The mixed bless of modern fishing technology

Anders Skonhoft
Department of Economics
Norwegian University of Science and Technology
N-7491 Trondheim, Norway
(anders.skonhoft@svt.ntnu.no)
(Tel.:+47 73591939, Fax:+47 73596954)

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Abstract

This paper formulates a simple biomass growth model of a fishery. The property rights regime is of the unregulated local common property type with a fixed number of fishermen and where the fish stock is exploited in a myopic profit-maximizing manner. Within this resource management setting it is demonstrated that more modern fishing technology has a two-sided profitability effect, and where the direct, short-run, positive effect is counterbalanced by a negative, long-run, indirect effect that slows down the stock growth and increases the harvesting costs. In the steady state, it is shown that more modern technology dissipates the rent under already high exploitation pressure, while the opposite occurs if the fish stock is initially little, or moderately, exploited. This is the mixed bless of modern fishing technology.

1. Introduction

Statistics from the United Nation's Food and Agricultural Organization (FAO) demonstrate that many of the world's fish stocks are depleted, many are overexploited, and only a minor part of all wild fishery resources can be said to be in a healthy state (FAO 2005). The reasons for this bleak picture include the unregulated nature of many fisheries combined with valuable fish stocks. In addition, new and modern fishing technology plays a role (see, e.g., FAO 2003). The goal of this paper is to take a closer look at the technology side of the debate and, from a theoretical point of view, demonstrate how and to what extent modern and more efficient harvesting technology may be a disaster not only for the 'sustainability' but also the profitability of a fishery. Modern fishing technology includes larger and better-equipped boats, use of new synthetic materials, new fish-finding equipment and techniques and so forth, with calculations indicating that productivity growth over the last few decades has been very significant (see, e.g., Eggert and Tveteraas 2007 and the references therein).

The suggestion that new and modern technology can be a disaster may come as a surprise as more efficient technology, at least among economists, has always been seen as a welfare-improving device (e.g., the pioneering growth-accounting work in Abramovitz 1956). In a fishery, however, the blessings of more modern technology depend crucially on the institutional structure, and in a *regulated* fishery with well-defined property rights, new and more efficient technology is likely to be economically beneficial. For example, predictions from the standard social planner model (or the sole-owner model, see, e.g., Clark 1990) are that improved harvesting technology, *ceteris paribus*, unambiguously increases the rent and reduces the fish abundance in the long run (the steady state). However, following this model, an ever-increasing fishing efficiency will normally never constitute an overexploitation threat[i].

In an *unregulated* fishery where the fishermen in a varying degree take into account their harvesting effect on the fish stock, the picture may be quite different. The so-called open-access fishery has for many years served as the benchmark of an unregulated fishery (e.g., Gordon 1954, Homans and Wilen 1997), but within such an exploitation regime, improved fishing technology has normally no long-run effect on the fish rent as the equilibrium rent, *per definition*, equalizes zero. In the short-run, however, more effective technology yields a positive rent in the transitional phase before a new zero rent equilibrium is reached (e.g., Anderson 1986, Ch.2).

In what follows, an unregulated fishery where it is allowed for a positive rent is examined. More specifically, we study the situation where the harvesters exploit the fish stock in a *myopic* profit-maximizing manner: that is, the fishermen maximize short-term profit while taking resource abundance as given. In contrast to standard open-access model, the number of harvesters is assumed to be fixed meaning that the number of fishermen (or vessels) is *not* flowing in (an out) of the fishery according to the profitability opportunities (but see Sandal and Steinshamn 2004 that includes such a mechanism in a myopic fishery). The exploitation takes hence place within a regime what Baland and Platteau (1996), among others, refer to as an *unregulated common property* regime where, contrary to a common property regime, no forms of group cohesion and identity, like social norms, are assumed to influence individual behavior. See also Bromley (1991). Contextually, the sort of resource management setting we have in mind may fall within Ostom's (1990) notion of small-scale local common-pool resources as for instance inshore fisheries, but where economic, cultural and economic changes, in short 'modernization', may have changed the way in which the fishery resources are exploited.

Within this setting it is shown how more modern fishing technology, or improved fishing efficiency, may be a mixed bless not only for the fish abundance, but also for the profitability of the individual fisherman and the local community. The possible mixed bless of more efficient fishing technology is discussed, among others, by Squires (1992). The main contribution of the present analysis is that the conditions leading to the various outcomes are more fully elaborated. The model is formulated in the next section where technological improvement is introduced in the most simple way through a costless shift in the productivity parameter in the Schaefer harvesting function. The two-sided effect of more modern technology, one positive short-term effect and one negative long-term effect, is demonstrated. The model is next illustrated numerically in section three while section four concludes the paper.

2. Model

We consider a simple biomass model ('a fish is a fish') exploited instantaneously and simultaneously by a fixed number of n identical fishermen. The population growth may hence be written as:

(1) $$X_{t+1} = X_t + F(X_t) - nh_t$$

where X_t is the stock size at time t, h_t is the individual harvest, and $F(X_t)$ is the natural growth function, assumed to be density dependent in a standard manner (see below).

Harvest is governed by the generalized Schaefer function, $h_t = qe_t^{\alpha} X_t^{\beta}$, with e_t as individual effort use and q as the productivity (efficiency) coefficient. This parameter represents the technology factor in the model, and a larger q is throughout said to represent more efficient or, synonymously, more modern fishing technology. β may be referred to as the stock elasticity and α as the input elasticity. The case $\alpha = \beta = 1$ is frequently used in the literature and coincides with the standard Schaefer harvesting function (again see, e.g., Clark 1990). However, for many fish stocks, β may be substantially lower than one ('schooling stocks'), and in many instances, there is not unrealistic to assume a decreasing effort effect so that α is also less than one[ii]. As follows, $0 < \alpha < 1$ is assumed to hold. For a given harvest price and effort cost, p and c, respectively, the current individual profit is $\pi_t = pqe_t^{\alpha} X_t^{\beta} - ce_t$. Maximization for a given stock $X_t > 0$ yields $e_t = (\alpha pq/c)^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)}$. Because of lack of any strategic interaction among the exploiters, the number of fishermen does not influence the individual effort use[iii iv]. Substituted into the harvest function gives $h_t = q(\alpha pq/c)^{\alpha/(1-\alpha)} X_t^{\beta/(1-\alpha)}$. Hence, irrespective of the price-cost ratio and other parameter values, harvest will always take place as long the stock size is positive. This is due to the fact that the marginal income, when $X_t > 0$, approaches infinite for a close to zero effort use (because $\alpha < 1$).

The dynamics of the fish stock is completed when the harvest locus is inserted into the stock growth equation (1):

(2) $$X_{t+1} = X_t + F(X_t) - nq(\alpha pq/c)^{\alpha/(1-\alpha)} X_t^{\beta/(1-\alpha)}.$$

This is a first-order nonlinear difference equation where the dynamics generally depends on the initial size of the fish stock as well as the parameterization of the model. However, typically there will be no oscillations, and the steady state will be approached monotonically as harvesting stabilizes the dynamic path (cf. the classical May 1975 paper, but also the numerical section below). It is also seen that the parameters of the model have the standard predictions as a higher price–cost ratio p/c, for a given stock size X_t, shifts up the harvest locus and hence reduces next periods population growth. More efficient technology and a higher q work in a similar manner.

The steady-state stock is found when $X_{t+1} = X_t = X^*$:

(3) $$F(X^*) = nq(\alpha pq/c)^{\alpha/(1-\alpha)} X^{*\beta/(1-\alpha)}.$$

Natural growth is represented by the standard logistic function $F(X_t) = rX_t(1 - X_t/K)$, with r as maximum specific growth rate and K as carrying capacity (the maximum number of fish that the environment can support in the long run). The steady state $X^* > 0$ determined by equation (3) will then be unique (see also section three below).

The current maximum individual profit is $\pi_t = pq(\alpha pq/c)^{\alpha/(1-\alpha)} X_t^{\beta/(1-\alpha)} - c(\alpha pq/c)^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)}$, which may be written as $\pi_t = (\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)})(pq/c^{\alpha})^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)}$ after a small rearrangement. Notice that the individual profit at time t is not directly related to the number of fishermen n. However, it is certainly *indirectly* influenced by n through previous periods fishing activity, cf. the above equation (2). The total rent at time t becomes:

(4) $$\Pi_t = n(\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)})(pq/c^{\alpha})^{1/(1-\alpha)} X_t^{\beta/(1-\alpha)}$$

which is positive for any positive stock size[v]. It is seen that more efficient harvesting technology q yields a higher total rent for any *given* stock size. This direct, short-run, effect, however, is counterbalanced by an indirect, long-run, effect as the stock at time t is contingent upon previous harvest activity where more efficient harvest technology slows down population growth (Eq. 2). The net result of these two effects is generally ambiguous, but at least in the beginning, when starting from an arbitrary initial stock value X_0, the direct, short-run, effect certainly will dominate.

At the steady state, we may, however, infer more. The equilibrium rent is $\Pi^* = n(\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)})(pq/c^{\alpha})^{1/(1-\alpha)} X^{*\beta/(1-\alpha)}$. When combined with Eq. (3), we find after a few rearrangements that the rent may be related to the (endogenous) population size as:

(5) $$\Pi^* = (1-\alpha)pF(X^*).$$

The equilibrium rent is hence simply *proportional* to the equilibrium natural growth. Accordingly, when the biomass grows according to a single-peaked growth function like the standard logistic function, the steady state rent will be ‘small’ for a high exploitation pressure and a ‘low’ stock value X^*, as well as for a ‘low’ exploitation pressure and a ‘high’ stock value. The rent will be at its maximum when $F'(X^*) = 0$, or $X^* = X^{msy} = K/2$ (*msy* = maximum sustainable yield population).

Through Eq. (3), it is seen that a higher q always increases the harvesting pressure and works in the direction of a lower X^*. Therefore, depending on the price–cost ratio p/c and the number of exploiters n, more efficient harvest technology will either lower or increase $F(X^*)$ and hence will either lower or increase Π^*. More specifically, in a situation with high exploitation pressure, channeled through a high price–cost ratio (p/c is high) and many harvesters (n is high), or both, we may find that more modern technology yields a lower equilibrium rent. The above-mentioned indirect, long-run, effect then dominates in the steady state. In the opposite case of a low price–cost ratio and few harvesters, more modern technology will produce a higher equilibrium rent, and the above-mentioned direct, short-run, effect dominates. See also Figure 1.

Proposition*: Fishing technology has a two-sided profitability effect under myopic exploitation. Under high exploitation pressure, more efficient harvest technology dissipates the equilibrium rent. Under low exploitation pressure, more efficient technology increases the equilibrium rent.*

Figure 1 about here

The fact that more efficient (and costless) technology may reduce the profitability of a fishery is a counterintuitive result. However, it can be explained by the myopic nature of the fishery. The various steady states, as well as the transition paths, are therefore of a second best type, and hence the fishermen may be better off with less efficient fishing technology, both individually and collectively. This possible outcome is in line with the results from the classic externality paper by Lipsey and Lancaster (1956)[vi]. Therefore, the proposition also prevails when there is only one harvester ($n = 1$) with (though somewhat unrealistic) myopic resource utilization. It contrasts what is found in the social planner model or in a common property regime where the presence of, say, social norms means that the fish stock, in various ways, is priced. Squires(1992) suggests that technical improvement can be a mixed blessing if the fish stock is not priced. The above proposition supports his hypothesis and indicates under what circumstances this may happen.

3. Numerical illustration

In the numerical examples, we work with the simple constant-return-to-scale situation $(\alpha + \beta) = 1$ and $\alpha = 0.5$. The individual myopic profit-maximizing harvest is then $h_t = aX_t$, where $a = pq^2 / 2c$, and the dynamics (2) is $X_{t+1} = X_t + F(X_t) - naX_t$. Therefore, the steady state condition (3) is found through $F(X^*) = naX^*$, or $X^* = K(1 - na/r)$ when applying the logistic natural growth function. The current rent (4) is $\prod_t = nbX_t$, where $b = pa/2$, while the equilibrium rent (5) follows simply as $\prod^* = (p/2)F(X^*)$. Inserting for X^* we find $\prod^* = (pnaK/2)(1 - na/r)$, or $\prod^* = (p^2nK/4c)q^2[1-(np/2cr)q^2]$ when replacing a (cf. Figure 1).

The logistic growth function is given with parameter values $r = 0.5$ and $K = 5,000$ while the harvesting price is assumed to be 8.6 per unit. For the given cost parameter c and number of harvesters n (together with the given fish price), the productivity parameter q is scaled such that the benchmark exploitation pressure is $na = 0.25$. Figure 2 yields the stock expansion path when the initial stock size is assumed to be quite modest ($X_0 = 1000$), so the transitional growth path yields recovery from a previous situation involving serious overfishing by a possible long distance fleet, or fish deceases. In this figure, two other expansion paths for other q-values are also depicted: the 'high'-efficiency growth path of $na = 0.30$ and the 'low'-efficiency growth path of $na = 0.20$.

Figure 2 about here

Figure 3 demonstrates the accompanying rent paths, $\prod_t$. As explained, the most efficient technology growth path yields the highest rent during the first period before the benchmark case takes over. At this takeover point, the indirect, long-run, profitability effect starts to dominate the direct, short-run, effect (section 2 above). At the steady state, the growth path with the lowest q-value also yields a higher rent than the most efficient technology case.

Figure 3 bout here

Finally, Table 1 shows the steady states of the different growth paths. In addition, the present-value (PV) rents are shown (calculated over a period of 50 years with a constant discount rent of 5 percent). As the benchmark case is constructed such that $X^* = X^{msy} = K/2 = 2,500$ and hence yields the maximum equilibrium natural growth, both the high- and low-technology efficiency scenarios yield a lower equilibrium profit (cf. also Figure 2). Therefore, this is the numerical demonstration of the above proposition.

4. Concluding remarks

This paper formulates a fishery harvest model where a fixed number of fishermen exploit the fish stock in a myopic profit-maximization manner: that is, the fishermen maximize short-term profit while taking resource abundance as given. This may typically illustrate a property rights regime of the unregulated local common property type. Fishery stock growth paths are compared for various degrees of technological efficiency, and the two-sided effect on fishery rents is demonstrated. When natural growth is governed in a standard density-dependent manner, this two-sided effect is found to have a very simple steady state interpretation, which leads to the above proposition.

The present model demonstrates the mixed bless of more modern technology where we find that more efficient technology increases the equilibrium rent under a low and moderate exploitation pressure while the opposite happens when the exploitation pressure is high. A high exploitation pressure typically occurs when the fish stock is valuable combined with low effort costs, or when the existing technology already is effective. When the property rights is of the unregulated common type, modern technology may hence under these circumstances be a disaster and seriously hurt the local fishing community, and this happens even if the number of fishermen is *fixed* and there is no inflow (or outflow) of fishermen (or vessels) due to changes in profitability. This result stands in sharply contrast the social planner (or sole-owner) situation where improved harvesting technology unambiguously improves the rent (but reduces the stock). Our proposition is demonstrated in the most simply way by allowing for exogenous productivity growth. However, within a small scale inshore fishery in a developing country context operating far behind the technological frontier, this may not be too unrealistic.

Therefore, following our theoretical model, more modern fishing equipment may threaten the ‘sustainability’ as well as the profitability of a fishery when being exploited in an unregulated common property manner. As about 90% of the world’s fishermen and half of the fish consumed each year are captured by small scale, inshore fisheries which often are common pool resources (Ostrom 1990, p. 27), the ‘technology threat’ may be a real life situation in many fisheries and local communities in the developing world. Such a situation is possible described in Susilowati et al. (2005, p. 842), analyzing the mini-purse seine fishery of the Java Sea where they conclude that ‘gains in *private* technical efficiency may…pose a *social* problem under…unregulated common property through the raising of catch rates, increases in ‘effective’ effort and fishing capacity…and further reductions in the resource stock’.

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Figure 1: *Equilibrium rent and harvesting efficiency*

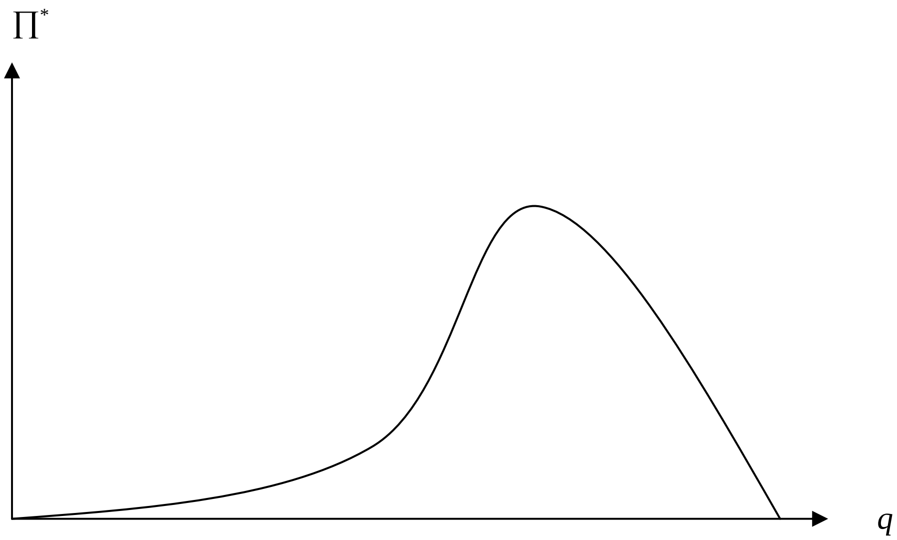

Figure 2: *Stock growth paths.*

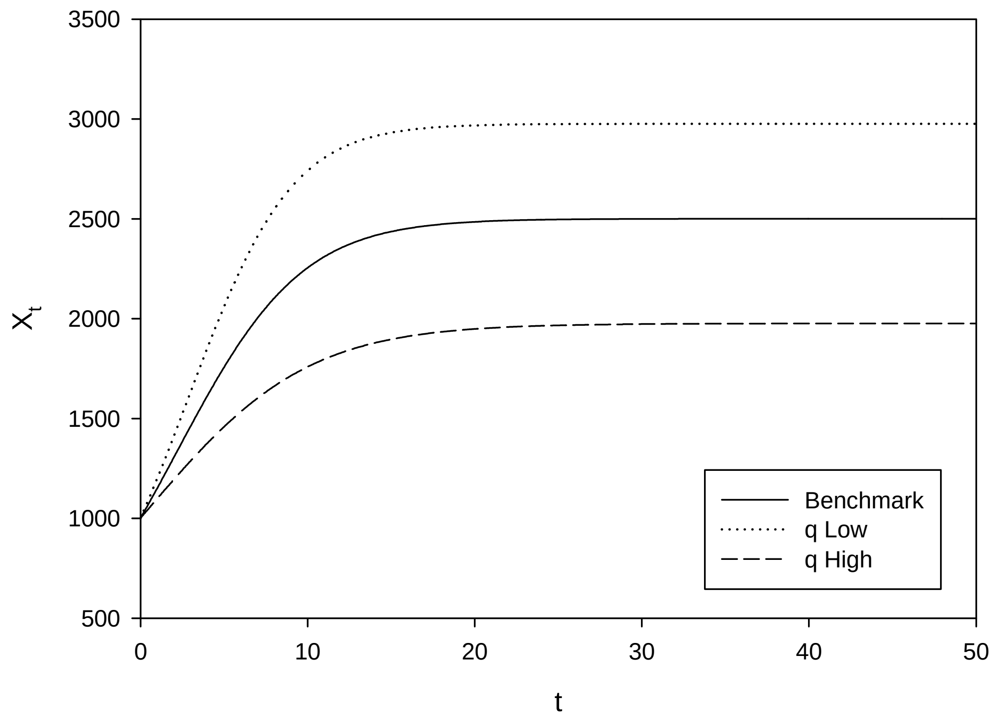

Figure 3: *Rent paths*

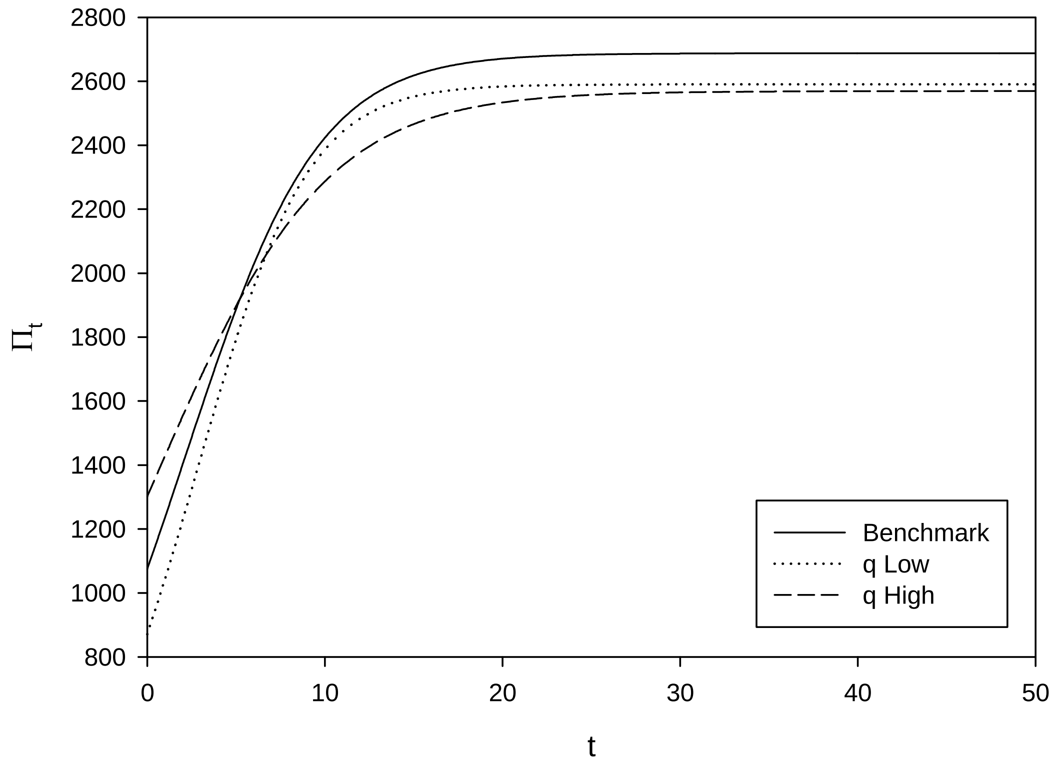

Table 1: *Harvesting efficiency and steady-states. Stock size (X^*), natural growth $F(X^*)$, rent (Π^*), and present-value profit (PV).*

	na	X^*	$F(X^*)$	Π^*	*PV*
Benchmark	0.25	2500	625	2687	43237
q low	0.20	2975	602	2590	41358
q high	0.30	1976	597	2569	42205

Endnotes

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[i] It can easily be demonstrated that the utilization approaches the costless harvesting case when efficiency approaches infinite: that is, the stock approaches the point where natural growth equalizes the rate of discount.

[ii] The scale properties of a fishery are examined, among others, by Hannesson (1983). The result from his finding as well as the results from other studies are mixed, and vary substantially across models and types of fisheries.

[iii] In renewable harvesting models, strategic interaction is usually channelled through the resource stock resulting in reciprocal cost externalities. Under myopic harvesting where the stock is treated as exogenous by the exploiters (as here), this type of strategic interaction is hence ruled out. However, there may also be strategic interactions through various markets where the product market for fish may be of particular relevance. However, this possibility is not explored in this paper as the harvest price is assumed to be fixed and given.

[iv] If the number of fishermen is ‘small’ which typically is the case when considering small-scale common-pool resources, we may imagine that each fishermen takes *own* harvest effect into account in the harvest decision, i.e., they are no longer atomists. The profit function may then be rewritten as $\pi_t = pqe_t^{\alpha}(X_t - qe_t^{\alpha} X_t^{\beta})^{\beta} - ce_t$. It is easily recognized that this effect shifts down the harvest locus (see main text below), but it will not qualitatively change the outcome of model.

[v] In this equation, profit increases linearly with n. However, notice again the indirect effect working through previous periods fishing activity (see also main text below).

[vi] The general theorem for the second best states that ‘if there is introduced into a general equilibrium system a constraint which prevents the attainment of one of the Paretian conditions, the other Paretian conditions, although still attainable, are, in general, no longer desirable’ (Lipsey and Lancaster 1956, p. 11).