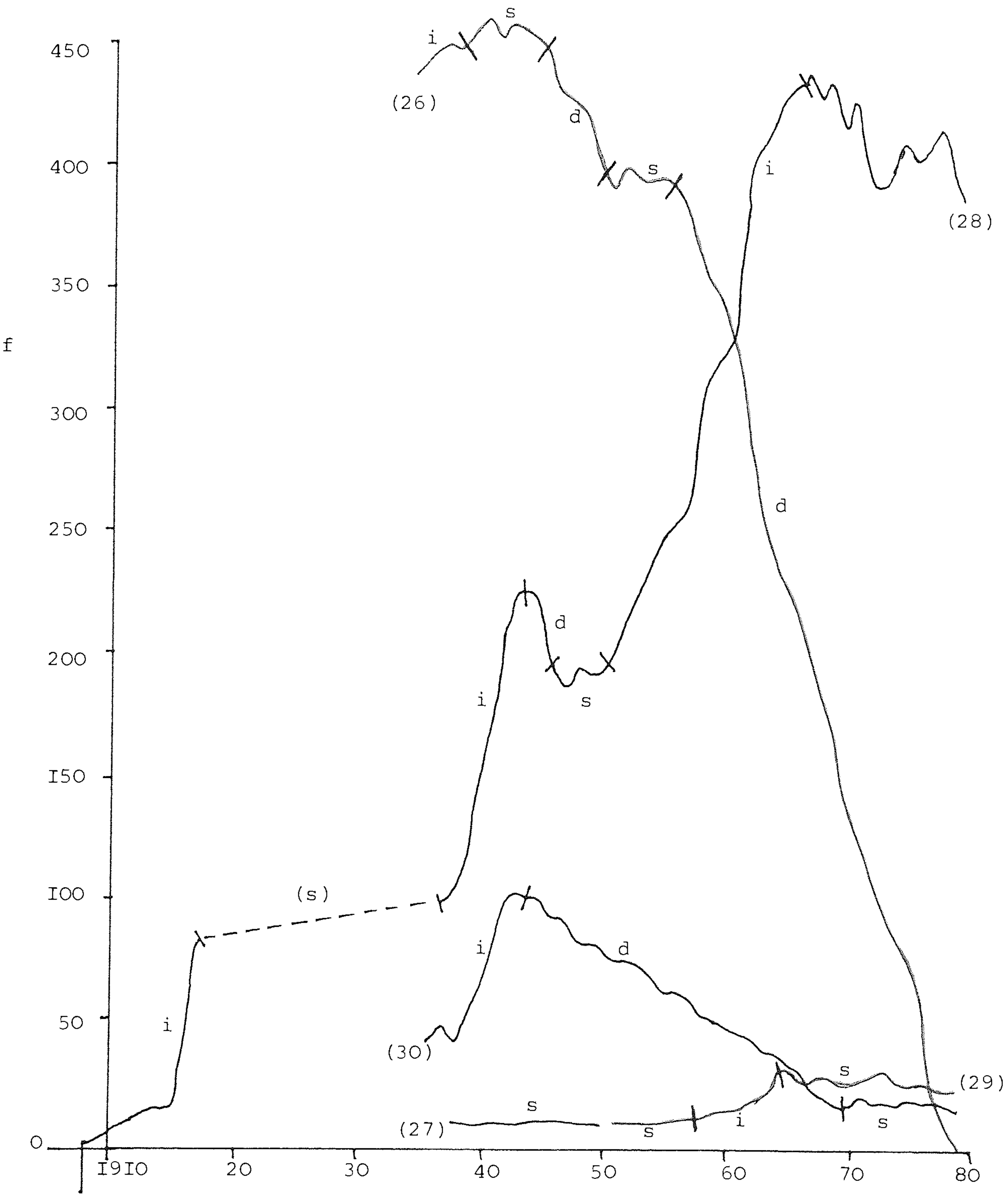
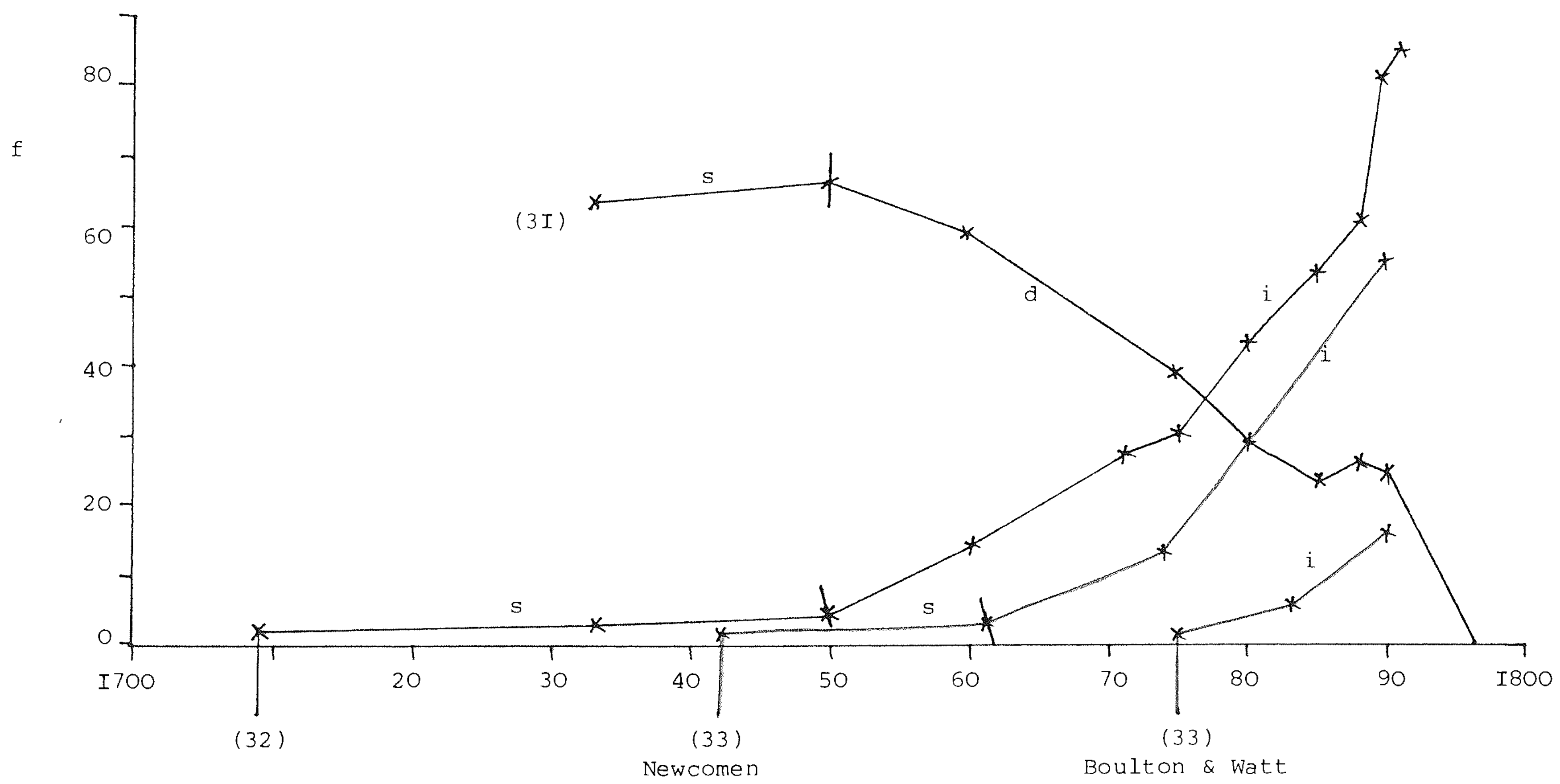


Figure 4.27 - Diffusion of steel production technologies (furnace numbers)

Figure 4.28 - Early diffusion of blast furnace technologies (furnace numbers)



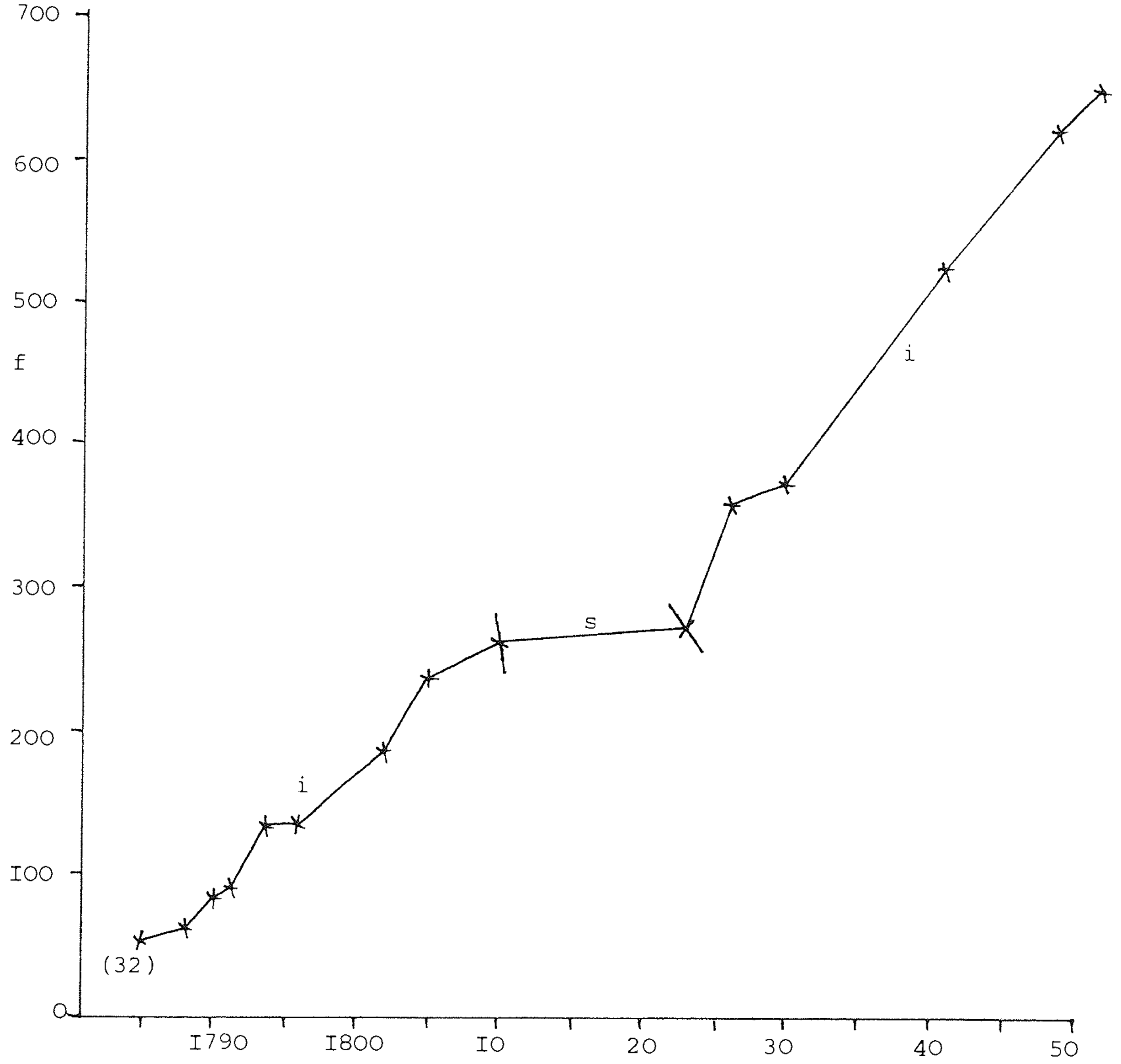


Figure 4.29 - Later diffusion of coke-fired blast furnaces (furnace numbers)

Figure 4.30 - Diffusion of wrought iron puddling (furnace numbers)

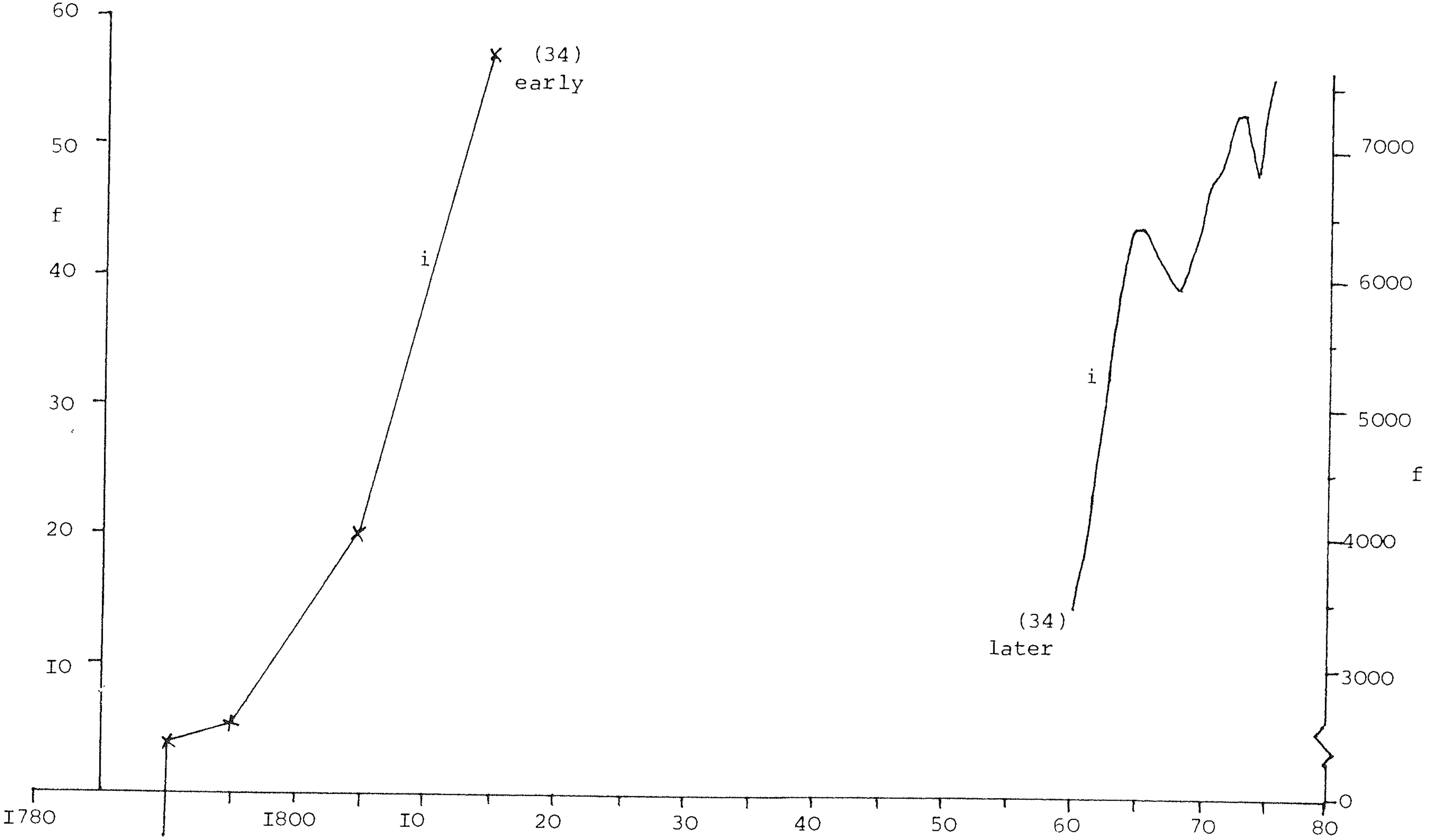


Figure 4.31 - Diffusion of steel production technologies (output weight - million tons)

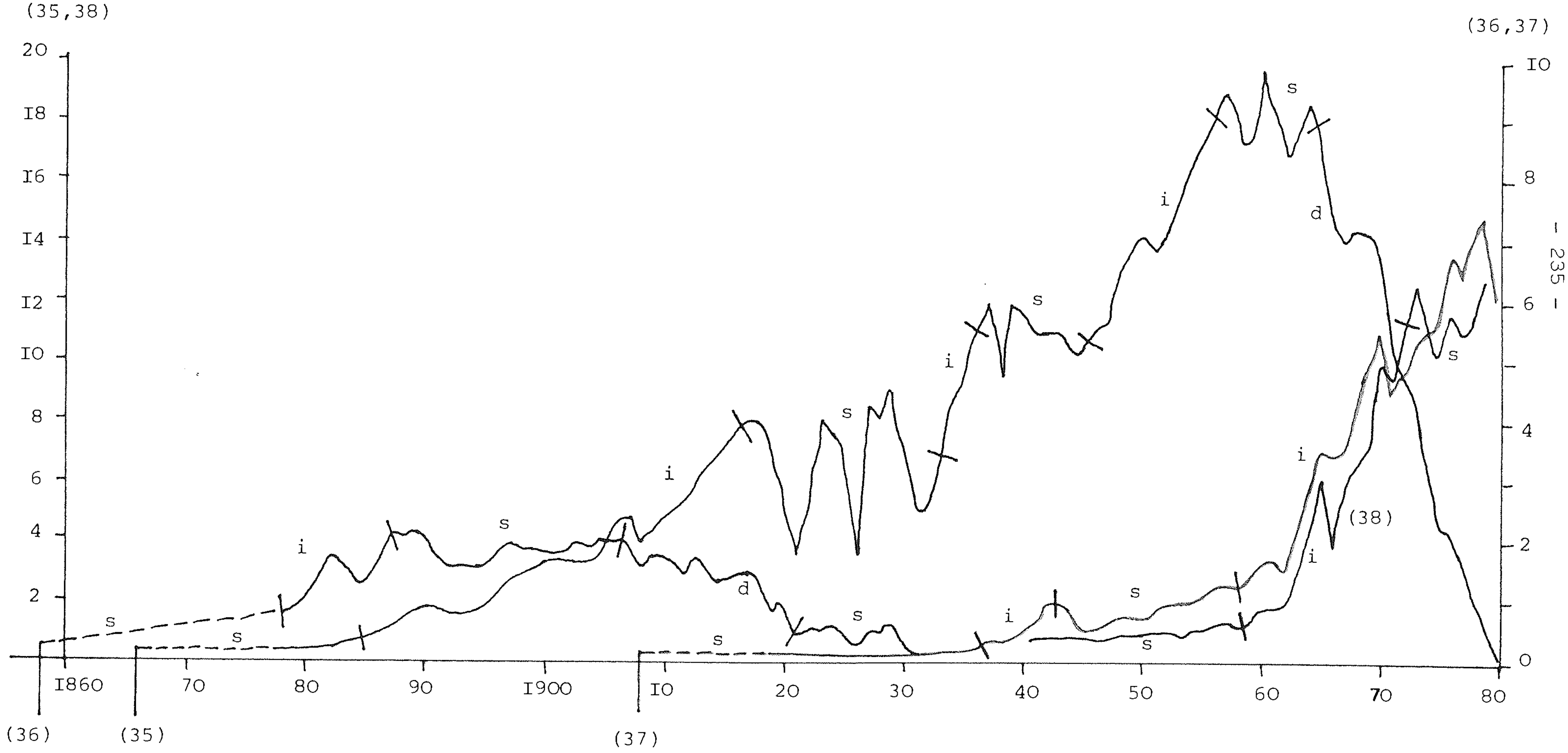
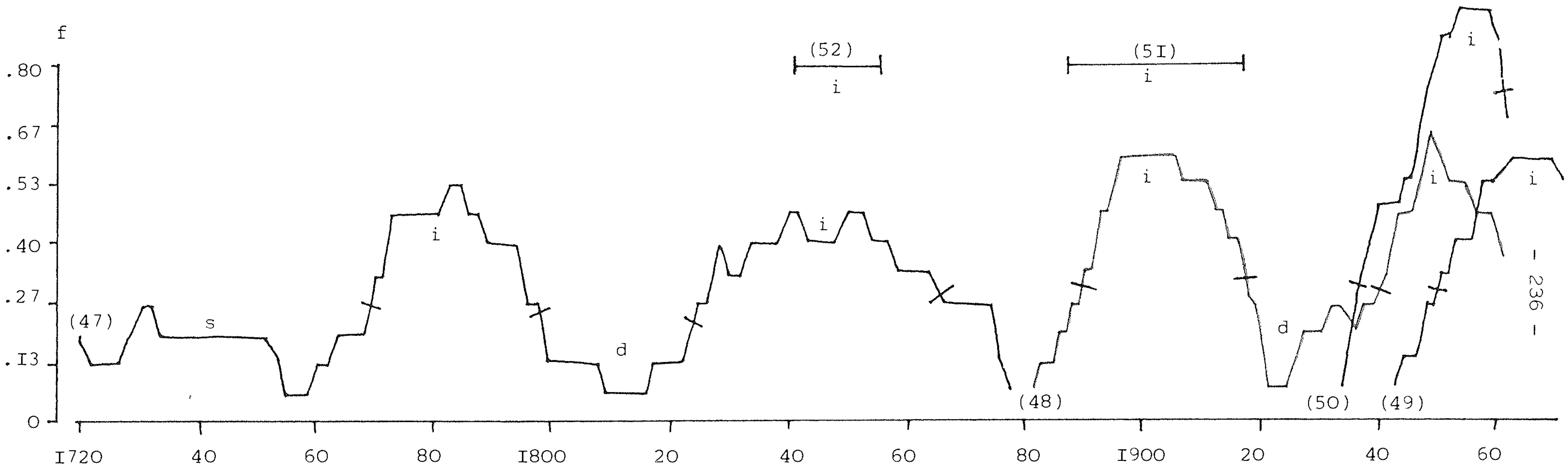


Figure 4.32 - Diffusion of broader technology types (innovation clustering)



Variables 47 to 50 - I5 year moving average of
separate applications
per year.

Variables 5I,52 - dated innovation clusters.

Figure 4.33 – Absolute output growth of pig iron

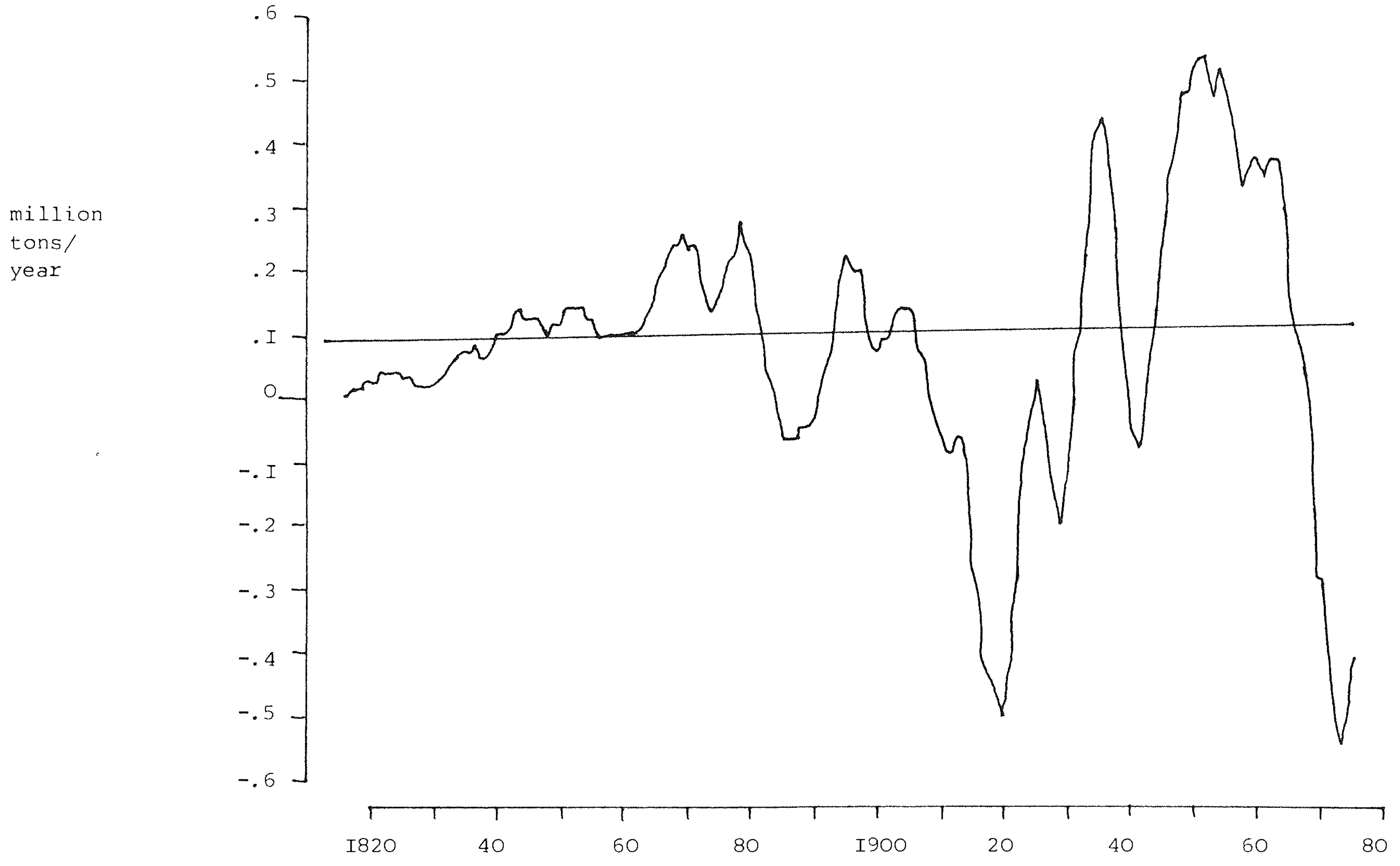


Figure 4.34 - Absolute output growth of crude steel

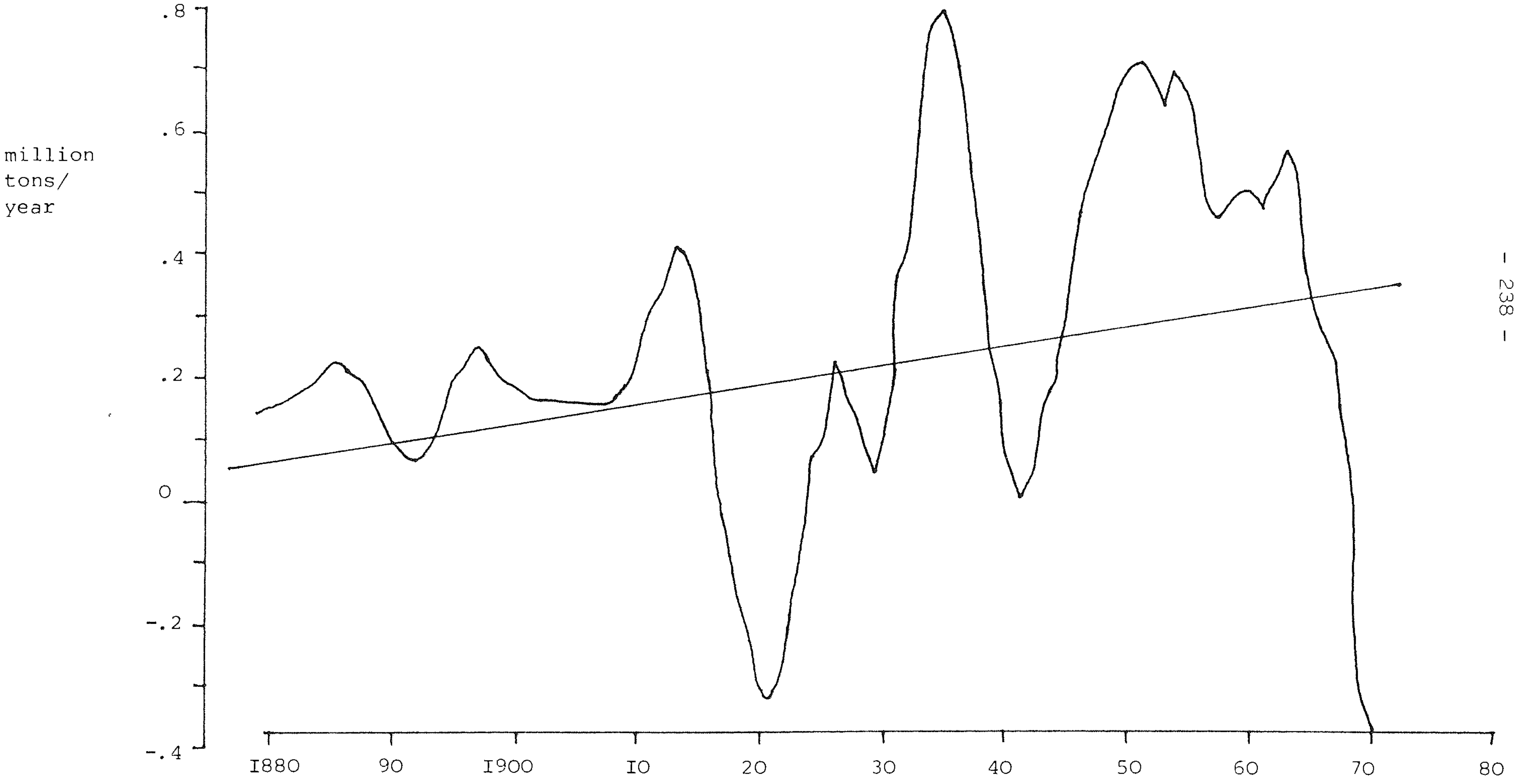


Figure 4.35 - Absolute output growth of iron and steel

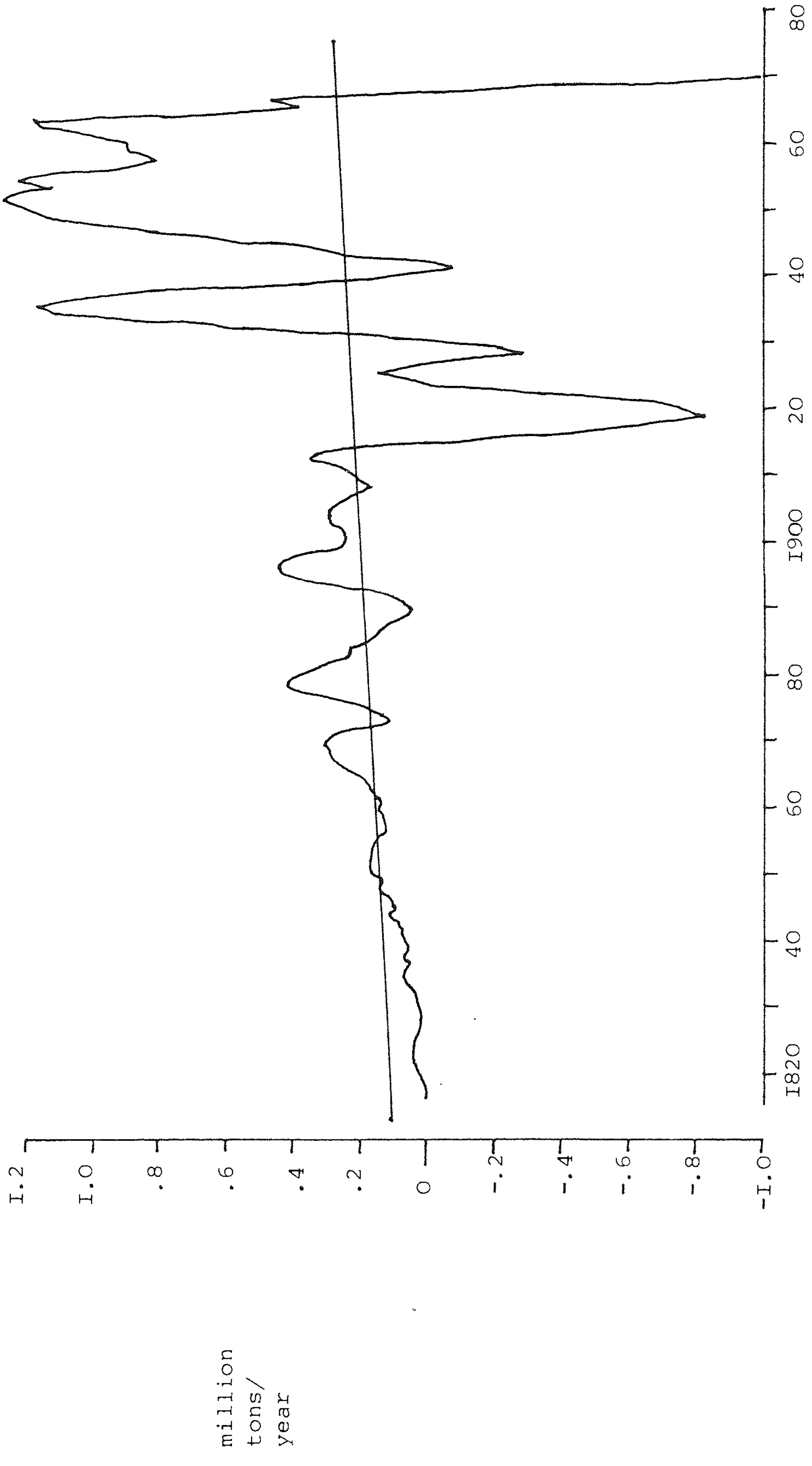


Figure 4.36 - Proportional output growth of pig iron

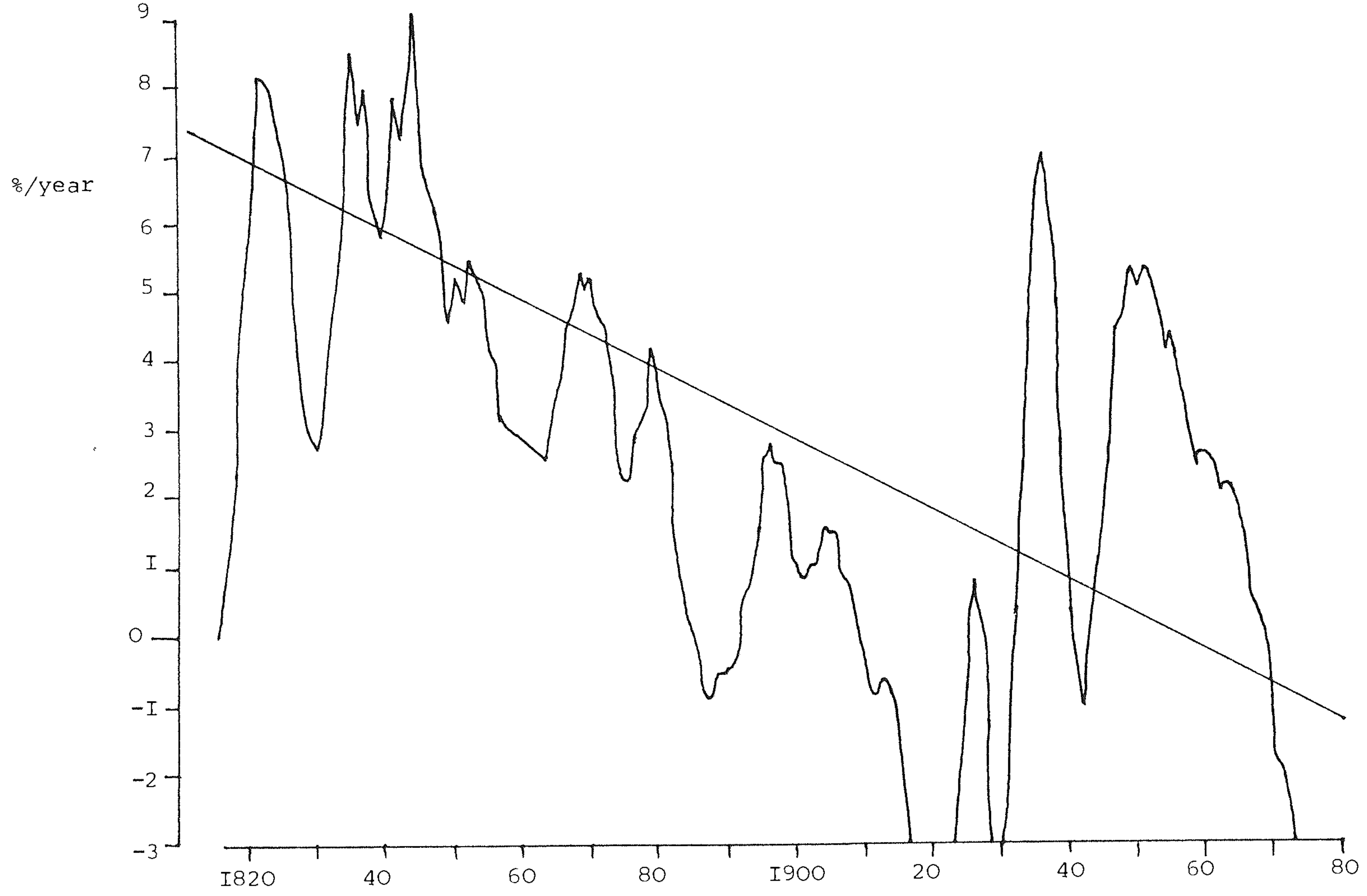


Figure 4.37 - Proportional output growth of crude steel

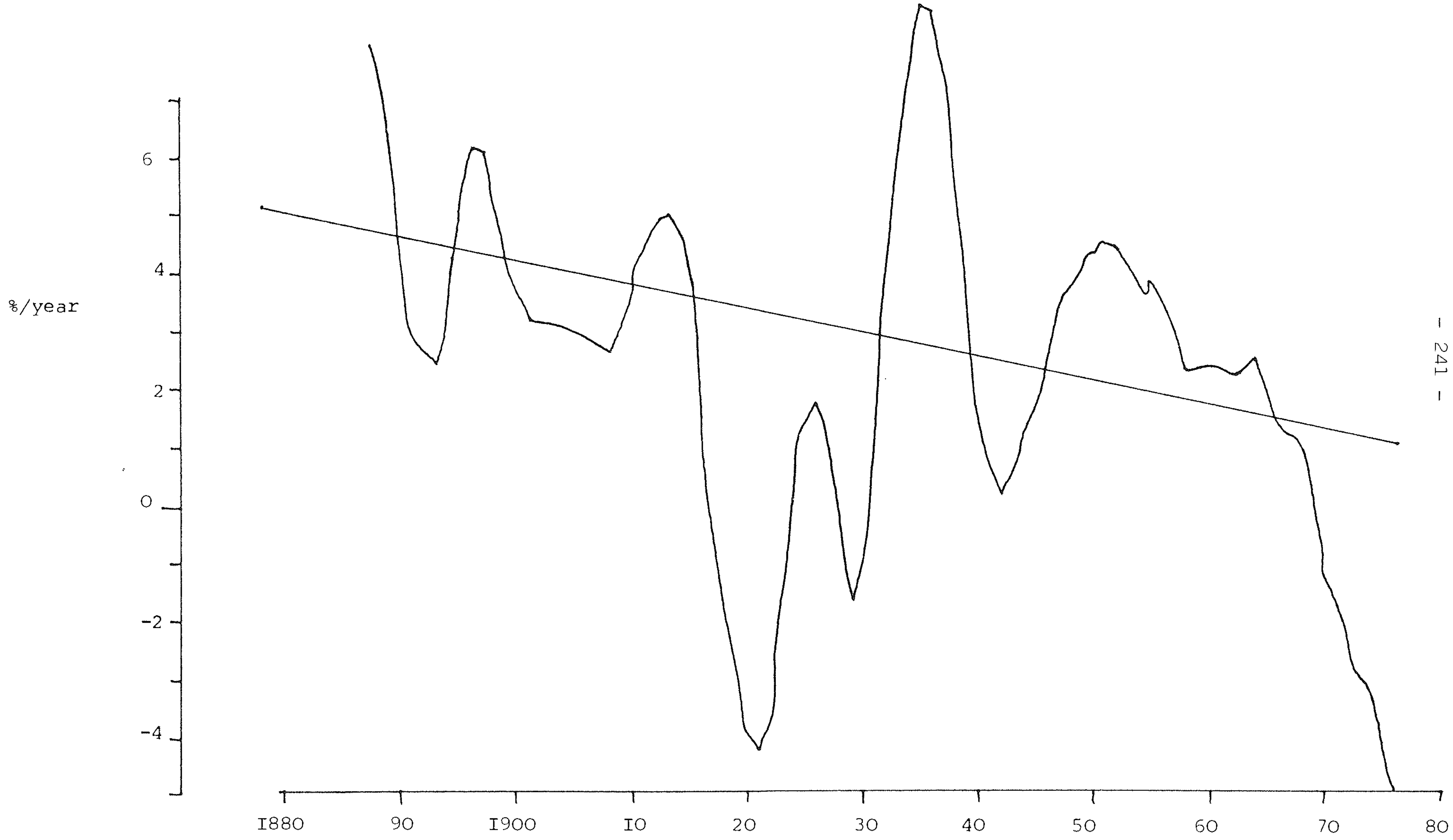
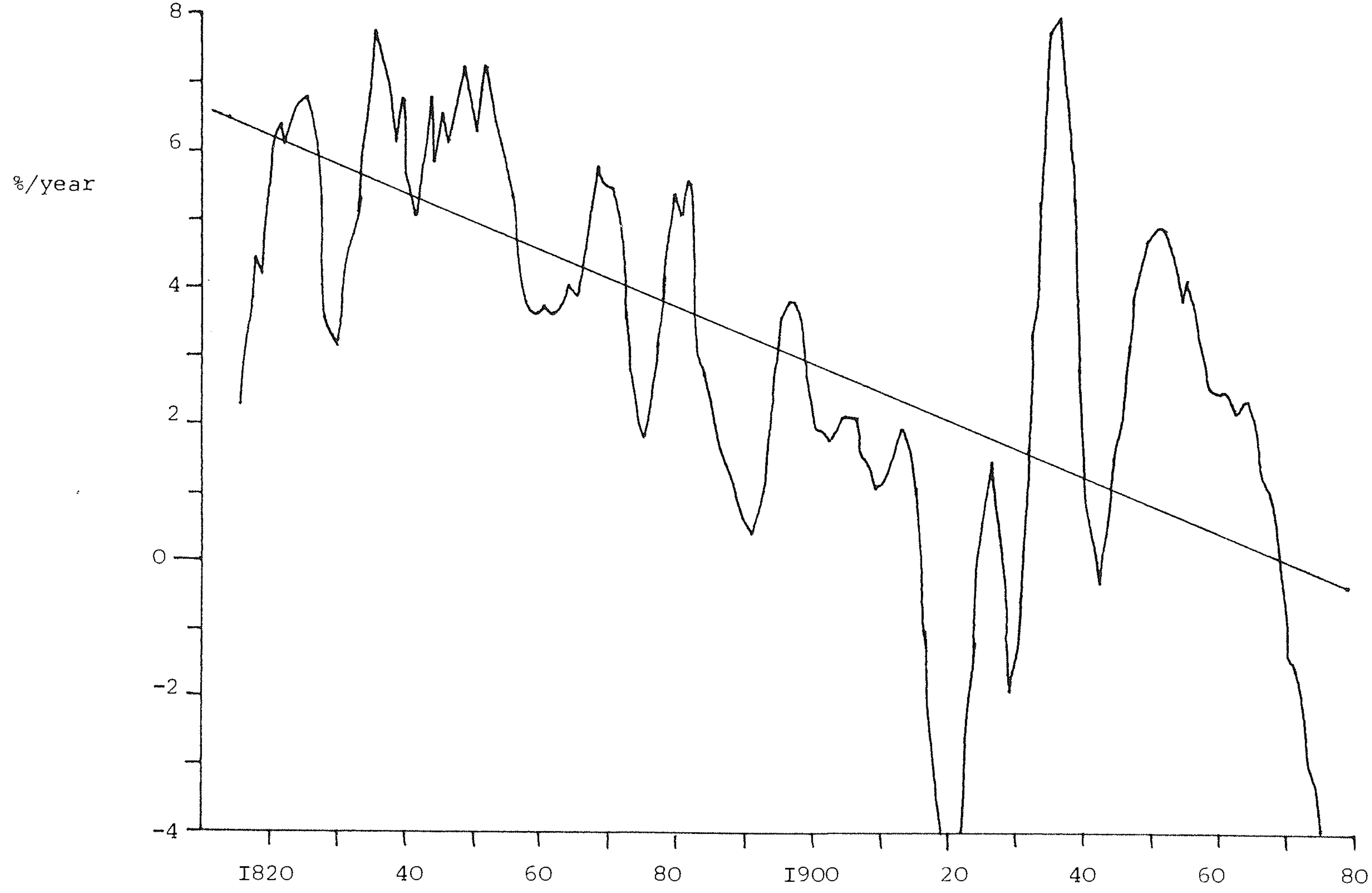


Figure 4.38 – Proportional output growth of iron and steel



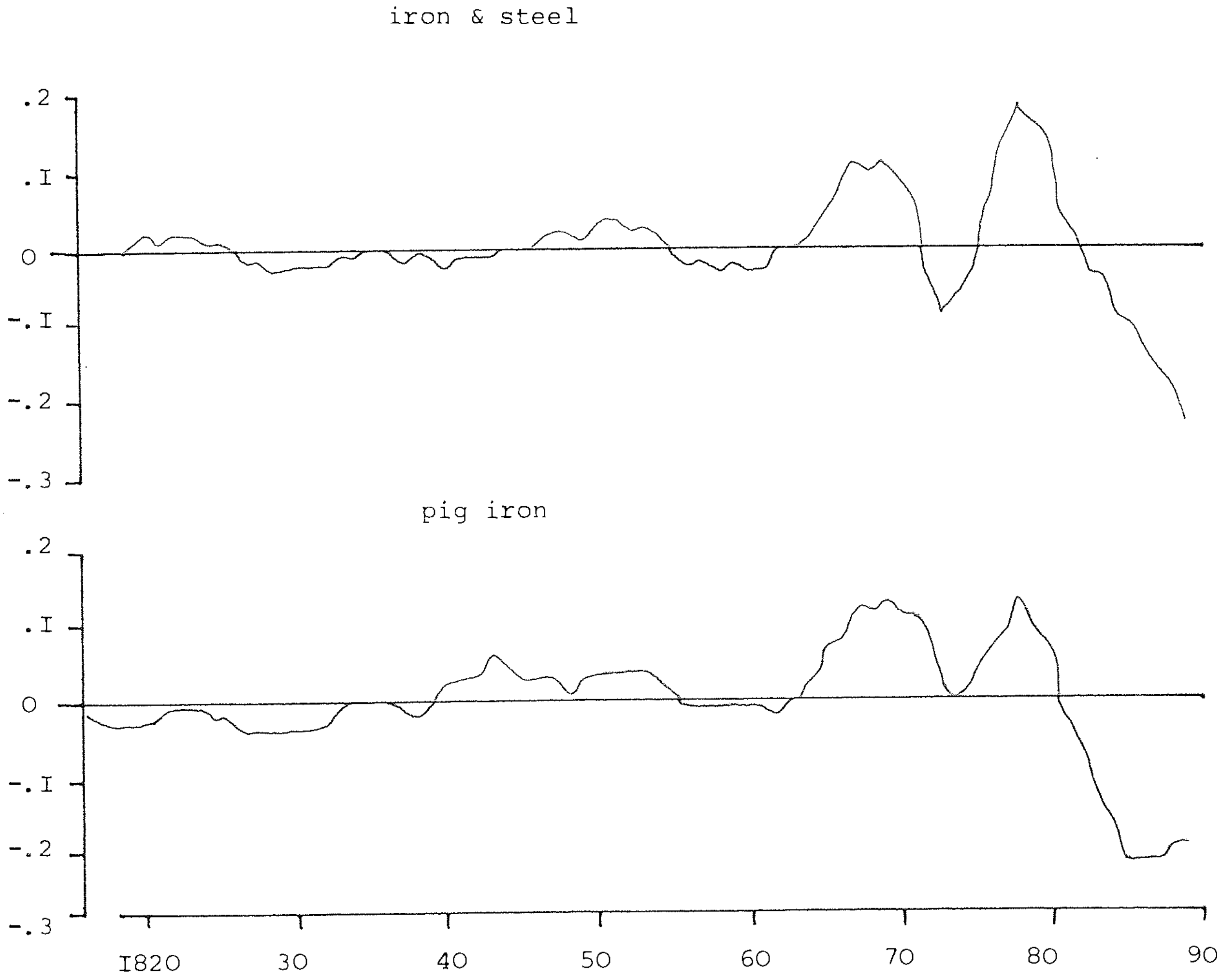


Figure 4.39 - Absolute growth rates: residual variation round trends in first cycle (million tons).

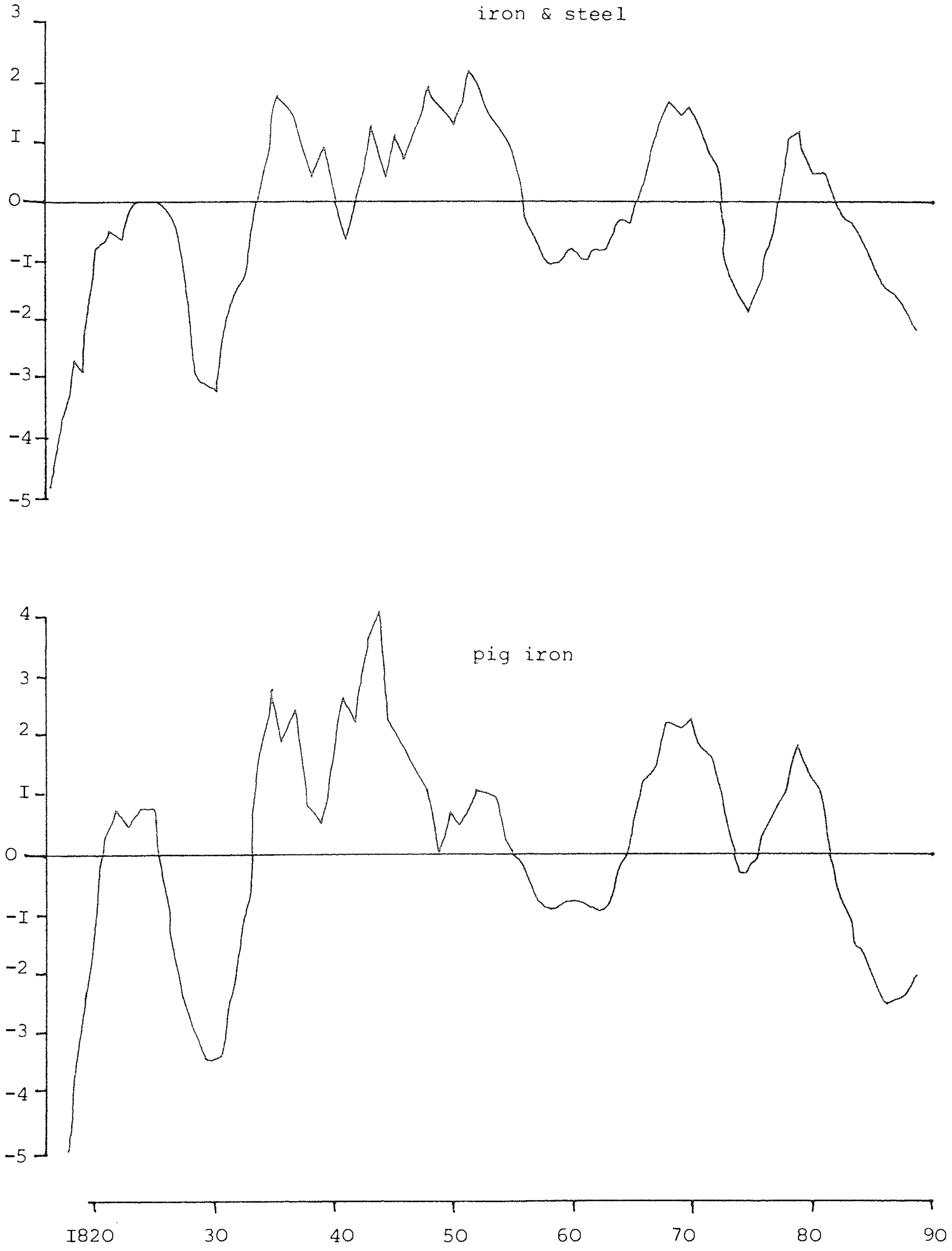


Figure 4.40 - Proportional growth rates: residual variation round trends in first cycle (%)

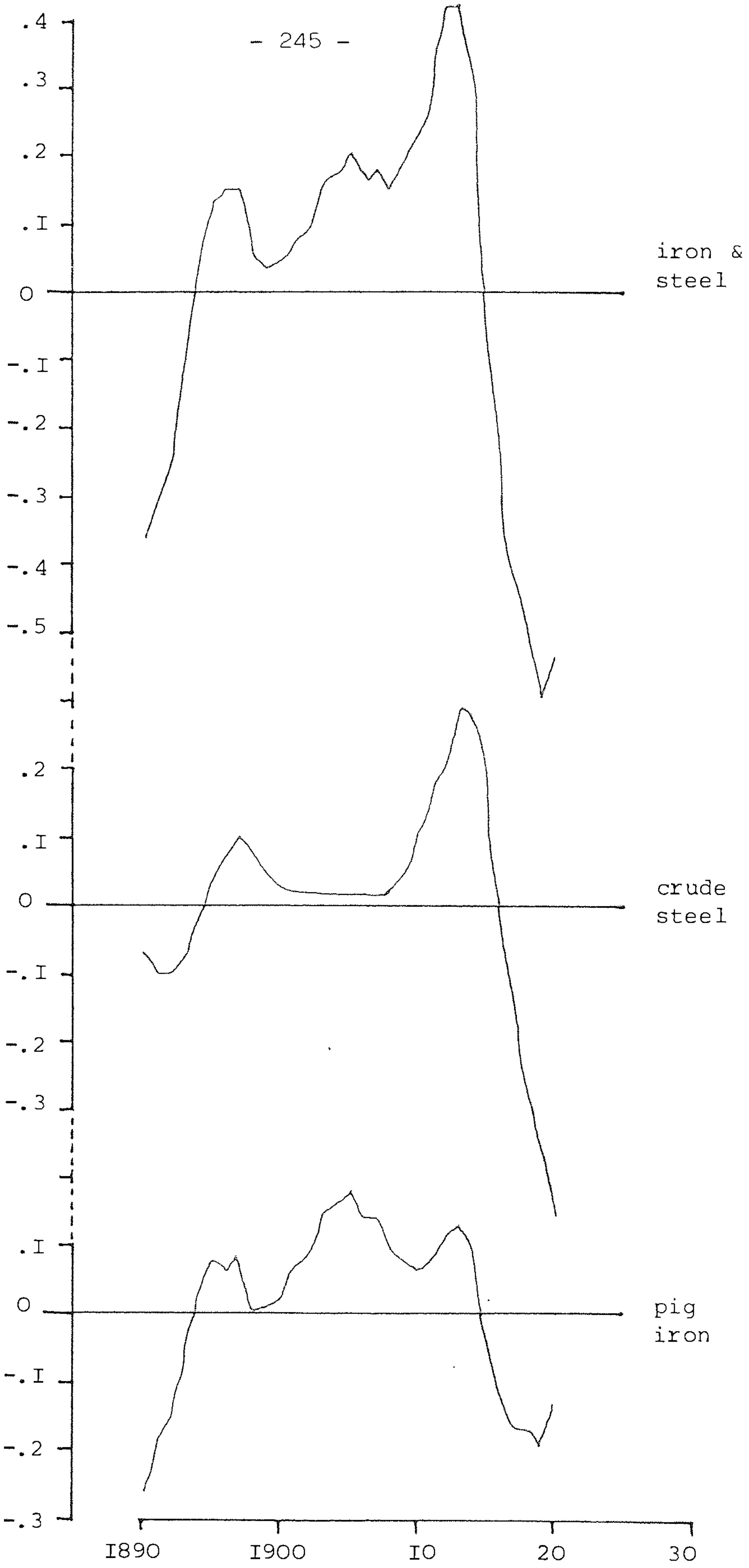


Figure 4.41 – Absolute growth rates: residual variation round trends in second cycle (million tons)

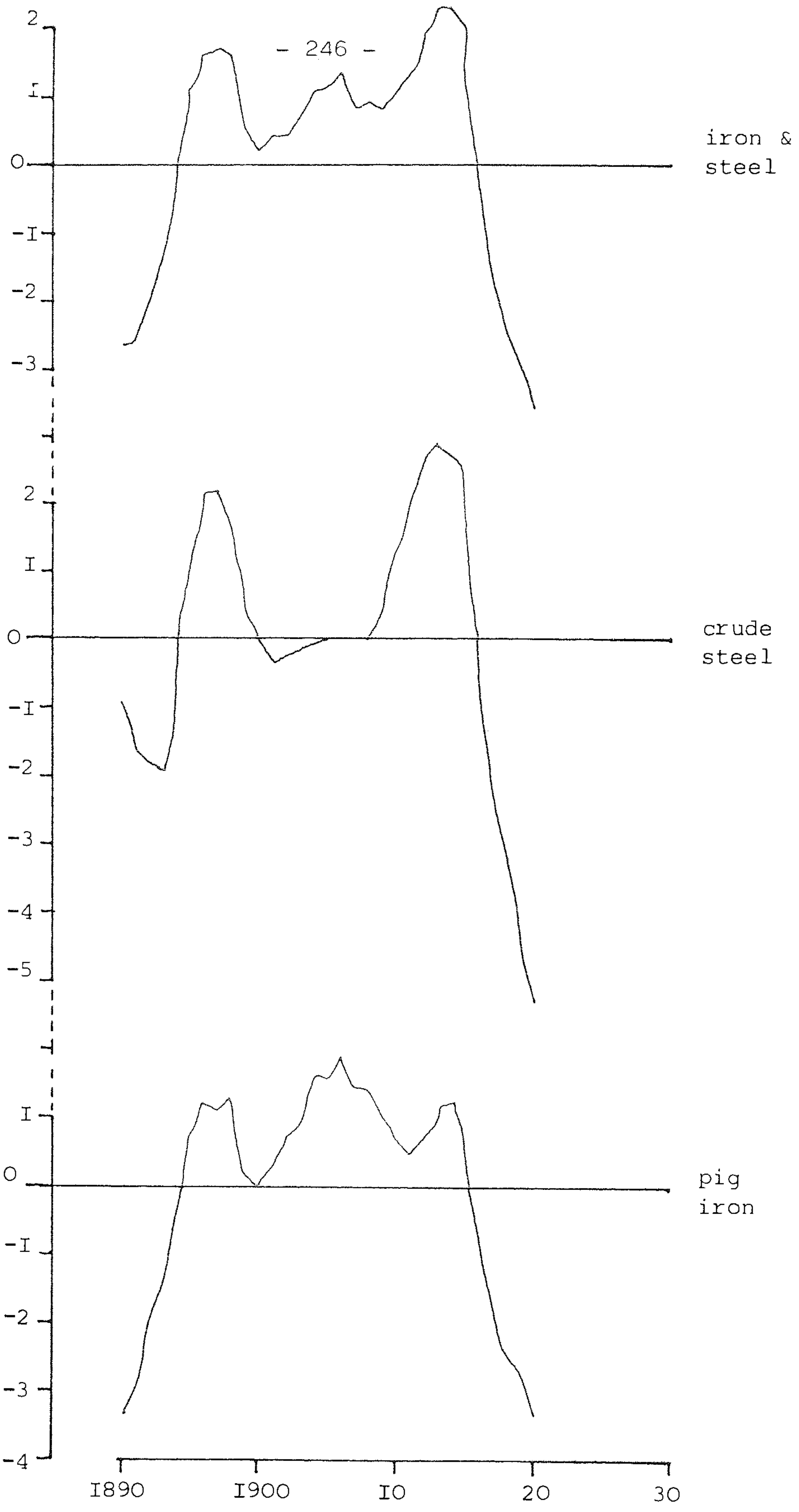


Figure 4.42 - Proportional growth rates: residual variation round trends in second cycle (%)

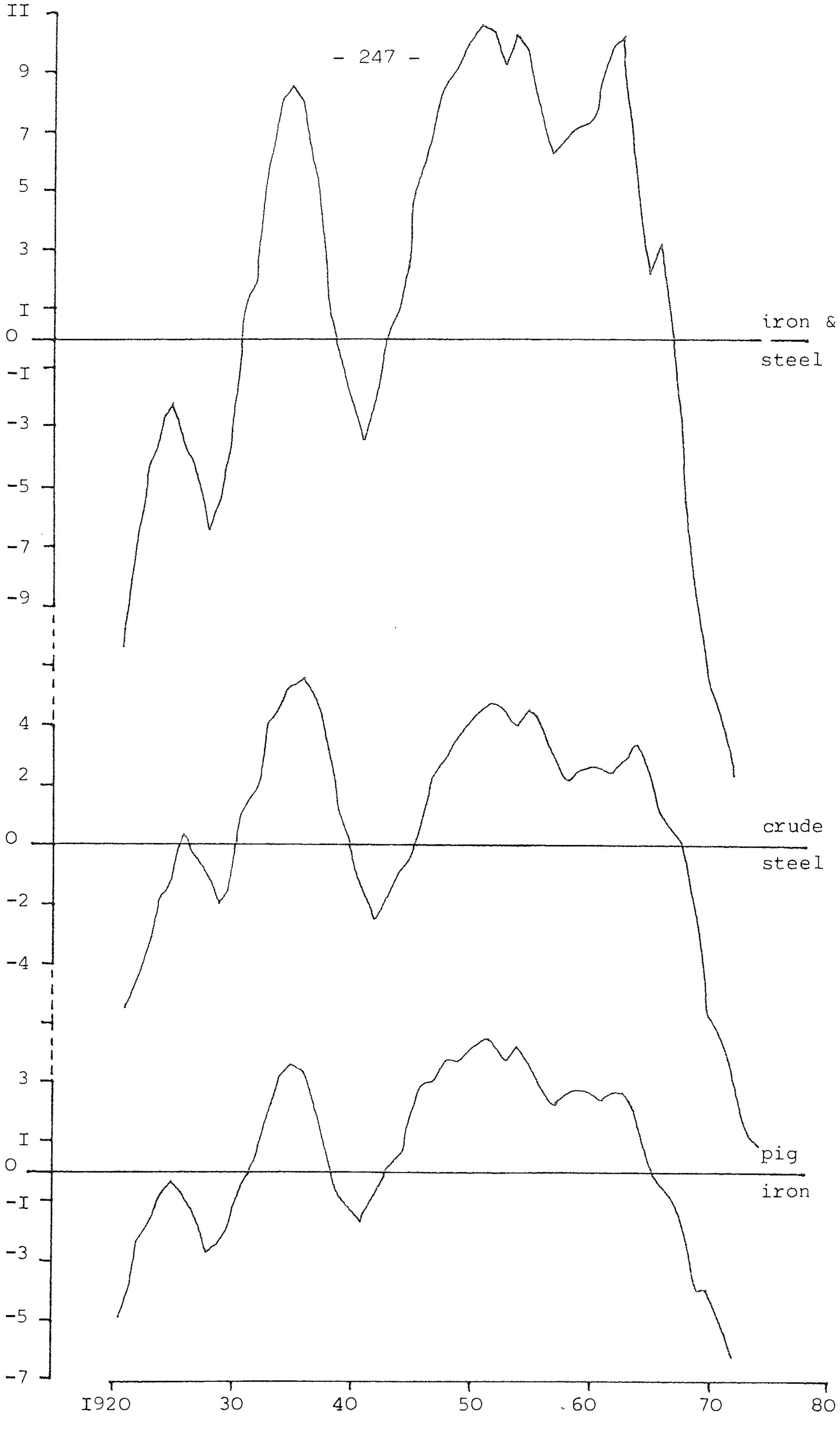


Figure 4.43 - Absolute growth rates: residual variation round trends in third cycle (million tons)

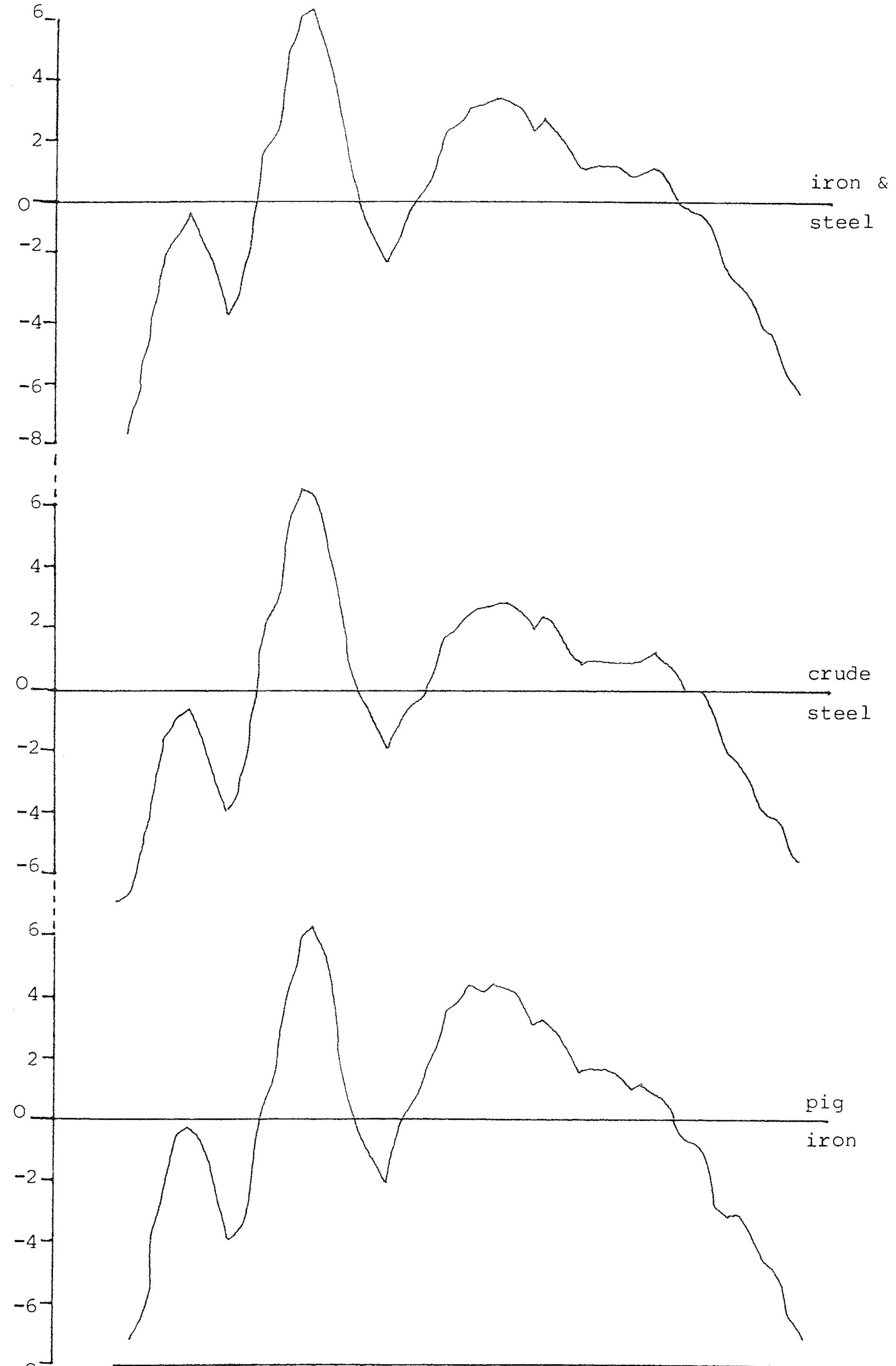


Figure 4.44 – Proportional growth rates: residual variation round trends in third cycle (%)

Chapter 5: Concluding Comments

The results of the various case studies have been discussed fully as they were presented, and do not need to be recapped here. Rather, the aim of this short chapter is to try and draw out the main implications of the thesis for the general area of interest identified.
At the broadest level, the importance of the thesis lies in the demonstration that the investigation of relationships between profit, technology and environmental change need not remain bound by the impasse outlined in chapter one - ie of alternative micro and conflicting macro levels of analysis. It is clear that there is a third, intermediate level of aggregation at which the variability in environmental outcomes is characterised by distinctive patterns that are themselves explicable in terms of systematic variations in aspects of profitability and technical change. This finding means that the thesis can perform two main functions in the development of this area of intellectual enquiry.

First of all, it reflects back on the traditional approaches, and suggests the lines along which some of the associated dilemmas may be resolved. One of these concerns the conflict between the neoclassical and neomarxist macro level analyses. The question of whether capitalism tends to produce any fundamental and underlying bias in the social utility of environmental change remains a valid one, and one over which the arguments are likely to continue. The problem with it, though, is that neither of the conflicting assertions can be proved to be generally true at the expense of the other. The results of the thesis provide two possible ways out of this dilemma. On the one hand, we can interpret the results as demonstrating that neither assertion has general validity, although there may be particular periods in which each of them appears to be correct at the expense of the other. Alternatively, we can interpret the results as demonstrating that, if there is any such fundamental bias, it seems to be unimportant to the observable patterns of variation, when compared to those influences resulting in periodization.

There is also the problem of the theoretical separation between the neoclassical and neomarxist accounts offered at the micro level. Conceptually, at least, the results of the thesis suggest that the separation could be removed by subsuming both accounts under the same meso level model, rather than relating them to their respective and conflicting macro level analyses. We can see that a model such as Long Wave Theory could be related to the neoclassical framework through an investigation of periodization of the balances between the various environmental costs and benefits of production. Equally, although the neomarxist accounts tend to see particular technical strategies for profit-maximisation as being environmentally either detrimental or beneficial, we can see that changes in the balances between such strategies may be explicable by reference to a model such as Long Wave Theory.

And there has also been a problem over the relationships between different levels of analysis. The results of the thesis suggest that empirical studies at the micro level should no longer be related directly to propositions made at the macro level. For example, case studies illustrating instances of profitable pollution prevention should not be used for or against propositions about general bias in relationships between profits and environmental change. And the same is true for case studies demonstrating that particular profit-maximising strategies involve technologies that badly degrade the environment. Rather, our results suggest that such empirical case studies should only be related to more restricted propositions about the systematic relationships between profits, technology and the environment - more restricted as regards time, space, economic sector and so on. And, most constructively, they should be used to try and identify the temporal, sectoral and spatial boundaries either side of which conflicting propositions may have some general validity.

The second main function of the thesis is that, despite the crudeness of the empirical work, it does show the potential utility of the meso level approach to these relationships. And, by implication, it suggests further avenues of research that would be useful in exploring this potential.

First of all, it was only possible here to look at a few of the descriptive levels at which we might try to measure environmental change over time. And, as a result, it was only necessary to examine the influences of a few different aspects of technical change. Although it was suggested that we might expect to find some periodization of environmental change at ecological and social levels of description, as well as within the production sub-system itself, work would be needed to establish to what extent this proposition is valid. Equally, the thesis results lead us to hypothesise that other environmentally relevant aspects of technical change are also likely to have been periodized. But a lot more work would need to be done on this hypothesis before generalisations about the patterns of technical change over time could legitimately be made.

Also, of the main dimensions on which it was suggested we might look for systematic patterns of distribution, the thesis was concerned solely with the variability in environmental outcomes over time. The structural change models of economic growth lead us to expect that various sectors of the economy may be characterised by different types and/or rates of environmental change. But the modelling of any such sectoral variations is something that has so far received very little attention.[1] Similarly, there is considerable scope for further study of those elements of the spatial and social distributions of environmental outcomes that might be systematic products of periodic structural change.

Thirdly, the thesis concentrated exclusively on description and explanation. Clearly, if the systematic patterning of environmental

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[1] The major exception being 'Pollution 1990' - a report compiled by Environmental Data Services Ltd, which examined the pollution prospects for various British industries in the coming decade (see ref: 14).

outcomes at the meso level is extensive, then there may well also be policy implications to be drawn. In particular, we can suggest that it might be worthwhile re-examining some of the traditional policy debates - such as that over the relative merits of taxes versus subsidies. The thesis suggests that the attempt to pick out one or other as being generally better may be misguided. Rather, we might expect that the utility of various possible measures would vary systematically across industrial sectors, with the different phases in developmental waves and so on. Again, this is a line of enquiry that the thesis results suggest may be fruitful, and that has so far received only very cursory attention.[2]

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[2] See, for example, M Elkington (ref: 12).

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