Where neoclassical economics fails the environment

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Abstract

This paper surveys the points where economics, as conventionally understood and taught, leads to conclusions which are less than helpful in relation to environmental policy decisions, with particular reference to the urgent problem of climate change. In particular, the fact that there is great danger that global warming could pass a 'tipping point' where it could run out of control in self-enhancing feedback. It is clearly difficult to integrate moral considerations in relation both to successor generations and populations already suffering from adverse weather events, associated with climate change, within any formal economic theory framework. However, the doctrine of discounting the value of the future, known as cost benefit analysis, is flawed in its own terms. The second point is the professions inability to face the urgency of the income distribution side of carbon pricing. In addition, the current reality is that a large scale investment program in renewable energy generation capacity, would actually support the stability of the market economy as a Keynesian prescription.

Introduction

Economics, as traditionally understood, focuses on the efficient use of scarce resources. Within the framework of market economics, efficient means: cost effective at the prevailing price structure. This approach claims to be value free. As long as the main scarce resource to be used efficiently was perceived as work performed by human beings, that claim appeared to have an element of reality. The answer to the question of who owns these scarce resources was assumed to be uncontroversial: those who do the work and possess the ingenuity for skilled work, own their own capabilities. The assumption that ownership of resources is an uncontroversial issue of little concern to the economist has always been problematic. Slavery may have been abolished, but access to locally available land and mineral resources has always been shaped by power in many cases originating outside the country in question.

We are now in a radically different situation, and any such an assumption has become a mockery of reality. Hitherto common global resources, such as the atmosphere and the oceans, are critically scarce and the rationality of market economics, i.e. providing (via cost prices) information on the appropriate level of demand for scarce resources, has disappeared. The prevailing price structure based on private property and on efforts to work bears no longer a meaningful relation to the amounts of natural resources that are available under conditions of sustainable use. On the contrary, it rewards their reckless over-exploitation as being cost effective.

Unfortunately, one of the more obvious blind spots of both neoclassical economics and a significant body of green 'alternative' literature is the failure to recognise the fact that costs are at the same time incomes for those to whom payments are made. And even those who do, seem not to recognise the urgency of this issue.

There is a perfectly logical answer to the above-mentioned question of ownership. These resources belong to humanity as a whole, therefore a supra-national body such as the United Nations should become a world government, and assign costs to them, to be paid in the form of taxation. The revenue should be spent either on maintaining global peace and security, or else shared broadly equal among all citizens of the earth. The reality is that the world is failing to take any decision as to the ownership of these resources. There now is an urgent issue of climate change and the danger of that process 'tipping' into an uncontrollable positive feedback with large additions to emissions from melting Artic permafrost and forest fires in hot and seasonally dry tropical and sub-tropical climate zone areas. What makes matters even worse is that it is now becoming clear that any illusion that this process could be controlled by some kind of techno-fix via climate engineering is, well, probably an illusion (New Scientist editorial, 2012).

Taking any decision on the issue of ownership of a critical common global resource and its rental value is, by its very nature, a political decision: It shapes the distribution of the income arising from the resource in question. There is now no realistic prospect of humanity being able to take any workable decision (fair or otherwise) on that point of resource ownership, on a time scale and level of carbon price that supports rapid decarbonisation of the global economy on the basis of market rationality. That was sadly the case at Copenhagen as well as at Durban. It is against this background that this paper discusses a number of specific topics, which are more directly related to the standard economic analysis framework of market rationality, than the unresolved issue of the ownership of so far common resources.

The following topics[1] arise in this context:

- The false price structure.
- The assumption of constant returns to scale. This assumption leads to conclusions which are not conductive to containing climate change with a minimum loss in material affluence.
- The use of discounting in environmental cost benefit analysis. Related to that is the assumption that there is for each market, including the capital market, always a positive price at which demand and supply become equal.
- Globalization and the growth of inequality.

These topics are interrelated in that they impact on the results of each other. Nevertheless, the distinction is a useful framework for reviewing them in separate sections below.

<u>The false price structure</u>

The basic proposition that global common resources, such as the ability of the atmosphere to absorb emissions without undesirable impacts on human health or the climate is by now obvious to anyone who takes these issues seriously. Acknowledging this fact is not as such in any way contrary to the neoclassical framework of analysis; the standard remedy is that such a scarce resource is a production factor, which really should have a price, a rental value assigned to it.

Indeed, there are economists, both regular environmental economists and more specifically 'green' ones, who recognise the inherent problem. There is nevertheless an element of unwillingness to take the subject seriously and to draw the relevant conclusions. Assigning a cost

[1] Most of these topics also figure in considerable detail in a forthcoming book entitled Rediscovering Sustainability: Economics of the Finite Earth (Gower, forthcoming 2012) which I wrote jointly with my wife, Dr. Wiebina Heesterman. I do nevertheless feel that a separate publication of a more limited number of pages and a less textbook style of editing is justified.

to a common resource does not by itself cost society as a whole anything. It involves payments by those who make use of it, to those who are deemed to be entitled to those payments. You cannot, however, organise a market in a hitherto common natural resource, without deciding who owns the resource, or at least to whom its rental value should be paid. Failure at successive climate conferences to agree who should be entitled to receive the payment has cost humanity dear. Yet the importance and the urgency of taking a political decision on this point is not taken seriously.

For example, Chichilnisky and Heal (1998: 629) commented as follows:

> *We* have to 'securitize' (sell shares in the return from) 'natural capital' and environmental goods and services, and enrol market forces in their conservation … Privatising natural capital and ecosystem services is a vital step, as it enlists self-interest and the profit motive in the cause of the environment' (italics ours).

These authors do not even ask who this all-important 'we' might be. Assigning a cost is the key issue: it treats efficiency as identical to cost-effectiveness, which requires identifying an owner or custodian of the resource to whom the payment should be made. One might also have reservations against the emphasis on the profit motive: the rationality of producing (or choosing a consumption basket) at minimum cost is not limited to production for profit. It applies also to cost effective management of a public corporation.

Jackson (2011: 178) writes:

> "Ultimately this will also mean raising tough questions about the ownership of assets and control over the surpluses from those assets"

This is an urgent issue *now*, rather than at some unspecified moment in the future.

More generally, the very term "market failure" indicates that absence of a price is viewed as an exception. The reality is that unpriced natural resources and capabilities are now at least as much a scarce resource, as is manpower and marketable mineral resources.

We are now in a phase of technological 'progress' and relative scarcity of some marketable resources and their consequent price-rises makes, which makes forms of over-exploitation and degradation of unpriced common resources commercially attractive even whilst this was not the case in the past.

Example 1: Industrialised fishing

'Factory' ships drag mile long seine nets over the sea floor, catching and destroying large numbers of marine creatures unfit for human consumption, the so-called 'by-catch'. What is more, the largest nets also lead to the destruction of habitats, stirring up sediments which suffocate everything below when settling again (Lees 2002: 52-62).

Example 2: Tar sands and fracking

These are both forms of extraction of carbohydrates, which became commercially viable because of the rising prices of oil and natural gas produced by the more convention method of drilling a well. In fact, both could be as emission intensive as coal (Nikiforuk, 2010; 2011;

Howarth et al. 2011). In both cases, local emissions at the site of extraction play a role. In the case of shale gas, which predominantly consists of methane -a very strong greenhouse gas in its unburned form-, the main reason is that whereas normally none escapes when extracting from a well from a field capped by a salt layer, this is not the case with fracking. In the case of tar the energy cost of getting it mobilised are substantial.

The statement that a distorted price structure constrains the utility value of any sustainable consumption basket is standard neoclassical economic theory. This argument is normally raised in relation to indirect taxes, but readily generalises to under-costed natural production factors. It also does so to investment evaluation, including that of renewable energy production. For example the use of naturally occurring rock instead of cement in building a hydro-electric dam is less emission intensive because cement manufacture uses energy and also causes CO_2 to escape in the atmosphere in the course of splitting $CaCO_3$ (limestone) in CaO and CO_2. Obviously, if emissions were counted as a cost and the energy used properly costed, it could make the use of naturally occurring rock more cost effective in comparison to that of concrete.

The false price structure distorts the evaluation of economic management decisions on a number of points, which are not always obvious, even to the typical economist. For example Dietz and van der Straaten (1992) argue that the situation that decisions on environmental policy are seldom taken on the basis of cost benefit analysis amounts to 'like an attempt to cure the patient without sound diagnosis'. The confusion around discounting is discussed further down. Here the focus is that cost benefit analysis is supposed to compare the cost of current investment and its contribution to economic growth with the future benefit arising from a proposed project. This comparison is valid, only if the cost of foregone economic growth is validly expressed by financially measured national income. Since economic growth itself has a cost in the form of further environmental degradation, the increase in financially measured income clearly needs a downward correction. Indeed, there are those (Meadows, Randers and Meadows, 2005) who argue that we are already living in 'overshoot' beyond the earth's natural carrying capacity. By implication, any further growth in material affluence does not enrich future generations, but is on the contrary, at the cost of future generations.

<u>The assumption of constant returns to scale</u>

This assumption is crucial to the internal consistency of neoclassical economic equilibrium, which assumes that competition is the norm, and that perfect competition equates the price to marginal cost, under the Law of One Price. If, as is the case in the presence of increasing returns to scale, marginal costs are systematically lower than average costs, then the full average cost cannot be recovered from sales under competition.

However, it is argued here, that there are industries where increasing returns to scale arise at all relevant levels of operation, and form a plausible explanation for an oligopolistic market structure.

A more general assumption is that (for a particular industry), the relation between output and inputs is characterised by a production function which is homogeneous of degree λ. For $\lambda>1$ (increasing returns to scale) this gives rise to an oligopolistic market structure, where all firms have a profit margin. No outsider will enter the market, unless the venture can still be expected to be profitable, once the price has adjusted itself to the resulting increase in the supply. This is Bain's (1956/1965) argument. However, Bain assumes Chamberlin's (1933) U-shaped cost

curve, whereas the assumption is here generalised to an L-shaped cost curve under general increasing returns to scale.

An exercise in formal modelling of market equilibrium under oligopoly is provided in the appendix on that topic below. The assumptions and results of the model are: The basic relationships of the model are: the production function for a particular firm, the demand function for the product, and the definition of the sales value of the output of a firm. There is also an economic assumption: Under conditions of increasing returns to scale and oligopoly, all established firms have a profit margin. This means that direct price competition between oligopolistic firms, trying to underbid and drive out rivals, require giving up that profit margin and is not cost-effective. Production planning has therefore to be based on the assumption that the output of other firms stays the same.

The main result of this model are:

1) The conditions of the profit margin under oligopoly are not as different if they are related to Bain's assumption of being the result of the limits on entry by an outsider, or to capacity variation by an established firm, as might perhaps be thought. In addition, the conclusion is that the condition of the investment decision by an established firm is the more stringent one, and once there is a number of firms for which the market stability condition is met, outsider entry would never happen. That raises the question whether perhaps Bain's (and Chamberlin's) original assumption of the U-shaped cost curve might be the more realistic one. It is nevertheless argued here that more general increasing returns to scale (an L-shaped cost curve) are a technological reality. Clearly mergers and take-over bids would make no sense, if both firms were already operating as profitable as possible under the prevailing market conditions. That apparent element of contradiction is, however, largely resolved if it is assumed that *advertising* in an already saturated market, is an attempt to sell more without reducing the price.
2) There is a second cause of natural monopoly under increasing returns to scale, where the demand for the product as such is *elastic*. This arises, if the stable market share as calculated conform the stability conditions develop in the appendix below, is greater than 1. If a monopoly firm finds that its profits would increase by expanding the output, it has an open-ended incentive to do so.

This interpretation leads to two quite different conclusions in different areas of application, the environmental implications of advertising, and the efficacy of tradable permits in comparison with taxation. Advertising for an environmentally harmful product which people might not buy otherwise, such as flying or running a fuel guzzling 4 by 4 car in a city, is clearly undesirable. The same result – an open ended incentive to expand – gives, however, rise to a quite different evaluation in the case of carbon pricing.

In the case of constant returns to scale, neoclassical economic analysis gives rise to the so-called 'no profit' condition, i.e. the purchaser pays the cost of production[2]. In that case, a system of tradable permits, linked to a sustainable 'cap', results in the same 'green' incentives as indirect taxation of products that cause pollution, That would appear to be the basis on which Stern (2006: 104) with his reference to providing 'quantity certainty', and Common (1996: 420) with his reference to 'dependability' come out in favour of tradable permits. Unfortunately, however,

[2] It should of course be kept in mind, that neoclassical economics treats thing as the special skill of a manager of a firm, or the rental value of buildings owned by it, as the imputation of income to a production factor, not as profit. The no profit condition does not mean no profit in the ordinary accounting sense.

the reality is that, certainly in the case of climate change and emissions, any politically feasible cap is not sustainable.

That means that the tradable permit system is a serious obstacle against exceeding the compromised target. Taxation, on the other hand, can create a situation, where renewable forms of energy become a near-perfect substitute to the polluting alternative of burning fossil fuels. If an alternative technology exists, which becomes commercially viable on account of an increase in the price, the 'clean' alternative can be considered as separate industry, for which the product is a near-perfect substitute for the dirty alternative. In that case, any firm or consortium that starts to produce renewable energy on a large scale has an open ended incentive, to drive its fossil fuel using competitors out of the market one by one. The tradable permit system on the other hand, will cause the permit price to collapse, as soon as the target is exceeded.

If the set target is genuinely a sustainable level of emissions or pollution, then Stern and Common might have a point, and the faster and possibly more cost effective transition that taxation might make possible, may not be all that relevant. That, however, is obviously not the situation in the case of climate change and emissions of greenhouse gases. The current greenhouse content of the atmosphere is already unsustainable. The composition of the atmosphere implies a lack of balance between the energy of the incoming sunlight and nightly cooling; the difference being absorbed by the enormous thermal capacity of the oceans. (IPCC 2007: 4) In addition, current targets for containing emissions are probably insufficient to avoid catastrophic climate change. (Anderson and Bows, 2008; 2011). Any target is bound to be a compromise between expediency and urgency, and 'quantity certainty' cuts off the possibility of exceeding it.

Globalization and the growth of inequality

In the neoclassical model of the world, where every scarce resource has a price which contains its use to the available and sustainable supply, whilst the owner of any resource is free to offer it to any user at the market clearing price, the doctrine of globalization is a straightforward application of the claimed efficiency of the market. I prefer to use the expression 'part-globalization', a term I coined to indicate the reality that the doctrine of globalization, as promoted by the World Trade Organization and forced on countries in debt, is, in practice, one-sided. It encourages the free movement of trade and of finance capital, but if the competition of cheaper imported goods (which assumes no cost of transport emissions) causes people to loose their livelihood in one country and try to find one in another country, they are 'economic migrants' and are kept out. The a-symmetric way in which globalization introduced the free movement of traded goods and of finance capital, but not of seeking employment in countries where there are higher wages, has been in practice been most unfair, in particular, to, the smaller less affluent countries. Labour saving production methods, i.e. by the use of tractors and other agricultural machinery, leave a large agricultural workforce unemployed, whilst local agriculture and handicraft industry cannot compete with the imported product. The technological capability and domestic market to also develop modern industry is lacking, but employment abroad is blocked by border controls. Globalization results in a most unequal playing field.

Indeed, there is a credible case for arguing, even within the limited framework of measuring welfare purely as material affluence, that import duties form an effective means of increasing domestic production and consumption for a poor country with an unemployed reserve of rural manpower (Khan, 2001). It is also argued that unemployment more generally supports exploitation and inequality, also inside developed countries.

Under the prevailing false price structure globalization and, more generally, the purely material affluence orientated view of economics, also brings other forms of environmental damage. Globalization, and more generally the spatial concentration of production in a limited number of geographical locations encourages under-costed long distance transport. If there are increasing returns to scale there is a trade-off between concentrating production at a low number of sites and transporting the products and raw materials over long distances, and reducing the transport cost. If the transport cost is understated because its emissions are not counted as a cost, then clearly the false price structure over-states the benefits of the spatial concentration of production. Incidentally, emissions are not the only cost of long distant transport. It also facilitates the spread of diseases and their vectors, to areas where local populations (of humans, of domesticated animals and of wildlife), lack acquired immunity to new imported diseases.

In addition, where globalization appears to be successful in promoting export led growth, it stimulates over-stressing of local unpriced resources ad ecosystems. Example: There is a suspicion that intensive farming with its crowded battery cages could potentially cause a bird flu epidemic, involving the virulent H5N1 strain, due to the presence of different species of birds on the same farms (New Scientist editorial, 2006).

There is a wider issue concerning the limits of economics and market rationality here. In the case of climate change and emissions, the main problem is political will. Getting on with de-carbonization incurs a cost, but it is within the remit of market rationality. We 'only' need to agree who will pay for it. However, it is also the case that humanity's onslaught on the planet is much wider than emissions, notably loss of biodiversity. Setting a price to anything of any importance is clearly impossible. If we view every aspect of economic management purely in terms of now identifiable advantages to humans, and are not prepared to make decisions on other than economic grounds, then surely we will end up with a world in which only humans and life forms enslaved to humanity can prosper. As long as it lasts. Undoubtedly this is a world in which the anthropocene mass extinction will end with the extinction of humanity itself.

Discounting and the rate of interest

There is a certain amount of confusion on this issue inside neoclassical economics.

Thus, Spash (2002: 204) offers the following statement:

> "Neoclassical economists have shown how, in a simplified world, a unique discount rate is determined by the free market system. … Under perfect competition, savings and investment schedules intersect to define a unique equilibrium, where the marginal rate of return on capital equals the marginal rate of time preference. Krutilla and Fisher, 1975: 61)"

This reference by Spash appears to relate to the following passage in Krutilla and Anthony Fisher's book:

> 'In the simplified neoclassical world of Irving Fisher (1907), the discount rate was determined in the market by the interplay between individual time preferences and the productivity of investment. … The intersection of the two schedules, of savings and of investment, respectively, would determine uniquely the equilibrium marginal productivity of capital and the marginal time preference rates."

If fact, Irving Fisher's interpretation of classical economic theory was not quite as simplified as Krutilla and Anthony Fisher appear to have thought it was:

> 'In a new country where the rate of interest is high and the return on sacrifice precarious or small, the cheapest and most primitive form of railway is first constructed. Very often it is a narrow-gauge road with many curves, costing little to construct, but much to operate. Later, when the rate of interest falls or the traffic so increases that the rate of return on sacrifice is greater, the broad-gauge comes into use and the curves are eliminated' (Irving Fisher 1907: 179).

The investment demand schedule is not static. It is a stock of blueprints, some of which may be implemented, given the local availability and price of production factors. In Irving Fisher's time such profitable projects were abundantly available in a new country (i.e. then Irving Fisher's nativer US). The investment demand schedule is depleted by new investment and replenished by new inventions. In the absence of the latter, it could be exhausted, and the economy could converge to John Stuart Mill's (1863) stationary state. The replenishment of the investment projects by new inventions does not take place at a constant rate.

> "This tendency, this gravitation than is happily checked at repeated intervals by the improvements in machinery, as well as in the science of agriculture"(Ricardo, 1821 / 1969: 71)

Irving Fishers understood this reality better than the simplified version ascribed to him suggests.

My assessment of the current state of the global economy is that the combination of three factors has brought us back to the situation where a balance between commercially sound and attractive investment no longer exists at any positive rate of interest (Keynes 1936/1954: 241).

These three factors are:

- The investment opportunities arising from the inventions of the internal combustion engine, the electric motor, and the jet engine are now weakening. Investment opportunities in the third quarter of the twentieth century were significantly enhanced by a major change in locational economics. Entire new cities, such as Lelystad in my native Netherlands, and Milton Keynes in the UK were built in that period.
- The waning of the Welfare State and the stronger incentives to save due to the greater need for personal financial provisions for retirement.
- The failure to make investment in renewable energy commercially attractive.

The outcomes that arise from this situation are discussed in more detail in the conclusions section

As to the existence of a 'proof' concerning the unique nature of the discount rate, there is one, as summarised by Hanley and Spash (1993:128ff). It is, however, flawed. First of all, it is assumed (relations 8.1 and 8.2 on page 129 of their book, and the use of the rate of growth in consumption as a given number on p.129) that under 'business as usual', the growth of human consumption can continue at a known rate until Kingdom Come. The environment may be

thrashed, but human affluence will continue to grow. That is not a realistic assumption in the light of what we now know about the effects of climate change. In addition, the use of calculus is legitimate only if the expressions to which it refers are assumed to have a finite value. It will be sufficient to discuss this problem in relation to (8.1)

$$W^u = \int_0^\infty e^{-\delta t} u_t \, dt$$

only.

Here u_t is the utility of consumption at time t, δ is the time preference coefficient. W^u is the total valuation of the utility stream from now to infinity. The transformation between the amount of consumption C_t at time t, and the matching utility, i.e. the higher the standard of living already attained, the less important the next unit of its increase, is usual and not by itself controversial.

However, the application of calculus to this expression is valid only if one begins by assuming that the value of W^u is final. The assumption that any valuation of the total of all future human consumption is finite is a strong one, and if it is made, it really ought to be stated explicitly and the reader's attention should be drawn to the fact that therefore the analysis is limited to the question how much greater than the rate of growth both the time preference coefficient and the discount rate are.

The assumption that a higher standard of living means that the next bit of even more affluence becomes less important can also be turned round. Thus Nordhaus (2008) accepts that a degraded earth could mean a lower standard of living. One reason why he still recommends a climate policy which results in 2.6 degrees Centigrade global warming by 2100 and 3.4 degrees by the year 2200 compared to 1900, as optimal (p.195), is that he takes IPCC's climate modelling as the last word. If a '4 degrees and beyond' world were figured into his model, it could well mean that a descent into social and economic collapse would be upcounted, and justify drastic action to avoid it. However, it is argued here that the question of safeguarding the state of the earth we leave to later generations is an absolute requirement, and that any discussion willfully compromising that duty falls outside the remit of rational economic calculation.

Conclusion

For several decades, the underlying lack of balance between the incentives to save and opportunities for commercially attractive productive investment, has been hidden by the creation of illusory assets and asset appreciation. That bubble has now burst, and the reality is that investment in renewable energy systems is one of the more suitable forms of investment able to promote an economic recovery, whether commercially attractive at the prevailing false price structure or not. If assigning a realistic price to emissions is off the agenda for political reasons, a global program of investment in renewable energy systems would be desirable alternative to quantitative easing. Both alternatives amount to creating money out of thin air, but the investment program ties that new money to useful real investment. For that reason, it creates less of a danger of inflation, as money created without conditions on its use could also be used to finance speculative purchases of raw materials. As financing objectively useful investment by increases in national public debt has now become quite difficult in political terms, it is here recommend that the source of finance should be new money, either Euros newly created by the ECB, or SDR, newly created by the IMF. Such a program would not only help to avoid a climate catastrophe, it would also stabilise the market economy.

Appendix: The oligopoly model

The production function (for the output of a typical firm) is assumed to be is assumed to be exponential.

$$Q = f(X) = \alpha X^{\lambda} \quad (1)$$

The first order derivative of this relationship is:

$$dQ/dX = \lambda X^{(\lambda-1)} = \lambda Q/X \quad (2)$$

We indicate the price of the product as p, and the cost incurred in financing the input as C.

We can, by appropriate choice of units impose without loss of generality the requirement that initial values conform to $Q=Q^*=1$, $X=X^*=1$, and $p=p^*=1$. That choice of unit implies a price of the input which conforms to a specific profit margin.

$$C = \beta X \quad (3)$$

Here β is not really a constant. Instead, it simply states the price of the input, and implies a profit margin of which the initial value conforms to:

$$\rho = (Q-C)/C = 1/\beta - 1 \quad (4)$$

We indicate the total supply of the industry as T, and we assume a demand function characterised by a price elasticity of δ, i.e. the differential form of that demand function is:

$$dT / dp = -\delta T/p \quad (5)$$

We indicate the share of the typical profit maximising firm as

$$Q = \phi T \quad (6)$$

The general expression for the proceeds of its sales S is:

$$S = p Q \quad (7)$$

For the initial values of $p=p^*=1$ and $Q=Q^*=1$ the differential form of (7) is:

$$dS = dQ\, p + dp\, Q = dQ + dp \quad (8)$$

The inverse relation of (5) is:

$$dp/dT = p\,(-1/\delta)/T$$

which for $p=p^*=1$ simplifies to

$$dp/dT = -(1/\delta)/T \quad (9)$$

Therefore:

$$dp = -(1/\delta)\, dT/T \quad (10)$$

As mentioned in the main text, we have to assume that production planning is based on the assumption that the output of other firms stays the same. Therefore:

$$dT = dQ \quad (11)$$

Substitution for dQ for dT into (10) results in:

$$dp = -(\phi/\delta)\, dQ \quad (12)$$

Substitution of the righthand side of (12) into (8) now results in:

$$dS = dQ\, p + dp\, Q = dQ - (\phi/\delta)\, dQ = (1-\phi/\delta)\, dQ \quad (13)$$

The necessary condition for the maximization of the profit P of a typical firm is

$$dP = dS - dC = (1-\phi/\delta)\, dQ - dC = 0 \quad (14)$$

Substitution of $\beta\, dX$ for dC conform (3) into (14) results in:

$$(1-\phi/\delta)\, dQ - \beta dX = 0 \quad (15)$$

By (2), we have for $X=X^*=1$ and $Q=Q^*=1$

$$dX = dQ / \lambda \quad (16)$$

Substitution of the righthand side of (16) for dX into (15) now results in:

$$(1-\phi/\delta)\, dQ - \beta/\lambda\, dQ = 0 \quad (17)$$

From which we resolve the share ϕ as:

$$\phi = \delta - \beta\delta/\lambda = \delta\,(1- \beta/\lambda) = \delta\,(1 - \beta/\lambda) \quad (18)$$

Relation (18) is also confirmed if we re-formulate (14) as:

$$dP/dQ = (1-\phi/\delta) - dC/dQ = 0 \quad (19)$$

The second term on the righthand side of (14) is now evaluated as follows:

First, we note that an application of (2) for Q=Q=1 and X=X=1 implies

$$dX/dQ = 1/\lambda \quad (20)$$

Application of the chain rule, using (20) and $dC/dX = \beta$ conform (3) now allows us to express dC/dQ as

$$dC/dQ = (dC/dX)(dX/dQ) = \beta/\lambda \quad (21)$$

Substitution of β/λ for dC/dQ conform (21) into (19) now results in:

$$dP/dQ = 1-\phi/\delta - \beta/\lambda = 0 \quad (22)$$

The share condition (18) now is also resolved from (22).

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