Working Paper Series No. 22

'LEARNING-BY-DOING' IN AN OPEN ECONOMY VERSION OF THE FEL'DMAN MODEL

Charles Cooper

Sept. 1984

'Learning-by-doing' in an open economy version of the Fel'dman model*'.

It is regrettable that solutions of problems of dynamic optimisation in the theory of economic planning tend to require quite demanding mathematics. Even when the 'economic system' is reduced to an exceedingly simple form - like the Fel'dman model - the algebraic demands can be rather daunting. This is a pity because, although results in planning theory are sometimes merely rigorous formulations of intuitively obvious points, this is not so in all cases. Some are much less obvious and most, whether obvious or not, provide helpful structures for discussion of planning policy and consequently deserve a wider audience than they normally get.

This paper is a modest expository attempt to make accessible to non-mathematical readers some 'planning theory' conclusions which might otherwise remain opaque. The results in question are relevant to current discussions of the role of technological change (and the capital-goods sector) in industrialisation policy. They relate to a planned economy -and an "idealised" one at that, but they have some points for policy in other forms of economic organisation as well. And, as will be suggested, they may have more than current relevance, since they suggest new ways of looking at the various industrialisation strategies which were disputed so heatedly in the Soviet debate of the 1920's, a debate in which so many central policy issues were raised [1].

---

1. The best secondary source is Erlich (1960). However, Isaac Deutscher's Trilogy on Trotsky (Deutscher,1970) especially Volume II, provides a splendid view of the Preobrazhensky-Bukharin debate. A classic primary source is Preobrazhensky's "New Economics",(Preobrazhensky,1965). Note that the discussion of the Soviet debate in this paper is primarily concerned with the nature of the strategic options which were in dispute, especially between Preobrazhensky and Bukharin. The paper has no pretentions to review Soviet economic history,nor to provide new insights into how Soviet policy itself might have been conducted in the 1920's and 30's.

* I am grateful to Professor Valpy FitzGerald of ISS, The Hague for drawing my attention to earlier work on open economy forms of the Fel'dman model on which I have drawn in this paper. In addition I thank Prof. Kurt Martin and Dr. David Dunham of the ISS for their timely correction of my more outrageous misconceptions of Soviet economic history in the 1920's. Participants in the Working Group on Science and Technology at the EADI Conference in Madrid, September 1984 also provided helpful comments.

The basis for the discussion is a simple model of planned economy - the Fel'dman model. However, the basic model is extended in two ways: first, an export sector is added; second, allowance is made for technological change in the form of Arrovian-type learning-by-doing in both the export-sector and the local capital-goods producing sector. The paper proceeds as follows. In section 2 which follows, there is a discussion of the model and of its dynamic properties. Section 3 then examines dynamically optimum policies to meet a crude but plausible planners' objective function in a plan of finite duration . Optimum policies are described for the case where there is no technical change. In section 4, optimal policies are explored for the more interesting case where there is technical change in the form of 'learning-by-doing' in both the export and the capital-goods sectors. Section 5 relates the discussion to two aspects of Preobrazhensky's position in the Soviet debate: first to his relative neglect of the export sector; and second to his somewhat tentative recognition of the role of learning effects in the production of capital goods. Section 6 contains some concluding remarks.

There is no difficult algebra - in fact there is hardly any at all. Planning theory results are not proved - they are simply given and as far as possible explained. The outcome is the kind of paper which mathematical economists might call an essay in 'hand-waving' - in what Koopmans dismissed scornfully (and quite illegitimately) as "the diplomatic method in economics" (Koopmans, 1957 ; Chapter 2). This does not really matter: the conclusions discussed here are either already to be found in more formal literature (in which cases references are given), or in a few instances in pieces of analysis in which I am currently engaged.

And, if a bit of 'hand-waving' or 'economic diplomacy' makes arguments more readily understandable to persons who are prone to symbol-shock even at low-levels of algebra-exposure - well, so much the better.

2.

The Feld'man model is exceedingly well-known. The structure is shown in Diagram 1. The I-sector makes

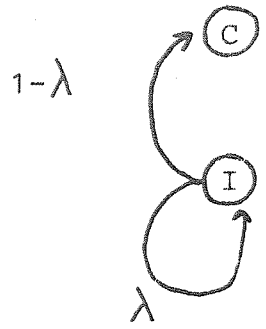

Diagram 1.

capital-goods in the form of 'machines'. These may be allocated to the C-sector where they are used to make consumer-goods; alternatively they may be installed in the I-sector itself where they expand the capacity for machine-making. The basic assumptions are: labour and machines are combined in fixed proportions in each sector (i.e. there are 'fixed coefficients'); labour is available in abundance so that the number of machines in each sector (i.e. the sectoral capital stocks), along with the machine productivities in producing consumer goods or capital goods, determine levels of output; and, most important, once a machine has been installed in a sector, it cannot subsequently be moved, (this is sometimes described as the assumption of 'non-transferability' of

capital stock).[2]

The model is often described as being based on the distinction between Department 1 and Department 2 in Marx's analysis. It would indeed have been natural for Fel'dman, a Soviet bureaucratic, to draw inspiration from Marx, but as a matter of fact there is little that is specifically Marxian about the distinction between capital-goods and consumer goods sectors,[3] nor therefore about the model itself. The model is essentially a technocratic device for assisting reflection upon policy options in a closed planned economy - and not much more.

Fel'dman ingeniously suggested that the appropriate policy variable for the model is λ (see Diagram 1) the proportion of capital goods output allocated to the capital goods sector itself. If this proportion is fixed and if the productivity of machines in the investment sector is β_I, the rate of growth of the investment goods sector will be constant at $\lambda\beta_I$.[4] Except under a special condition the proportionate rate of growth of the C-sector will be different from this. It is, however, a feature of the model that provided λ is held constant, the rate of growth of the C-sector will 'converge' to that of the I-sector.

---

2. It is discussed in all the standard analyses: For example Chakravarthy (1969). Weizman (1971) gives a particularly interesting discussion.

3. Distinctions between machine-making and consumer goods sectors are present in pre-Marxian classical writing as well as in later non-Marxian neo-classical analysis of growth and accumulation.

4. It is worth noting the following for later reference: β_I measures the number of machines produced by each machine in the I-sector capital-stock per unit of time. Therefore, β_I has dimensions $(\text{time})^{-1}$. More precisely $1/\beta_I$, the capital-output ratio of the I-sector measures the time needed for a machine in the I-sector capital stock to produce a machine as output (which may then be allocated to the I- or C-sectors).

This convergence (which obviously results in 'steady-state' growth with all sectors growing at the same constant rate) in general takes an exceedingly long time to come about.[5] However, this is largely beside the point for present purposes. The behaviour of the model of when λ is held constant helps understanding of its dynamics. But in this paper we shall be concerned mainly with how λ must be changed over time, so as to meet particular plan objectives.

So much for the basic Fel'dman model - at least for the rest of this section. This paper is concerned mainly with an extension of Fel'dman's system, in which an export sector is included in the economy. This extended model, originally set out by Harris (1972), is represented in Diagram 2.

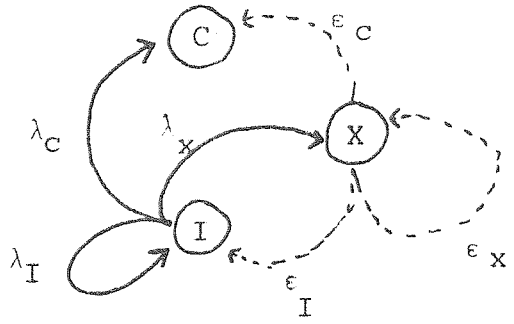

Diagram 2

---

5. In fact, formally the steady-state is never reached but only approached as an asymptotic condition. Convergence properties of the model are discussed in many texts (eg. Hywel Jones, 1975 ; Taylor, 1979). They are usually described in unnecessarily complex ways. Essentially convergence depends on the fact that when enough time has passed, the ratios of capital-stocks in the C- and I- sectors will approximate to the (constant) proportion, $(1-\lambda):\lambda$, in which increments are made to them. Once this has happened the steady-state is approached. Of course if the initial proportions of sectoral capital stocks had happened to be as $(1-\lambda)$ to λ, a steady-state would have existed from the outset. This is the special condition referred to earlier.

The X-sector makes an export commodity (which is not directly used in the domestic economy - or, more realistically, only demanded in quantities so small as to be negligible). The machines made in the I-sector may now be allocated to the X-sector so as to expand export production, or to the I-sector, to expand local output of machinery, or to the C-sector, to expand output of consumer goods. The proportions of I-output allocated to these sectors are λ_X, λ_I and λ_C respectively, and $\lambda_X + \lambda_I + \lambda_C = 1$.

Following the simplifications used by Harris we assume that foreign demands for our X-goods are infinitely elastic at the going price, and that they are exchanged for I-goods only, in foreign markets. The price of these foreign-made I-goods is assumed constant at P_I, while our exports are priced at P_X in foreign markets. The external terms of trade are $P = P_X/P_I$ and measure the number of foreign machines purchasable by a unit of our exports. There are no changes in relative prices[6]. Finally, the total import of foreign-made I-machinery is allocated between the local C-, I- and X-sectors in the proportions ε_C, ε_I and ε_X, and $\varepsilon_X + \varepsilon_I + \varepsilon_C = 1$. These allocations are shown by the dotted lines in Diagram 2 (which thus do not refer to direct allocations of X-godds but to allocations of the I-goods imported in exchange for X-goods exported).

---

6. The assumptions about the export sector may seem heroic. However, the important ones (i.e. no domestic demand for X-goods, infinite price elasticity and constancy of external terms of trade) can all be relaxed without changing the qualitative nature of the results.

Plainly, the export-sector is an alternative (indirect) source of I-machinery Intuitively, it is plain that the model can encompass a range of strategies: these may be 'inward-looking', in which case the emphasis will be on local production of I-goods, or 'export-oriented', in which case the priority will be to expand exports so as to import more I-goods. Oddly, this simple but interesting extension of Fel'dman's original idea has received little attention since Harris first put it forward - and unfortunately its dynamic properties and implications for policy choices were wrongly presented in the original article.

To get an idea of the dynamics of the model, consider the case where the proportionate allocations of locally-produced and imported I-goods (i.e. the λ's and the ε's), are held constant. In this case, the growth rate of the I-sector, g_I will depend, inter alia, on the proportion of I-output which is 'ploughed back' into the I-sector itself (λ_I) - as in the simple Fel'dman model - as well as on allocation of imported I-goods to the sector (i.e. on ε_I). Similarly, the growth rate of the X-sector, g_X, and hence ultimately of the supply of imported I-goods, depends on ε_X, the proportion of imported I-goods allotted to the X-sector as well as on λ_X, the proportion of locally made I-goods invested in it. In general, these growth rates g_I and g_X will be different initially, but it can be shown that over time they converge asymptotically a common growth rate, $\bar{g}$, always intermediate between the initial values of g_X and g_I. In this sense the two sectors which in their different ways act as sources of 'machines' or I-goods, eventually come to act as if they were a single sector with a single constant growth rate of I-supply of $\bar{g}$. Taken together they then become analogous to the investment-good sector of the Fel'dman model.[7] After enough time has passed, the consumption-sector growth rate g_C also converges towards $\bar{g}$, and the economy makes an

[7] In which the supply of I-goods grows at a constant rate when Fel'dman's λ is held constant

asymptotic approach to steady-state constant proportional growth at this rate.

Once again the approach to this steady-state is very slow, and - once again - this does not matter much. The more important considerations, which do not depend on the steady-state conditions, concern the time-paths which the λ's and c's must follow to maximise an objective function. This is the topic of the next section.

3

An 'optimal plan' may be described as a set of policies, which typically change over time, and which ensure that some specified socio-economic objective is reached to the maximum possible extent consistent with structural relations in the economy, (i.e. with the 'model'). The question of choice of objective is value-loaded and so is naturally a matter of extensive debate. In this discussion we stick to an extremely crude form of socio-economic objective which has the merit of simplicity and which produces results of reasonable generality. Thus, we shall require that the optimum plan should maximise the sum total of consumption goods made available over some defined period, T.[8] The problem is to find the policies which will

---

8. A more general objective function would require maximisation of total utility, where the utility of an extra unit of consumption is assumed to decline with the amount of consumption, (for a discussion see Chakravathy, 1969). We avoid this complication. In addition, the assumption of a finite plan period, T, raises well-known problems - in particular because it implies lack of concern for post-plan consumption levels and ultimately for forthcoming generations. (See Heal, 1974, p.97). Nevertheless the crude objective function described in the text has considerable advantages for exposition and we stick to it.

accomplish this. In the case of the simple Fel'dman model these policies amount to the specification of required changes in λ over the plan. In the more complex open-economy variant the problem is to specify how the various λ's and ε's must be set over the period T. In general, problems of this sort may be solved mathematically by applying the Pontryagin Maximum Principle. (See Dorfman, 1969 for a lucid account of this mathematical method). In this text, we shall not discuss the algebra involved but simply set out the results it yields and briefly discuss them. Three sets of results are discussed: first, those for the simple Fel'dman model; second, those for the slightly more complex open-economy variant; and third, those for the open- economy variant when there is learning - by-doing in production of both the export-good and locally-made I-goods.

(a) The Fel'dman model

Given this objective function, optimum plans for a Fel'dman economy' are strikingly simple,[9] and though they are perhaps not intuitively predictable, they are quite readily understandable. For the Fel'dman model, the optimum path (provided the plan period T is long enough), consists of two phases: one in which $\lambda=1$, and a second, running up to the end of the plan, in which $\lambda=0$, (see Diagram 1 for a specification of λ). Thus, in a first period (say, up to a time t_o), all machines produced in the I-sector are used to add to the capacity of the I-sector

9. The following results were first shown by Chakravarthy (1969) using calculus of variations. The simpler form used here is taken from Cooper (1984a) and was originally discussed in a paper presented to the DSA Conference, Dublin September, 1982. Similar results for a 3-sector variant of the Raj-Sen model are found in Atkinson (1969) and Bardhan (1970).

itself; there is no expansion of consumption output which remains constant. After t_o and up till T, when $\lambda=0$, all machinery produced is invested in the C-sector; accordingly consumption grows and I-sector output is constant. For simplicity and without too much misrepresentation, we may call the first sub-period ($\lambda=1$), the 'accumulation phase', and the second ($\lambda=0$), the 'consumption phase'. In Diagram 3 below, the growth paths for these phases are sketched.

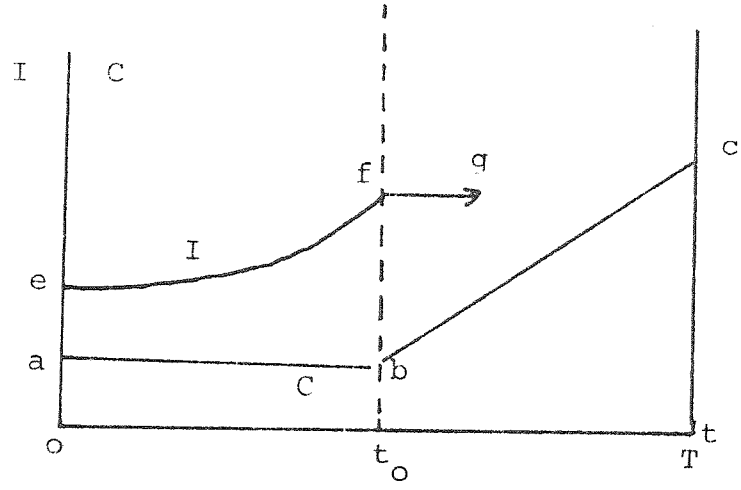

Diagram 3.

The optimal path for investment output, I, is shown as efg: i.e. I-output expands exponentially up to t_o and is constant thereafter (since $\lambda=0$ between t_o and T). The optimum path for C-sector output is abc: constant in the accumulation phase up to t_o, and then expanding in the consumption phase, when $\lambda=0$. In effect, the optimisation procedure 'discovers' the time, t_o, which maximises the area under the curve abc (i.e. total consumption over the plan period). For example, if t_o had been shorter, the period of growth of consumption t_o to T would have been longer; however, since I-output of machines would not have had as much time to grow, it would be smaller and as a result the rate of growth of C-output would have been smaller during the consumption phase. This slower

growth rate would more than offset the effect of the longer period of growth, so far as the aggregate availability of consumption goods over the plan is concerned (i.e. the area under abc).[10]

(b) The Open-economy variant:[11]

The open economy version of the Feld'man model (Diagram 2), has optimal growth properties which are analogous to those of the simple Fel'dman model. In particular, if T is sufficiently long, the plan consists of an accumulation phase followed by a consumption phase as before.[12] In the consumption phase, all investment-goods (i.e. I-machines) go to expand the C-sector: in terms of Diagram 2 this means that $\lambda_C=1$ in the consumption phase - so that λ_I, $\lambda_x = 0$ and similarly $\epsilon_C=1$ and ϵ_I, $\epsilon_x=0$.

As far as the accumulation phase is concerned, it is plain that there are, in principle, alternatives available. The supply of investment-goods (I-machines) can be expanded either by building up local capacity to produce them - i.e. the capacity of the I-sector - or by expanding the export sector so as to increase capacity to import I-machines. The optimisation exercise yields the result that local capacity should be expanded if $\beta_I > \beta_x.P$, where β_I and β_x are the capital productivities

---

10. It is easy to show that t_o is given by $(T-t_o)=2/\beta_1$ a result which is more fully discussed in Cooper (1984a).

11. Results in this and subsequent sections are in Cooper (1984b)

12. If T is very short, one could have $T<t_o$ (in footnote 10) In this case the optimal plan has no accumulation phase, only a consumption phase. Similar arguments hold for both the open-economy and simple Fel'dman cases.

of the I- and X-sectors respectively, and as before $P=P_X/P_I$, the external terms of trade (see section 2). Thus $\beta_X P$ measures the amount of I-goods that can be obtained at going international prices by a unit investment in the export sector; and - obviously - β_I measures the increase in I-goods supply obtainable by a similar investment in the local I-sector. The rule for the accumulation phase is therefore, either

(i) set $\lambda_I=\varepsilon_I=1$ and all other λ's and ε's = 0 if $\beta_I > \beta_X P$; or

(ii) set $\varepsilon_X=\lambda_X=1$ and all other λ's and ε's = 0 if $\beta_I < \beta_X P$.

This is recognisably a simple efficiency rule: the marginal unit of investment must go where it adds most to the capacity to supply I-goods. The rule can also be expressed as follows: invest in expansion of the local I-sector if

$$P < \beta_I/\beta_X \qquad (1)$$

Now, using the argument of footnote (4), the right hand side can be written as

$$\beta_I/\beta_X = \tilde{P} = \frac{\text{'capital-time' to produce a unit of X-goods}}{\text{'capital-time' to produce a unit of I-goods}}$$

Since by assumption, capital stock is the only scarce 'factor of production', $\tilde{P}$ measures the ratio between domestic costs of production of exportables (X-goods) and importables (I-goods). Plainly condition (1) for basing the accumulation phase on local production of capital-goods - or I-machines, can be written

$$\tilde{P} > P \qquad (2)$$

In other words, it is optimal to expand supply of I-machines by local production rather than imports if the ratio of domestic costs of production of exportables to machines (importables)

is greater than the ratio of the prices of exportables to importables in foreign markets. This is simply Ricardo's law of comparative advantage - with a twist. Whereas it was reasonable for Ricardo to base his famous examples on labour-time as a measure of costs, our case must - by virtue of its assumptions - use 'capital-time' (or perhaps less ambiguously 'machine-time').[13]

In short, the open-economy variant of the Fel'dman model has an optimal plan (for our objective function), in which allocation in the accumulation phase is determined by comparative advantage rules.[14] We shall use this as a point of departure in the analysis of learning-by-doing effects in the next section. It is rather piquant that the supposedly 'Marxian', Fel'dman model should have a 'capital-theory of value' embedded in it - brought to the surface by considering the open-economy form.

4

In this section we discuss the implications of technological change through 'learning-by-doing' for optimal plans in the Harris variant of the Fel'dman model.

---

13. There is no ambiguity about measures of capital because both the Feld'man model and the open economy variant assume that all capital stock is made up of one kind of machine. Under some restrictive conditions 'multiple' machine models can be encompassed (see for example, Cooper, (1984a)).

14. Note, that even if it is optimal to expand local production of capital-goods in the accumulation phase, imports in exchange for exportables should continue, i.e. $\varepsilon_I = 1$.

One point is immediately clear. Given our assumptions, in particular that labour is available in abundance, the only forms of learning-by-doing which will influence optimal plans, are those which effect the productivity of machinery (or 'capital'). Harrod-neutral technical change at the sector level will simply leave capital or machine productivities unchanged. These productivities (the β's of the previous section) determine the form of the optimal plans; if they are unchanged, so also will be the conclusions of the previous section. This means that to be 'interesting' from our present point of view, learning-by-doing must have some capital-augmenting component (though it may, of course, have labour-augmenting effects as well which - aside from the simple objective function used here - may be socially very important, conceivably damaging).

The nature and causes of learning-by-doing are matters of debate. In the seminal paper on the topic, Arrow (1962) assumed that productivity changes induced by experience are a function of cumulated gross investment (i.e. capital stock). This is the assumption made here - as in some more complex and sophisticated analyses (e.g. Sheshinski, 1967). As Sheshinski (op.cit. p.33) and Bardhan (op.cit. p.105, n.1) point out, the Arrovian index is based on industry level empirical studies. However, in his own work, Bardhan (ibid. pp.104 ff) measures learning-by-doing as a function of cumulative output. The cumulative output index might be argued to have the advantage that it allows experience-based advances in producitivity even when gross investment falls to zero, whilst the Arrovian index does not. It is however analytically harder to use for our problem and does not have much effect on the qualitative nature of the results (which is the main concern in the present discussion). Complaints have been raised against both measures (see Maxwell, 1983 for a good review). For example, Katz (1976) expresses

concern at the assumption that 'learning' is costless; R.M. Bell has expressed similar worries (private communication). This is a real bother; if 'learning-by-doing' involves specific costs, analyses like the present one become much more complicated. For the present, at least, it is not clear that the greater complexity would much improve understanding of fundamentals.

In the following, we assume that producitivity gains due to learning-by-doing are confined to the export (X) and capital-goods (I) sectors in diagram 2. Moreover, we shall use the Arrow formulation to define the magnitudes α and γ. These are the 'learning-elasticities' in the I- and X- sectors respectively. The learning process implies that the productivities β_I and β_x increase as investment of machines increases the capital-stocks in the sectors in question. The interpretation of the elasticities follows directly: α is the percentage increase in the productivity of I-sector machines (in the capital stock), when the capital stock in that sector increases by 1 per cent; γ has an analogous meaning for the X-sector.[14]

The general form of optimal plans is not changed when learning-effects are introduced. The optimal plan for the open-economy model (in Diagram 2) still falls into two phases: an initial accumulation phase followed by a consumption phase. There are, however, differences of considerable relevance to planning policy. The first (and least considered in the literature) is that the

---

14. Formally, the capital productivity of the I-sector (for example), is defined as

$$\beta_I(t) = \beta_I . (K_I(t)/K_I(0))^{\alpha}$$

which gives the above interpretation of α. Note that $\beta_I(0) = \beta_I$ on this definition.

consumption phase itself becomes a shorter portion of the total plan period T. Diagram 3 helps to explain this. Suppose, as in Section 3, that t_o is the optimal time for shifting from the accumulation to the consumption phase; in other words, when the shift is made at t_o, the area under abc, which measures aggregate consumption - the social objective - is maximised. Then, if a shift were made a bit later than t_o, the absolute growth rate of consumption after t_o - given by the slope of bc and ultimately by the size and productivity of the machine supplying sectors - would be greater, but the implied shortening of the period up to T would more than offset the effect of this increased slope of bc. Aggregate consumption over the plan would fall. However, this is on the assumption that the productivities β_I, β_X are constant. If, on the other hand, β_I, and/or β_X - the capital-productivities of the machinery-providing sectors - increase with growth of the I- and X- capital stocks the story changes. Now, a given extension of the accumulation phase has a distinctly greater effect in increasing the rate of growth of consumer goods output (i.e. the slope bc), for two reasons. First, as the capital productivities of machinery-providing sectors increase so the absolute size of these sectors expands more during any given extension of the accumulation phase than if their capital productivities had remained constant.[15] Second, this effect is reinforced by the fact that more accumulation

---

15. Because in the accumulation phase, the increase in β_I, β_X increases the rate of accumulation in whichever of the I- or X-sector has priority - since all I- or X-output goes to expand one or other of these sectors themselves. Note that, under our assumptions there are no learning effects in the consumption phase because it is assumed that there are no learning effects in the C-sector, and all accumulation in the 'learning' sectors (i.e. I- and X-sectors), ceases. If there were learning effects in the C-sector, they would presumably offset the tendency for the optimal plan to have a shorter consumption phase.

in the machinery-providing sector further expands their capital productivities, through learning effects. As a result, when learning is confined to the machinery-providing I- and X-sectors, it becomes worthwhile to trade-off a longer delay in the expansion of consumption for the considerably higher rate of expansion in C-output that can be got than in the absence of learning effects. As footnote (15) suggests this conclusion will need to be modified if there are sufficiently strong learning effects in the C-sector (though the analysis becomes much more complicated if there are).

More interesting results concern the nature of optimal policy in the accumulation phase itself. In Section 3, we showed that when β_I, β_X are simple technical constants, the allocation of investment between local production of machinery, and development of exports for importation, should follow the principle of comparative advantage (appropriately specified for factor scarcities). Matters change when there are learning effects. The main outcome can be expressed as a modification of equation (2), the comparative advantage relationship. When Arrovian learning-by-doing is present, two results can be shown:

(i) <u>in that part of the accumulation phase immediately preceding the consumption phase</u>, all investment should go to expand local production of capital goods, if

$$\frac{1+\alpha}{1+\gamma}.\ \tilde{P} > P. \qquad (3)$$

Plainly if learning elasticities in both sectors are the same this simply reduces to (2), the comparative advantage rule.[16]

---

16. In equation (3)

$$\tilde{P} = \beta_I (K_1(t)/K_I(0)^{\alpha}/\beta_X (K_X(t)/(K_X(0)^{\gamma},$$

and therefore allows for the effect of past accumulation on sectoral capital productivities. It is important to bear this in mind. The 'learning-effect' is important not simply because it <u>changes</u> factor productivity, as Arrow pointed out, (loc.cit.).

The departure from the comparative advantage rule arises when there is differential learning, a point which is often lost sight of in the 'technology' literature.[17] If however there are differential learning effects and, for example, α is greater than γ, the rule in (3) amounts to a recommendation to planners to behave 'as if' the production costs of locally-produced I-machines were subsidised in the accumulation phase.[18] This will provide an optimal path which takes account of the larger 'external economies' generated by expanding the I-sector's capacity rather than the X-sector's. To strengthen the point: the differential learning advantages might well make it socially desirable (in terms of the objective function), to invest in local production, even if

$$\tilde{P} < P$$

when the comparative advantage rule suggests otherwise. It is worth noting, however, that a great deal of the 'technology literature' appears to proceed on the implicit assumption that learning elasticities are (differentially) high in certain sectors: the manufacturing sector as a whole in some cases; the capital-goods sub-sectors in others. By and large, the empirical basis for this assumption is slender. In the above discussion the assumption that learning elasticity is higher in local production of capital goods than in export production can only be regarded as illustrative.

---

17. As one might expect the point is made with some force and considerable clarity by Little, Scitovsky and Scott (1971), in relation to the 'external economies' argument for protection in market economics, though in the main their opinion is that since learning effects are hard to measure, it is better to ignore them.

18. In the case of a centrally-planned system no actual subsidy need be necessary, depending of course on the extent to which the price system is used.

(ii) Despite these caveats, suppose that condition (3) holds in the period immediately before t_o, i.e. at the end of the accumulation phase. Accordingly, in that period investment is used to expand the I-sector. It is nevertheless possible, if the plan T is long enough, that this 'local production' period be preceded by a period when export development is optimal. A necessary, but not sufficient condition for this is that

$$\frac{1+\alpha}{1+\gamma} \cdot \tilde{P} < P. \qquad (4)$$

This is possible (given the definition of P in footnote 16) early in the plan period,[19] even though later in the plan (3) holds. In this case the optimal plan will consist of three phases. Two of these are sub-periods in the initial accumulation period: in the first all investment goes to the export-sector and increases in supply of I-machines come entirely through expanding imports (at the terms of trade P); in the second all investment goes to the I-sector, expanding local production of I-machines (though, of course, X-goods - in constant amounts per annum - continue to be exported and I-machines imported).[20] This double accumulation phase is then followed by a consumption phase.

19. Essentially, if (3) holds at t_o, investment in the part of the accumulation phase immediately preceding t_o is in the I-sector. Consequently $\tilde{P}$ (as defined in footnote 16) must have increased up to t_o as the capital-stock of the I-sector grew. Accordingly, if ^oT is long enough the necessary condition (4) may be met - because $\tilde{P}$ is much smaller than at t_o, and conceivably the more demanding - and complex - sufficient condition for initial investment in the X-sector may be met. If indeed (3) is met at $t = t_o$, it is easy to show that the existence of an initial export oriented phase depends upon $\beta_X(0) > \beta_I(0)$.

20. This is mainly a consequence of the assumption that X-goods are used in negligible amounts in the domestic economy. With this assumption, it would be pure waste of resources not to export X-goods in exchange for I-machines. The alternative would be to leave X-capacity unused. Of course, on more realistic assumptions (for example, ones which allow for materials used in X-production), continued exports might have real opportunity costs.

Patterns of this kind are more likely to arise when the plan has a long horizon (i.e. T is big enough). They are also more likely when β_X, the productivity of capital-stock in the export sector is initially high compared to its productivity in the I-sector, β_I - perhaps because of limited past experience in the local production of machinery. And, finally, the 'three step' plan (import machines - make machines at home - expand consumption) is more likely when though $\beta_X >> \beta_I$ initially, the 'learning elasticity', α, in local capital-goods production, is much higher than γ, the learning elasticity in export production, (if both $\beta_X >> \beta_I$ initially, and γ were greater than α, sufficient conditions for a purely export-oriented accumulation phase will be met).

Intuitively it is plausible to suppose that the conditions for a three-phase optimal plan of the kind discussed above may arise in practice. It is possible to give a 'feel' of the underlying economic logic of such a plan. Initially, it is optimal to exploit the relatively high capital productivity of the export-sector for a certain period, using imports to increase the annual rate of supply of I-machinery to the economy. Then, when this rate of supply is high enough, it becomes optimal to switch the high rate of investment attained by having expanded exports, to the development of local machine-making in the I-sector. Although the productivity of capital is initially low in this sector, its learning-elasticity is high. Accordingly, the high rate of investment in the sector, based in the first instance on the large supply of imported machines, induces a correspondingly high increase in capital productivity through learning.[21] This ultimately 'pays off', in the

21. An obvious practical concern arises here: even if one believes the form of learning function used here is realistic, one would be obliged to recognise that very high rates of capacity expansion in local capital-goods sectors might well produce as much disorganisation and chaos as learning-by-doing. The elasticity α may not be constant over all rates of investment in a sector.

sense that the advantages of induced learning effects in increasing the rate of accumulation (and so the capacity to supply I-machines), more than compensates for the short-run opportunity costs of departing from the comparative advantage rule. The final shift, to the consumption phase, follows the logic discussed in Section 3.

To conclude this section, it is important to note that - despite rather strong presumptions that are sometimes made about the need for local capital-goods production - there are no a priori grounds for assuming that optimal plans will require one sequence rather than another. In the next section, which reviews some strategic options discussed in the Soviet Industrialisation Debate, we point to some of the difficulties that arise about which empirical assumptions to make.

5

It is obviously risky to use the stylised theory of preceding sections to make inferences about current or historical realities. Yet, equally obviously, the theory has some lessons to teach, and provided one is clear about its limitations, the risks are worth running. A natural question to ask (given the provenance and publication date of the Fel'dman model), is whether the analysis throws any light on positions taken in the remarkable debate on Soviet industrialisation in the 1920's. Since that debate ranged widely, (see Erlich, op.cit.), we can only touch upon it superficially. The comments in this section relate only to a part of Preobrazhensky's analysis (op.cit.).

First - some caveats. Ironically enough, we must start by noting that the Fel'dman model is not a particularly convincing representation of the Soviet economy of its time, and in some respects is actually unhelpful. It is hard to locate the agriculture-industry division in Fel'dman's consumer goods-investment goods structure. At one level this is a technical weakness, a problem of aggregation. But there are more profound matters involved: a central preoccupation of all protagonists in

the debates of the 20's, was precisely that there were vast differences in relations of production between the peasant-cum-petty capitalist rural sector and 'socialist' industry in the towns. The technocratic Fel'dman framework (with its implicit assumption of full and benign state control over production and investment in both sectors) simply cannot reflect these aspects of intersectoral differences which lay at the centre of the policy debate.

Furthermore, the 'open-economy variant' discussed in Sections 3 and 4, departs from contemporary Soviet reality in other important ways. The most significant is that in the 1920's , the 'export good' for the Soviet economy was grain. Far from being used only for trade (the assumed characteristic of X-goods in our analysis), grain was a crucial consumption and wage-good and as the successive crises of the 1920's made clear, was quite essential in a direct way to the process of accumulation in the industrial sector.[22] The three-sector breakdown of preceding sections therefore, obviously misses a tricky and important point.

Aside from these difficulties about the way the model is specified, the 'planner's objective function' we have used is embarassingly crude. A more sophisticated (concave) utility function might be more realistic, though that must remain a matter of doubt, (and anyway such a function would not have much effect on the results for the 'finite' plans we have considered). The real point, however, is that we have not explicitly incorporated the alternative political constraints on trade perceived as desirable by the various participants in the policy debate. This is probably most important in the case of Preobrazhensky and, accordingly, we touch on the point once again later in this section.

---

22. Kalecki's approach to 'financing economic development', though not used here, has a direct relevance, (Kalecki, 1976). Kalecki emphasises the importance of the supply of wage-goods in accumulation.

Despite these rather formidable ifs and buts, we may use the earlier results to comment on two aspects of Preobrazhensky's position on international trade. These are: first, the implicit assumption that runs through much of his analysis that trade should only play a small role in the industrialisation programme; and second, his simultaneous recognition of the significance of comparative advantage, and his attempts to cope with learning-by-doing.

It is perhaps as well to start by noting that despite his formidable reputation as a closed economy super-industrialiser , and despite his predictable adherence to the Marxian view that trade with capitalist economies must be exploitative, Preobrazhensky was sensitive to the relevance of comparative advantage. His political mentor, Leon Trotsky, always had a clear conception of the difficulty (and dangers) of aiming at self-sufficiency in production of means of production in a short time period, (Trotsky, 1926). Preobrazhensky himself proposed "....to import more of those machines whose domestic production is less advantageous under existing economic conditions".[25] He asserted (somewhat heavily) that "the law of value of world economy can also exert its influence...in cases where...we have to hold back, contract or completely put an end to the production of certain means of production where, given...prices on world markets and a certain level of development of our engineering industry, it would be inexpedient to...develop our own production...", (Preobrazhensky, op.cit. p.165).

The point is clear - if a little strange to read from the supposed arch protagonist of closed economy capital goods production. Moreover, supposing that Preobrazhensky had in mind some social objective roughly similar to ours,

---

23 Quoted in Erlich, op.cit.,p.46 from the 2nd edition of 'Novaya Ekonomika', Moscow, 1926.

(which is plausible enough), and therefore saw it as crucially desirable to put the economy into a phase of high accumulation (which he plainly did), his concern with efficiency of machine production was entirely appropriate, as Section 3 shows. It was also entirely appropriate, as that section again shows, that he should be concerned with using imports if that indeed turned out to be the least cost way of carrying through the programme of accumulation.

These passages make it clear that whilst Preobrazhensky was disposed to believe that priority should go to local 'production of means of production', the reason for this was not that he was in some inherent sense, 'against trade', in a simple-minded way. In fact, against the background of section 3, it is possible to suggest two underlying explanations for his position. First, he appears to have assumed that it was as a matter of fact, generally more productive in terms of speeding accumulation to allocate investment goods to local machine production rather than expansion of agricultural exports. The evidence on this point - at least at the level of generality which is implicitly assumed in the 'New Economics'- is obviously open to debate. Second, Preobrazhensky's approach seems at first sight to overlook a point made earlier in section 3 (see, in particular footnote 14), viz. even if it were optimal to expand local production of capital-goods in the accumulation phase, imports of capital goods in exchange for exportables should continue and the imported machinery used to expand the capacity of the local machine-making sector. The explanation for this probably lies in the fact that the available exportables were - as noted above - important wage-goods in the Soviet case. Thus, an expansion of grain exports in the absence of substantial investment in the agricultural sector may well have reduced supplies to urban areas and hence the real wage - as well as conceivably

from requiring requisitioning the peasantry[24].

Beyond these technical considerations, Preobrazhensky certainly had political worries about export development as a basis for accumulation. These were not so much focussed on concerns about 'dependence' in the modern sense. They were, more likely, centred around the economic and hence political power which the more or less independent peasantry and especially the kulak elements would have acquired through export-led accumulation.

Preobrazhensky recognised the importance of 'learning' with great clarity. Though he might accept that the principle of comparative costs could render it "... inexpedient to develop...(local)...production", he argued that "...the question would be decided mainly on the basis of a calculation of all the means of production needed..., and the prospect of improving and cheapening our own products". He notes that this implies the determination of an "optimum worked out in a very complicated way in accordance with an economic plan". (ibid, p. 165). This is a striking observation, if only because it is a very early (and correspondingly perceptive) recognition of the limits to which comparative advantage principles might be used in planning. It is hard not to sympathise with the faint despair in Preobrazhensky's fudgy remark about 'very complicated' calculations. In effect we still await a convincing empirical basis for determining optimum policies when there is learning-by-doing (in both planned and market economies). Most discussion of the point today is every bit as fudgy as Preobrazhensky's, and some is less honest.

However, though his insight on this point is remarkable (even if we make the plausible assumption that he drew on the 'bourgeois' classical economists), he is in general almost entirely concerned with circumscription of the role of trade. There is no discussion of differential opportunities

24. If however, a grain surplus had been available, without large investment in agriculture the policy of producing capital goods locally could have been reinforced by importing 'machines to make machines'. The debate between Bukharin and Preobrazhensky would in this case have included a discussion of whether exported grain should be exchanged for machinery for consumer-goods production (Bukharin) or for capital goods production (Preobrazhensky).

for 'cheapening' production and no recognition that the opportunities for improving capital productivities in this way might conceivably have been greater in export production. Nor, for that matter, is the plausible point encompassed that even if learning rates might be much higher in industry, factor productivities (especially the productivity of investment goods), could have been much higher initially in the rural sector than in urban 'socialist' industrial enterprises. And, if that had indeed been the case, an optimum policy might well have been to increase the capacity to expand the 'learning elastic' sector, by first building up the high productivity export-sector. This is the policy option we discussed in Part 4.

These points are not meant to suggest that Preobrazhensky was wrong to propose a high rate of expansion of local capital goods production, and Bukharin therefore 'right'. Rather, the point is that Preobrazhensky may conceivably have put forward sub-optimal policies in terms of his own view of the desirable objectives for the Soviet economy. The optimality of Preobrazhensky's proposals could be defended on one of two grounds. In the first place, his approach would plainly be defensible if the productivity of investments in the local capital goods sector were sufficiently higher than in the agricultural export sector (measured in terms of 'machines' for addition to the capital stock). This is a strong empirical assumption on which he offered no direct comment. Secondly, his approach could be defended despite a higher capital-productivity in export-production, if the rate of learning-by-doing were much higher in local capital goods production than in production of agricultural exports. This is plausible, though once again undiscussed. However, even if the 'learning-by-doing' assumption could be justified, it is nevertheless possible (especially with a long planning horizon), that an initially higher capital productivity in export production might require the optimal policy to

start with investment in export production as a basis for accumulation, and subsequently to switch to local production of capital-goods in order to take advantage of higher 'learning elasticity' in local industrial production. This possibility was not considered.

6.

This paper has attempted to elucidate some results in planning theory from the Fel'dman model, and in particular, from an open-economy variant of it. This variant, first put forward by Harris has been unsatisfactorily discussed in the literature and part of the paper has been concerned to give a simple and hopefully correct account of its dynamics.

More interesting, however, are the optimum growth paths obtained with the 'Harris-variant' for very simple planning objectives (viz. maximisation of aggregate consumption). These are discussed in some detail. Our main focus has been on the implications of learning-by-doing effects for optimal plans. We have shown how comparative advantage principles which clearly apply in the 'accumulation phase' of optimal plans when there are no learning effects, must be modified.

Finally, the last section of the paper tries to indicate some of the practical relevance of these theoretical conclusions by applying them in a qualitative way, to a few limited but important aspects of Preobrazhensky's strategy for Soviet economic development.

Charles Cooper
Professor of Development Economics
Institute of Social Studies
The Hague

July, 1984.

Bibliography

Arrow, K.J. (1962); "The Economic Implications of Learning-by-Doing", Review of Economic Studies, Vol.29, June.
Atkinson, A.B. (1969); "Import Strategy and Growth under conditions of stagnant export earnings", Oxford Economic Papers Ns. Vol. 21 nr 3. November
Bardhan, P.K. (1970); "Economic Growth, Development and Foreign Trade", Wiley, London
Chakravarthy, S., (1969); "Capital and Development Planning", MIT Press, Cambridge, Mass.
Cooper, Charles (1984a) "Two Planning Models: A Comparison of Optimal Growth Paths in the Feld'man and Mahalanobis and Raj-Sen Models". ISS Mimeo.
Dasgupta, P.S. (1969):"Optimal Growth when Capital is non-transferable", Review of Economic Studies, January.
Deutscher, Isaac (1970); "Trotsky", Oxford University Press, London
Domar, E.D. (1957); "A Soviet Model of Growth" in "Essays on the Theory of Economic Growth", Oxford University Press, Oxford
Dorfman, R. (1969); "Economic Applications of Optimal Control Theory", American Economic Review, December.

Erlich, A., (1960); "The Soviet Industrialisation Debate, 1924-28", Harvard University Press, Cambridge, Mass.
Feld'man G. (1928a and b); "K feorii tempor narodnogo dokhoda", Planovoe Khoziaistro, November and December. Quoted in Domar (1957).
Harris,D.K. (1972); "Economic Growth with Limited Import Capacity", Economic Development and Cultural Change, Vol. 20, nr. 3 April.
Heal, G.M. (1973); "The Theory of Economic Planning", North-Holland, Amsterdam and American Elsevier, New York
Jones, Hywel, (1975); "Modern Theories of Economic Growth", Nelson
Little, I.M.D., Scitovsky, T. and Scott, M. (1971): "Industry and Trade in Some Developing Countries", OECD Development Centre and QUP, Oxford
Kalecki, M. (1971); "The Problem of Financing Economic Development" in 'Selected essays in the growth of the Socialist and Mixed economy', Cambridge.
Katz, J, (1976); "Importación de Tecnología, Aprendizaje e Industrialisación Dependiente', Fondo de Cultura Económica, Mexico.
Koopmans, Tjalling, (1957); "Three Essays on the State of Economic Science", McGraw Hill.
Maxwell, P., (1981); "Technology and Firm Learning Efforts in Less-Developed Countries", Unpublished DPhil thesis, University of Sussex
Preobrazhensky, E.(1965); "The New Economics"; translation by Brian Pearce, Clarendon Press, Oxford, 1965.

Sheshinsky,, E., (1967); "Optimal Accumulation with Learning by Doing", in K.Shell, (ed.); "Essays on the Theory of Optimal Economic Growth", MIT Press, Cambridge, Mass.
Taylor, Lance (1979); "Macro-models for Developing Countries", McGraw Hill.
Trotsky, L., (1926);"Towards Socialism or Capitalism", London.
Weizmann, Martin L. (1971); "Shiftable versus non-Shiftable Capital: an Analysis", Econometrica, vol. 39, nr. 3 May.