SOCIAL WELFARE LOSSES UNDER R&D RIVALRY AND PRODUCT DIFFERENTIATION

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DISCUSSION PAPER No. 185
June 2007

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Social Welfare Losses under R&D Rivalry and Product Differentiation*

Yannis Katsoulacos[1] and David Ulph[2]

Abstract

This paper uses a non-tournament model of R&D rivalry under product differentiation to compute the welfare loss that arises in the market equilibrium. We distinguish between a dynamic loss (from too little cost reduction and an inappropriate number of research laboratories) and a static loss (from suboptimal output levels and an inappropriate number of product varieties and firms). We explore the possibility of a trade-off between static and dynamic efficiency for two cases: those of non-product specific and product-specific research paths. For both of these we examine the effect of competition policy (driving price towards marginal cost) and industrial policy (lengthening patent life). ***In both cases the total welfare loss is increasing as regulation pushes price towards marginal cost and is decreasing as patent life increases***. The value of the welfare loss, relative to the economy as a whole, is quite substantial for reasonable parameter values in both cases. However, while there is generally no trade-off in either case with respect to industrial policy (as in the homogenous products case considered by Beath and Ulph (1990)), a trade-off with respect to competition policy emerges in both cases. This is quite unlike the homogeneous products case.

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* The original version of this was published as Discussion Paper 90/285, University of Bristol.

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1. Introduction

Economists have been preoccupied with the size of social welfare losses resulting from market failure for a very long time. This preoccupation has been articulated in three distinct stands in the literature. Our main objective in this paper is to bring together and unify these three distinct strands, in a model that encompasses them all.

The first strand has been concerned with losses from distortions in output resulting from the exercise of monopoly power (Harberger, 1952) and with losses from the pursuit of monopoly power (Posner, 1975).

The second strand has been concerned with losses from distortions leading to the market generating a suboptimal rate of innovation, or, more specifically, cost reduction, and an appropriate number of competing research laboratories (Arrow, 1962; Dasgupta and Stiglitz, 1980).

The third strand has also a very long history. It has been concerned with losses arising from the market generating an inappropriate number of product varieties (Chamberlin, 1929; Dixit and Stiglitz, 1977; Hart, 1985; Yarrow, 1985).

However there is still no model that brings together elements from all these three strands in a way that makes possible the evaluation of the relative significance of each of the welfare losses mentioned above. The closest that there is to such a model is the model of Beath and Ulph (1990). However, this assumes that products are homogeneous. Further, it seems natural to accompany this assumption with another crucial assumption: that all the potential research paths that firms might follow to obtain an innovation are perfect substitutes.

In this paper we extend the non-tournament model of R&D rivalry under product differentiation of Katsoulacos and Ulph (K-U; 1990) to allow for (a) imitation and (b) to allow for research paths to be either perfect substitutes (non-product specific research paths), or product specific. We use this extended model to compute the welfare loss that arises in the market equilibrium. As in Beath and Ulph (1990) we decompose this loss into four components, two dynamic and two static. These capture the main losses identified in the literature mentioned above but their interpretation is somewhat different from that under product homogeneity.

Another theme that runs through much of this literature is that of the possibility of a trade-off between static and dynamic efficiency. For example, it has been common to argue that a policy that extends patent life by providing grater incentives to firms to engage in research will increase dynamic efficiency (or, equivalently, it will reduce the dynamic welfare loss). However, such a policy prevents competition from imitation for a longer period and this will reduce static efficiency (or increase the static welfare loss). What this argument ignores, by taking market structure to be exogenous, is the effect of policy on market structure. If, for example, the increase in patent life provides the incentive for more firms to compete in research the effect of this on static and dynamic efficiency will the opposite of that suggested above. The net effect of the policy is therefore unclear.

In the model presented below market structure is endogenous and this allows us to capture this latter effect. We use the model to examine the effect of the two policies: the first is that of altering patent life; the second is that of government regulation that pushes price towards marginal cost. We study the effect of each of these policies on each one of our welfare loss components.

Our main findings are as follows. In both the cases of non-product specific and product specific research paths the total welfare loss is increasing as regulation pushes price towards marginal cost and is decreasing as patent life increases. The value of the welfare loss, considered relatively to the economy as a whole, is quite substantial for reasonable parameter values in both cases. However, whilst there is generally no trade-off in either case with respect to the industrial policy, (as in the homogeneous case examined by Beath and Ulph (1990)), a trade off emerges in both cases with respect to the competition policy (unlike the homogeneous product case).

In the next section we detail the assumptions we will use and set out the market equilibria in the absence of regulation. In section 3 we introduce regulation. We then, in section 4 derive the social optimum for our two cases, and in section 5 we discuss how we propose to decompose the welfare loss and how we can evaluate each of the welfare loss components. Section 6 describes the simulation results and finally section 7 provides a lengthy discussion of these results.

2. <u>The Model</u>

2.1 <u>Basic Assumptions</u>

As in Beath and Ulph (1990) we will consider the perfect equilibrium of a two-stage game in which firms chose to enter the market <u>either</u> at date *0*, undertake cost-reducing innovation and receive patent protection for T periods <u>or</u> else at date T when they may imitate best-practice technology.

The firms that decide to enter at date *0* (the innovators) engage in <u>non-tournament</u> rivalry. This means that there are a potentially infinite number of research paths that these firms can follow to get an improved production process (innovate) and that a firm innovating does not preclude another firm doing the same at the same time.

Unlike Beath and Ulph we will assume that firms offer differentiated products. Innovation results in a cost of $c(z)$ when z is the amount invested in research. However before production takes place firms must also incur a fixed product-specific cost D. In the present context of differentiated products the natural way to interpret D is as a product-development cost. It has to be incurred also by the firms that decide not to engage in research-the imitators, who enter the market once the patents held by the innovators lapse – so it can also be thought of as a fixed entry cost that limits the number of firms that eventually enter the market to a finite number.

We will consider two cases depending on whether or not research investment is product-specific.

In the first case research is not product specific. This means that research paths are perfect substitutes so that whatever of the available research paths a firm follows an equivalent amount of research expenditure will lead to an equivalent amount of cost reduction <u>irrespective of the product produced by the firm</u>. However innovations can be patented for T periods after which they can be costlessly imitated. The results from research have to be known before expenditures on product development are made. Once the latter are also made firms can then enter the market. Note that with research non-product specific the imitators can enter the market (after incurring D) <u>with their own new products</u>. Thus the range of available products expands once the patents lapse and imitation occurs.

The case where research is non-product specific is the one that is closest to the homogeneous product case analyzed by Beath and Ulph (1990). As in the latter case, the social planner will only have a single firm engage in research and will then costlessly disseminate the resulting information. However, unlike the homogeneous product case, the social planner now haw to incur a product development cost for <u>each</u> of the products introduced.

When research is product specific, on the other hand, research paths are not perfect substitutes so the social planner must engage in research <u>and</u> product development separately for each product that is introduced. Clearly, in this case, the firms that decide to engage in research will only be able to imitate, after the patents lapse, the same products that were introduced by the innovators. Thus the number of products, n, is determined, in this case, at the innovation stage.

We will use Π_1 to indicate the profit flow of firms (innovators) before imitation. Π_2 will indicate profits per firm after imitation.

As already noted we will think of firms' decisions as being taken over two stages. In stage 1 the firms that decide to engage in research (the n innovators), solve the following problem:

$$\max_{x,z}(\lambda'/r)\Pi_1 - z - D$$

where x is the output and $\lambda' = 1 - e^{-rT}$ (where T = life of the patent and r is the discount rate).

In stage 2 imitators enter the market at a cost of D and

$$\max_{y}\Pi_2$$

where y is output after imitation. We assume free entry in stage 2 which we take to imply that

$$\Pi_2 - rD = 0 \tag{1}$$

Similarly, the zero profit condition for stage 1 implies that:

$$(\lambda'/r)\Pi_1 + \left[(1-\lambda')/r\right]\Pi_2 - z - D = 0 \tag{2}$$

2.2 The Market Equilibrium

Case A: Non-Product Specific R&D

As in K&U (1990) we will suppose that the individual preferences over the n products ($i = 1,\ldots n$) can be described by using a utility function that takes the form:

$$u = [\sigma/(1-\varepsilon)]\left[\sum_{i=1}^{n} x_i^{1-a}\right]^{(1-\varepsilon/1-\alpha)} + y \tag{U1}$$

where $\alpha, \sigma, \varepsilon$ and y (that represent expenditure on all other goods in the economy) are non-negative constants. (In the following we will suppress, for simplicity the constant y and we will use $u = u(x, n)$ to describe the first term on the RHS of (U1)). As is well known, since (U1) implies that the marginal utility of income is unity, the inverse demand function for good *i* is given by

$$P_i = \partial u / \partial x_i = \sigma \left[\sum_{i=1}^{n} x_i^{1-\alpha} \right]^{(\alpha - \varepsilon / 1 - \alpha)} x_i^{-a} \tag{D1}$$

a is the inverse elasticity of substitution between commodities so notice that when $a = 0$ this is just the D&S case. $\varepsilon \succ 0$ is the inverse price elasticity of the Chamberlinian *DD* curve and $\sigma(\succ 0)$ measures the size of the market.

For unit and marginal costs we will make use of the specific function

$$c(z) = \gamma z^{-\beta}; \gamma, \beta \succ 0$$

so that the elasticity of marginal cost with respect to R&D is β; the parameter β will be used to measure the effectiveness of R&D in lowering costs. (A large amount of empirical evidence on R&D productivity suggests that the value of β is approximately *0.125*; for a summary of this work see, P. Stoneman, 1987.

Given this, it is easily seen that, since we now distinguish between a pre- and a post – imitation stage with, respectively *n* and *t* firms in each stage:

$$\Pi_1 = \sigma\left[(n-1)x'^{1-a} + x^{1-a}\right]^{\frac{a-\varepsilon}{1-\alpha}} x^{1-a} - \gamma z^{-\beta} x \tag{3}$$

and

$$\Pi_2 = \sigma\left[(t-1)y'^{1-a} + y^{1-a}\right]^{\frac{a-\varepsilon}{1-\alpha}} y^{1-a} - \gamma z^{-\beta} y \tag{4}$$

In (3), [resp. (4)], Π_1 [resp. Π_2] is the profit of a firm producing *x* [resp.y] when all other firms produce x' [resp. y']. From (1) and (2) $(\lambda'/r)(\Pi_1 - rD) = z$. Given this, from (3), the first order conditions with respect to *x* and *z* and the zero-profit condition (equation (2)) can be written, in a symmetric equilibrium, as follows:

$$\sigma n^k \left[(1-a)n + a - \varepsilon\right] x^{-\varepsilon} = \gamma z^{-\beta} \tag{5}$$

$$\lambda x \beta \gamma z^{-\beta} = z \tag{6}$$

and

$$\lambda\left(\sigma n^{1+k} x^{1-\varepsilon} - \gamma z^{-\beta} x - F\right) = z \tag{7}$$

where, to simplify notation, we have used:

$$\lambda = \lambda' / r, F = rD \tag{8}$$

and

$$k = (2a - \varepsilon - 1)/(1 - \alpha) \tag{9}$$

Similarly, from (4), the first order condition with respect to *y* and the zero-profit condition (1) can be written, respectively, as follows:

$$\sigma t^{k}\left[(1-a)t + (a-\varepsilon)\right]y^{-\varepsilon} = \gamma z^{-\beta} \tag{10}$$

and

$$\sigma t^{1+k} y^{1-\varepsilon} - \gamma z^{-\beta} y = F \tag{11}$$

Using subscript "*e*" to indicate the market equilibrium values, equations (5)-(7) can be re-written as:

$$z_e = \lambda \beta F\left[G(n_e)/ H(n_e)\right] \tag{12}$$

$$x_e = \left(z_e^{1+\beta}\right)/ \lambda \beta \gamma \tag{13}$$

and

$$H(n_e)^h n_e^k G(n_e)^{1-h} = \frac{F^{1-h}}{\sigma}\delta \tag{14}$$

where

$$h = \varepsilon(1+\beta) - \beta \tag{15}$$

$$G(n_e) = (1-a)n_e - (\varepsilon - \alpha) \tag{16}$$

$$H(n_e) = n_e - (1+\beta)G(n_e) \tag{17}$$

and

$$\delta = \left[\gamma / (\lambda\beta)^{\beta}\right]^{1/1+\beta} \tag{18}$$

Similarly, for the post-patent equilibrium, equations (10) and (11) can be re-written as:

$$y_e = \frac{F}{\gamma} z_e^{\beta} \left[\phi(t_e) / \omega(t_e)\right] \tag{19}$$

and

$$\sigma t_e^k \phi(t_e)^{1-\varepsilon} \omega(t_e)^{\varepsilon} = F^{\varepsilon} \left(\gamma z_e^{-\beta}\right)^{1-\varepsilon} \tag{20}$$

where

$$\phi(t) = (1-a)t - (\varepsilon - \alpha) \tag{21}$$

and

$$\omega(t) = t - \phi(t) \tag{22}$$

Equations (12) – (14) and (19) – (20) define respectively, the market equilibrium before and after the patents lapse. The first set of equations can be used to determine research expenditure per firm and the number of firms and output per firm before the patents lapse. The second set can be used to determine the number of firms and output per firm after the patents lapse.

<u>Case B: Product Specific R&D</u>

We now turn on the case of product-specific R&D. Here, because research paths are not perfect substitutes, imitators cannot, having not done research themselves, introduce <u>new</u> products. Once the patents on existing products lapse these new firms can enter the industry and imitate these <u>existing</u> products.

The <u>market equilibrium</u> before the patents lapse remains exactly as in Case A. After the patents lapse the market equilibrium is characterized as follows:

Let $y_{ji}\,(i = 1,......n;\, j = 1,.......t)$, be the output of firm *j* producing product *i*. Given the demand function in K-U the inverse demand function for product *i* in this case is (using *q* to indicate the price after imitation):

$$q_i = \sigma\left[\sum_{\kappa=\iota}^{n} y_k^{1-a} + \left(y_{ji} + \bar{y}_{ji}\right)\right]^{a-\varepsilon/1-\alpha} \left[y_{ji} + \bar{y}_{ji}\right]^{-a} \tag{D2}$$

where $\bar{y}_{ji}$= output of all firms other than *j*. Given that, under symmetry, $\bar{y}_{ji}$= y_i / t where *t* is the number of firms per product and that the profit of firm *j* is $\Pi_j = q_i y_{ji} - c y_{ji}$, it follows that maximization with respect to y_{ji} requires that:

$$q_i + \left(\partial q_i / \partial y_i\right)\left(y_i / t\right) = c$$

where *c* is the unit and marginal cost $\left(= \gamma z^{-\beta}\right)$. From (*D2*), this first-order condition can be written, under symmetry as follows:

$$\sigma n^k y^{-\varepsilon}\left[n - \left[\frac{a(n-1)+\varepsilon}{t}\right]\right] = c \tag{5'}$$

Also, using (*D2*), the zero profit condition under symmetry after the patents lapse is:

$$\left(y/t\right)\left[\sigma n^{1+k} y^{-\varepsilon} - c\right] = F \tag{7'}$$

3. <u>The Market Equilibrium Under Regulation</u>

<u>Case A: A Non-Product Specific R&D</u>

Suppose now that market prices are regulated by the government. Let *p* be the price before imitation and *q* after imitation, with corresponding prices p_r and q_r under regulation. We will assume that regulated prices are given by:

$$p_r = p(1-\theta) + \theta\gamma z^{-\beta} \tag{23}$$

and

$$q_r = q(1-\theta) + \theta\gamma z^{-\beta} \tag{24}$$

where $0 \le \theta \le 1$, so that the regulated price is the weighted average of market price and unit cost. Thus there is no regulation when $\theta = 0$ whilst when $\theta = 1$ price is driven to marginal cost. From the demand function (*D1*), in symmetric equilibrium,

$$p = \sigma n^{1+k} x^{-\varepsilon} \tag{25}$$

and

$$q = \sigma t^{1+k} y^{-\varepsilon} \tag{26}$$

Substituting from (25) into (23) and using *c* for unit cost and the first-order condition with respect to *x* (equation (5)), the regulated price contingent on any given number of firms and unit cost is given by:

$$P_r = (1-\theta)\frac{nc}{(1-a)n + a - \varepsilon} + \theta c \tag{27}$$

or,

$$P_r = \frac{c\left[n(1-\alpha\theta) + \theta(\alpha - \varepsilon)\right]}{(1-\alpha)n + \alpha - \varepsilon} \tag{28}$$

To obtain the equilibrium values of *x, z,* and *n* under regulation first note that from (25) and (28),

$$\sigma n_r^{1+k} x_r^{-\varepsilon} = \frac{c\left[n_r(1-\alpha\theta) + \theta(\alpha - \varepsilon)\right]}{(1-\alpha)n_r + a - \varepsilon} \tag{29}$$

From (29), the first-order condition with respect to z (equation (6)), and the zero-profit condition (equation (7)), we can also obtain:

$$(z_r / \lambda\beta)\left[\frac{(1-\theta)(n_r\alpha + \varepsilon - \alpha)}{(1-\alpha)n_r + a - \varepsilon} - \beta\right] = F \tag{30}$$

Equations (29), (6) and (30) can be used to obtain the values of *x, z,* and *n* under regulation. Note that the first term in the square brackets of (30) is decreasing on *n* and *θ*. to guarantee that the expression in the square bracket is positive we have to impose an upper bound on θ that is given by:

$$\bar{\theta} = 1 - \frac{\beta(1-\alpha)}{\alpha} \qquad \text{(C1)}$$

For as long as $\theta \le \bar{\theta}$ the expression in the square brackets is positive irrespective of how large n gets.

Similarly we can now obtain the values of output and number of firms under regulation after imitation. From the first-order condition with respect to y (equation (10)) and equation (24) and (26) the regulated price after imitation contingent on a given number of firms is:

$$q_r = (1-\theta)\frac{c}{(1-a)t + \alpha - \varepsilon} + \theta c$$

or, using again (26):

$$\sigma t_r^{1+k} y_r^{-\varepsilon} = \frac{(1-\alpha\theta)ct_r + (a-\varepsilon)\theta c}{(1-\alpha)t_r + a - \varepsilon} \qquad (31)$$

Equation (31) and the zero profit condition (equation (11)) can be used to derive:

$$cy_r\left[\frac{(1-\theta)(\alpha t_r + \varepsilon - \alpha)}{(1-\alpha)t_r + a - \varepsilon}\right] = F \qquad (32)$$

(31) and (32) determine the values of y and t under regulation after patents lapse.

Case B: Product Specific R&D

Turning to market equilibrium under regulation when research is product-specific first note that the solution of equations (5’) and (7’) gives the market equilibrium values of y and t. From ($D2$) the inverse demand function under symmetry can be written as:

$$q = \sigma n^{1+k} y^{-\varepsilon} \tag{26'}$$

From (5') and (26'),

$$q = \frac{ctn}{nt - \left[a\left(n-1\right)+\varepsilon\right]}$$

Thus price, q_r, under regulation is, given (24):

$$q_r = \left(1-\theta\right)\frac{cn_r t_r}{n_r t_r - \left[a\left(n_r - 1\right)+\varepsilon\right]} + \theta c$$

i.e., the weighted average of *q* and *c*. To obtain output per firm and the number of firms under regulation first use the last equation and the zero profit condition (7'), to obtain:

$$\left(1-\theta\right)c\left(y_r / t_r\right)\left[\frac{a\left(n_r - 1\right)+\varepsilon}{n_r t_r - \left[a\left(n_r - 1\right)+\varepsilon\right]}\right] = F \tag{32'}$$

Finally, substituting (26') into the expression for q_r above and rearranging we can get:

$$\sigma n_r^{1+k} y_r^{-\varepsilon} = \frac{c\left[n_r t_r - \theta\alpha\left(n_r - 1\right)+\varepsilon\right]}{n_r t_r - \alpha\left(n_r - 1\right)-\varepsilon} \tag{31'}$$

(31') and (32') determine the values of *y* and *t* under regulation for the present case of product-specific R&D.

4. <u>The Social Optimum</u>

<u>Case A: Non-product Specific R&D</u>

The social planner chooses *x, z,* and *n* to maximize social welfare. When research is not product specific the social planner has to spend only *z* in order to achieve a unit cost of *c(z)* for <u>all</u> *n* products (assuming a development cost is additionally incurred for each one). In contrast, the market achieves the same result at an expenditure on research of *nz*.

The problem of the social planner is to maximize, with respect to *x, z,* and *n*, social welfare, *W*, where:

$$w = u(x,n) - n\gamma z^{-\beta} x - z - nF \tag{33}$$

and the utility function (U1) is, under symmetry, given by

$$u(x,n) = \left(\frac{\sigma}{1-\varepsilon}\right) n^{1-\varepsilon/1-\alpha} x^{1-\varepsilon} \tag{34}$$

From the first-order conditions for welfare maximization we can derive (using " ˆ " indicate optimal values) the values of *n, z* and *x* that maximize social welfare (for details see also K&U, 1990). These are given by:

$$\hat{n} = \left\{ \sigma \left[\frac{\alpha}{(1-\alpha)F} \right]^{h} \left[\frac{\beta^{\beta}}{\gamma} \right]^{1-\varepsilon} \right\}^{1/\hat{h}} \tag{35}$$

$$\hat{z} = \frac{\hat{n}(1-a)F\beta}{\alpha} \tag{36}$$

and

$$\hat{x} = \frac{\hat{n}^{\beta}}{\beta\gamma} \left[\frac{(1-\alpha)F\beta}{\alpha} \right]^{1+\beta} \tag{37}$$

where $\hat{h} = h - a(2+k)$.

<u>Case B: Product Specific R&D</u>

When research is product-specific instead of the social planner maximizing (33) he will be maximizing:

$$W = u(x,n) - n\gamma z^{-\beta} x - nz - nF \tag{33'}$$

Comparison of (33) and (33') indicates that (33') incorporates the assumption of product specific research paths: research has to be incurred on each one of the *n* products introduced by the social planner.

It has been shown in K-U (1990) that maximizing (33') with respect to *z, x*, and *n* gives the following social optimum values:

$$\hat{n} = \sigma^{\frac{1-\alpha}{c-a}} \left(\beta^{\beta} / \gamma\right)^{\frac{(1-\varepsilon)(1-\alpha)}{\varepsilon-\alpha}} \left(\frac{\hat{z}}{\beta}\right)^{\frac{-h(1-a)}{c-a}} \tag{35'}$$

$$\hat{z} = \beta F\left(1-a\right) / \left[a\left(1+\beta\right)-\beta\right] \tag{36'}$$

and

$$\hat{x} = \hat{z}^{1+\beta} / \beta\gamma \tag{37'}$$

5. <u>The Decomposition of Social Welfare</u>

<u>Case A: Non-Product Specific R&D</u>

Before we turn to a detailed discussion of the various components into which we will decompose the overall welfare loss, note that the value of the social welfare in the market equilibrium can be written as:

$$V_e = \lambda\psi_1 - n_r\left(z_r + F\right) + (1-\lambda)\left[\psi_2 - \left(t_r - n_r\right)F\right] \tag{38}$$

$\psi_1 - n_r\left(z_r + F\right)$ is the value of social welfare whilst the patent lasts, where, using the utility function (34):

$$\psi_1 = \left[\left(\frac{\sigma}{1-\varepsilon}\right) n_r^{\frac{1-\varepsilon}{1-\alpha}} x_r^{1-\varepsilon} - c n_r x_r\right] \tag{39}$$

and $\psi_2 - (t_r - n_r)F$ is the value of social welfare in the market equilibrium after the patents lapse, where,

$$\psi_2 = \left[\left(\frac{\sigma}{1-\varepsilon} \right) t_r^{\frac{1-\varepsilon}{1-\alpha}} y_r^{1-\varepsilon} - c t_r y_r \right] \quad (40)$$

On the other hand, from (33) and (34) the value of the social welfare at the social optimum is:

$$\hat{V} = \left(\frac{\sigma}{1-\varepsilon} \right) \hat{n}^{\frac{1-c}{1-\alpha}} \hat{x}^{1-\varepsilon} \gamma \hat{z}^{-\beta} \hat{n}\hat{x} - \hat{z} - \hat{n}F \quad (41)$$

The total loss in social welfare, L, at the market equilibrium is therefore:

$$L = \hat{V} - V_e \quad (42)$$

We will now decompose the overall welfare loss into four components: a dynamic loss (*D1*), a loss from excessive duplication in R&D in the market equilibrium (*D2),* a static loss (*S*), and a loss from the lack of optimality in the number of varieties produced in the market equilibrium (*VL*). Each of these welfare losses is explained in detail below.

First, we deal with the dynamic loss, *D1*. This is usually associated loosely with the loss arising from firms spending the wrong amount on R&D and hence generating the wrong amount of cost reduction (of suboptimal degree of technical change). To turn this loose definition into a rigorous specification of *D1* we need to calculate what the (hypothetical) value of optimum social welfare would have been given that the firms spend z_r and generate a cost-reduction $c(z_r) = c$. This involves calculating the number of firms and the output per firm that will maximize social welfare given a marginal cost of *c*. Let $\overline{V}$ be maximum social welfare given *c*. That is,

$$\overline{V} = \underset{x,y,n,t}{Max} \left\{ \lambda \left[u(x,n) - cxn \right] - nz - nF + (1-\lambda) \left[u(y,t) - cyt - (t-n)F \right] \right\}$$

Now, in the present case we know that in a social optimus the number of firms that should engage in research is unity, that is, that z_r rather than nz_r is the socially optimal expenditure on research. Using this fact in the above expression, we can then proceed to obtain the values of x, y, n and t that will maximize social welfare given $z = z_r$. We will use an upper bar to indicate these values. From inspection of the maximization problem above it is clear that $\overline{x} = \overline{y}$ and $\overline{n} = \overline{t}$. Using this fact in the above expression and the utility function (34) gives:

$$\overline{V} = \overline{V}_1 - z_r \tag{43}$$

where

$$\overline{V}_1 = \left(\frac{\sigma}{1-\varepsilon}\right)\overline{n}^{\frac{1-\varepsilon}{1-a}} x^{1-\varepsilon} - c\overline{nx} - \overline{n}F \tag{43'}$$

and where, fro the first-order conditions with respect to *x, y, n* and *t*, respectively, we get:

$$\overline{x} = \overline{y} = \left[(1-a)F/ac\right]$$

$$\overline{n} = \overline{t} = \left[(c/\sigma)\overline{x}^{\varepsilon}\right]^{1/1+\kappa}$$

We can now define the dynamic loss, *D1*, as the difference between welfare at the social optimum and the maximized social welfare given that the firms face a marginal cost of c, that is:

$$D1 = \hat{V} - \overline{V} \tag{44}$$

To put it otherwise *D1* is the loss from too little cost reduction given that output and the number of firms are optimally chosen.

Coming to the loss from excessive duplication of R&D, *D2*, - the loss on which Dasgupta and Stiglits (1980) focus on in their analysis – since the social optimum number of R&D laboratories is 1, this is defined in a straightforward way by

$$D2 = z_r(n_r - 1) \tag{45}$$

Turning now to the static loss S and using standard practice we will define this as the loss that arises purely from firms producing the wrong output (that is, not the output that equates price to marginal cost) given the available technology. (This is the standard Harberger (1954) welfare loss). To calculate this, we assume that the technology that allows production at a marginal cost of c is freely available and we maximize social welfare with respect to output given this technology and contingent on the market equilibrium number of firms using it. Let ϕ_1 be the maximized value of social welfare whilst the patent lasts given a marginal cost of c and a number of firms equal to n_r, that is,

$$\phi_1 = \underset{x}{Max}\left[u\left(x, n_r\right) - cxn_r\right] \tag{46}$$

Similarly, let ϕ_2 be the optimized value of social welfare after the patents lapse given a marginal cost of c and a number of firms equal to t_r, that is,

$$\phi_2 = \underset{y}{Max}\left[u\left(y, t_r\right) - cyt_r\right] \tag{46'}$$

Indicate by $\underline{x}$ and $\underline{y}$, respectively, the values *of* x and y resulting from these optimization problems. Using the utility function (34), and substituting into the above expressions gives:

$$\phi_1 = \left[\left(\frac{\sigma}{1-\varepsilon}\right) n_r^{\frac{1-\varepsilon}{1-\alpha}} \underline{x}^{1-\varepsilon} - cn_r\underline{x}\right] \tag{47}$$

and

$$\phi_2 = \left[\left(\frac{\sigma}{1-\varepsilon}\right) t_r^{\frac{1-\varepsilon}{1-\alpha}} \underline{y}^{1-\varepsilon} - ct_r\underline{y}\right] \tag{48}$$

where, from the first order conditions with respect to x and y:

$$\underline{x} = \left[\left(\sigma/c\right) n_r^{1+k}\right]^{1/\varepsilon}$$

and

$$\underline{y} = \left[(\sigma/c) t_r^{1+k} \right]^{1/\varepsilon}$$

The static loss, s, can now be defined as:

$$S = \lambda(\phi_1 - \psi_1) + (1-\lambda)(\phi_2 - \psi_2) \tag{49}$$

Finally, we come to the welfare loss arising from the wrong number of product varieties produced in the market equilibrium. Clearly in this model this is captured by calculating the welfare loss due to the wrong number of firms participating in the market equilibrium (since the number of firms is here identical to the number of products) and is part of the "rent dissipation" loss that Posner (1975) has stressed. Now we have already defined $\overline{V}_1$ as the value of social welfare when this is maximized with respect to *x* and *n* given the market equilibrium choice of z and neglecting R&D expenditures. We have also defined $(\phi_1 + \phi_2)$ as the value of social welfare when this is maximized only with respect to *x* neglecting research expenditures and the fixed product – development costs. Clearly,

$$VL = \overline{V}_1 - (\lambda\phi_1 - n_r F) - (1-\lambda)\left[\phi_2 - (t_r - n_r)F\right] \tag{50}$$

or

$$VL = \overline{V} - (\lambda\phi_1 - z_r - n_r F) - (1-\lambda)\left[\phi_2 - (t_r - n_r)F\right] \tag{50'}$$

is the social welfare loss from the wrong number of firms operating at the market equilibrium. From (44), (45) (49) and (50) it is easy to confirm that the sum of our four components of the welfare loss gives the total welfare, *L*, as defined by (42):

$$L = D1 + D2 + S + VL = \hat{V} - V_e \tag{51}$$

Case B: Product Specific R&D

We can now proceed with the welfare decomposition for the case of product specific R&D. We will again decompose the welfare loss into four components. However these do not exactly correspond to those of the previous case. Whilst the straight static and dynamic welfare losses (that we termed *D1* and *S1*) have the same interpretation in the current case and whilst there is a direct analogue of *VL* with the same interpretation here too, (since there will be a loss from an excessive number of firms entering the market once the patent lapse) – which we will indicate by *S2*), the analogue of *D2* does not have the same interpretation. This is because in the case of non-product-specific research, with the social planner operating a single laboratory, *D2* was clearly associated with excessive duplication of research. In the present case *D2* has to be interpreted as the social welfare loss from the "wrong" number of research laboratories in the market equilibrium where the latter can exceed or fall short of the socially optimal number.

More specifically, we will now write the value of social welfare in the market equilibrium, V_e, as follows:

$$V_e = \lambda\left[u\left(x_r, n_r\right) - cx_r n_r\right] - n_r\left(z_r + F\right) + \left(1-\lambda\right)\left[u\left(y_r, n_r\right) - cy_r n_r - n_r\left(t_r + F\right)\right]$$

The welfare loss is $L = \hat{V} - V_e$. We can decompose this loss as follows. First we define

$$\bar{V} = \underset{x,n}{Max}\left[u\left(x,n\right) - cxn - n\left(z_r + F\right)\right] \tag{43'}$$

where $c = \gamma z_r^{-\beta}$. Thus, $\bar{V}$ as in the case of non-product-specific research is the maximum social welfare given the technology arising from the market equilibrium level of research.

Second, we define the maximized social welfare with respect to x only (that is, contingent on the market equilibrium technology and number of firms) and neglecting the research and the fixed development costs:

$$\phi = \underset{x}{Max}\left[u\left(x, n_r\right) - cxn_r\right] \tag{46'}$$

Note that, since with product-specific research the number of products remains the same after the patents lapse, the maximized social welfare ϕ is the same before and after the patents lapse, so we need not distinguish, as in the non-product-specific case, between ϕ_1 and ϕ_2.

Let $\overline{x}, \overline{n}$ be the values that maximize the RHS of (43’) and $\underline{x}$ the value that maximizes the RHS of (46’). From the first-order conditions of (43’) we obtain:

$$\overline{x} = \frac{(1-a)(F+z_r)}{ac}$$

and

$$\overline{n}^{1+k} = (c/\sigma)x^{-\varepsilon}$$

From (46’):

$$\underline{x}^{\varepsilon} = (\sigma/c)n_r^{1+k}$$

Finally, let the market equilibrium value of social welfare before and after imitation occurs and neglecting the research and the fixed development costs, be given, respectively, by:

$$\psi_1 = (\sigma/1-\varepsilon)n_r^{1+k}x_r^{1-\varepsilon} - cn_r x_r \tag{52}$$

and

$$\psi_2 = (\sigma/1-\varepsilon)n_r^{1+k}y_r^{1-\varepsilon} - cn_r y_r \tag{53}$$

In a manner exactly analogous to the previous case we can therefore now define the four components of the welfare loss as follows:

$$D1 = \hat{V} - \overline{V}$$
$$D2 = \overline{V} - [\phi - n_r(z_r + F)]$$
$$S1 = \lambda[\phi - \psi_1] + (1-\lambda)[\phi - \psi_2]$$

and

$$S2 = (1-\lambda)n_r(t_r - 1)F$$

With respect to *S2* note that since $t_r - 1$ measures the excessive number of firms per product, $n_r\left(t_r - 1\right)$ measures the total excessive number of firms after imitation. Clearly given the utility function (34) $D1 + D2 + S1 + S2 = L = \hat{V} - V_e$.

6. Description of the Simulation Results

We have used the above model to simulate, for various parameter sets, the values of social welfare at the optimum and at the market equilibrium, for out two cases of non-product-specific and product-specific research. These values are then used to compute the values of the overall welfare loss of its components at the market equilibrium.

In presenting the results, we felt that it would not be very useful to present the absolute value of the various welfare losses since these apply to specific sector of the economy. Ideally one needs to know how important are various distortions in generating welfare losses in a specific sector relative to the economy as a whole. For this reason we have used a relative welfare loss measure in presenting the simulation results.

Our measure uses as a benchmark the aggregate resource cost (*RC*) requires for attaining the social optimum in the specific sector under consideration. This is equal to total production costs plus costs of research plus fixed costs at the optimum, i.e.,

$$RC = \hat{n}\left(\gamma \hat{z}^{-\beta}\hat{x} + \hat{z} + F\right)$$

or, since at the optimum prices equal marginal costs,

$$RC = \hat{n}\left(\hat{z} + F\right) + \sum_{i=1}^{\hat{n}} \hat{p}_i \hat{x}_i$$

Thus, if *M* is aggregate expenditure in the economy (our measure of GNP), then

$$M = RC + y$$

Using subscript "a" to indicate the absolute values of *L, D1, D2, S1, VL* and *S2* derived in the previous section, we computed the various welfare losses as follows:

$$L = 100(L^a / RC)$$
$$D1 = 100(D1^a / RC)$$
$$D2 = 100(D2^a / RC)$$
$$S1 = 100(S1^a / RC)$$
$$VL = 100(VL^a / RC)$$

and

$$S2 = 100(S2^a / RC)$$

Thus, a value of *9.3* for, for example, *S1* indicates a pure static welfare loss that is *9.3* percent of the resource cost of attaining the social optimum in the specific sector. Thus if the sector (as measured by *RC*) is *10* percent of the economy (i.e., of *M*), *S1* will be *0.93* of one percent of GNP.

Apart form obtaining relative values of the various welfare components of the welfare loss we are interested in the way these are affected by economic policy. We have considered how each of the welfare loss components varies as we increase patent life (*T*) and as we increase the parameter ϑ (thus driving price closer to marginal cost – competition policy). By doing so we have been able to see whether the variation in dynamic loss is opposite to that of the static loss – that is, whether there is a trade-off between dynamic and static efficiency as we vary the values of our policy instruments.

The following Tables and Diagrams give a broad picture of the results for various sets of parameter values. Note that in the Tables we also show the value of the total dynamic and static losses:

$$D = D1 + D2$$

and

$$S = S1(orVL) + S2$$

Note that a value of patent life *T=1* corresponds to a value of λ of approximately 0.1 and a patent life of *50* to a value of λ of approximately *0*. These were the values of λ that were used to compute the welfare losses that are shown in Tables 1 to 3. Also note that, in these Tables we present the values of the various losses for two values of ϑ. The first is the minimum value of ϑ (equal to 0). The maximum value of ϑ, $\overline{\vartheta}$, as noted in section 3 above, is endogenously set and will vary with changes in the parameter set. We have used, in all three Tables a maximum value of ϑ=0.73 which is the minimum value of $\bar{\vartheta}$ from the three parameter sets. Finally note that in all tables we use the values

$$s = 10, \varepsilon = 0{,}8, \gamma = F = 1$$

and vary the values of *a* and *β*.

After Tables 1-3, we use Diagrams 1-4 to indicate in greater detail how the various welfare losses vary with changes in ϑ and changes in *T*. In Diagrams 1 and 2 we show how *L, D1, D2, VL* and *S1* vary for the non-product-specific research case. Diagram 1 shows how the losses vary with T for ϑ=0. Diagram 2 how the losses vary with ϑ for *T=15* (*λ* approximately *0.7*). Diagram 3 and 4 contain the same information for the product-specific research case. Finally, Table 4 provides a summary of all the results.

Table A: Parameter values: α= ,45, β= ,125

A1: Non-Product Specific Research

		L	D1	D2	S1	VL	D	S
$\vartheta = 0$	**T=1**	54	27	0,16	20	7	27	27
	T=50	34	14	1,7	7,4	10,6	15,7	18
$\vartheta = 0.73$	**T=1**	61	19,7	0,16	18,5	22,4	20	40,9
	T=50	43,6	7,2	1,85	1,4	33,2	9,05	34,6

A2: Product Specific Research

		L	D1	D2	S1	S2	D	S
$\vartheta = 0$	**T=1**	31,6	10	12	8,5	1,1	22	9,6
	T=50	19	0,08	9,5	9,3	0	9,58	9,3
$\vartheta = 0.73$	**T=1**	41,5	2,9	35,3	2,3	0,96	38,2	3,26
	T=50	31	5,13	24,04	1,77	0	29,17	1,77

Table B: Parameter values: α= 0,55, β= 0,125

B1: Non-Product Specific Research

		L	D1	D2	S1	VL	D	S
$\vartheta = 0$	**T=1**	53	26	0,07	12	15	26,07	27
	T=50	43	16,5	0,9	6	19	17,4	25
$\vartheta = 0.73$	**T=1**	60,5	20,1	0,09	9,45	31	20	40,5
	T=50	54,1	10,1	1,06	0,96	41,9	11,16	43

B2: Product Specific Research

		L	D1	D2	S1	S2	D	S
$\vartheta = 0$	**T=1**	39	7,7	23	7,5	0,6	30,7	8,1
	T=50	30	0,01	21,5	8,5	0	21,51	8,5
$\vartheta = 0.73$	**T=1**	51,9	1,76	48,2	1,4	0,5	50	1,9
	T=50	45,2	6,6	37,3	1,3	0	44	1,3

Table C: Parameter values: α= 0,45, β= 0,15

C1: Non-Product Specific Research

		L	D1	D2	S1	VL	D	S
$\vartheta = 0$	T=1	57	31	0,17	18,5	7	31,17	25,5
	T=50	37	17	2	7	11	19	18
$\vartheta = 0.73$	T=1	62	23	0,17	17	22	23,17	19
	T=50	46	8	2	1,4	34,5	10	36

C2: Product Specific Research

		L	D1	D2	S1	S2	D	S
$\vartheta = 0$	T=1	34	12	12	8,5	1,3	24	9,8
	T=50	19	0,11	9,5	9,4	0	9,61	9,4
$\vartheta = 0.73$	T=1	44	3,3	37	2,5	1	40,3	3,5
	T=50	32	6,17	23,3	1,8	0	29,4	1,8

Diagram 1: Non-product-specific research; Effect of T
(ϑ=0, *α=0,55, β=0,125*)

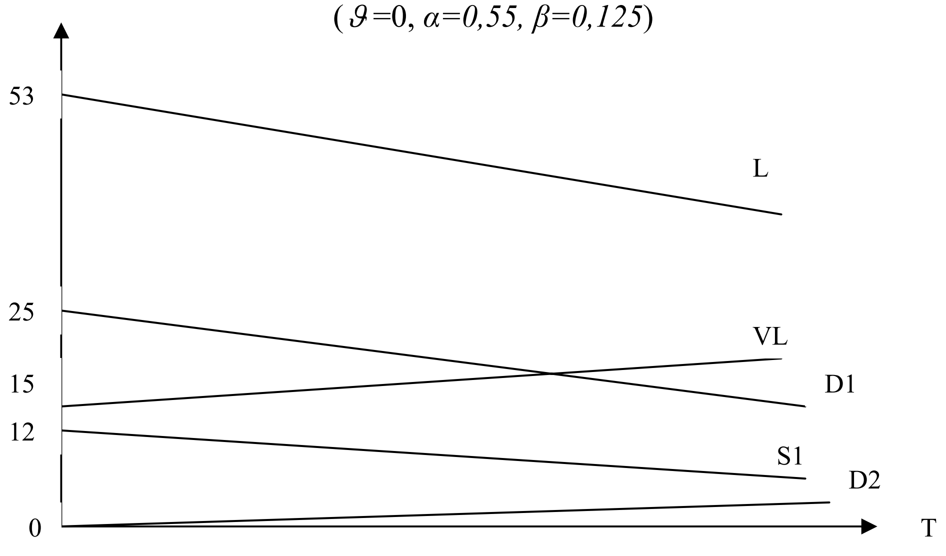


Diagram 2: Non-product-specific research; Effect of ϑ
(*T=15, α=0,55, β=0,125*)

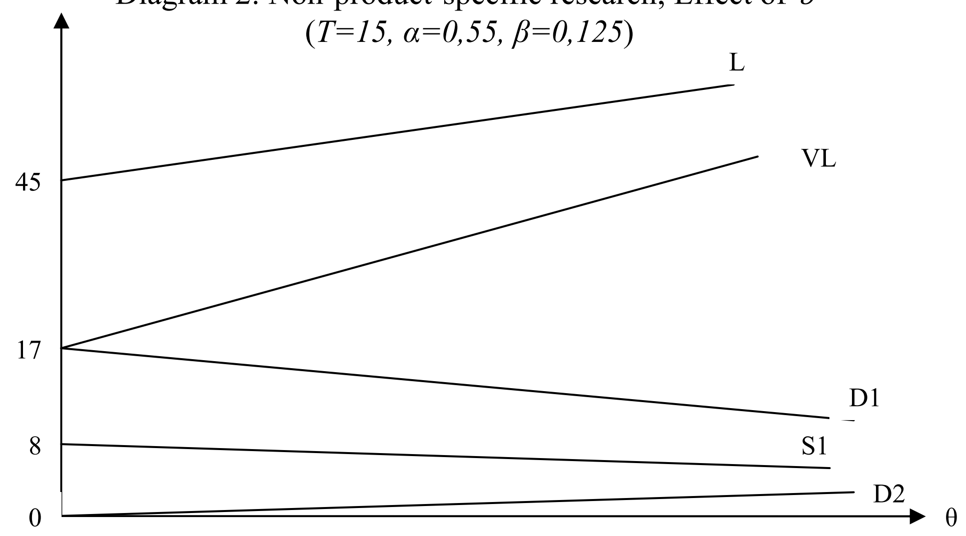
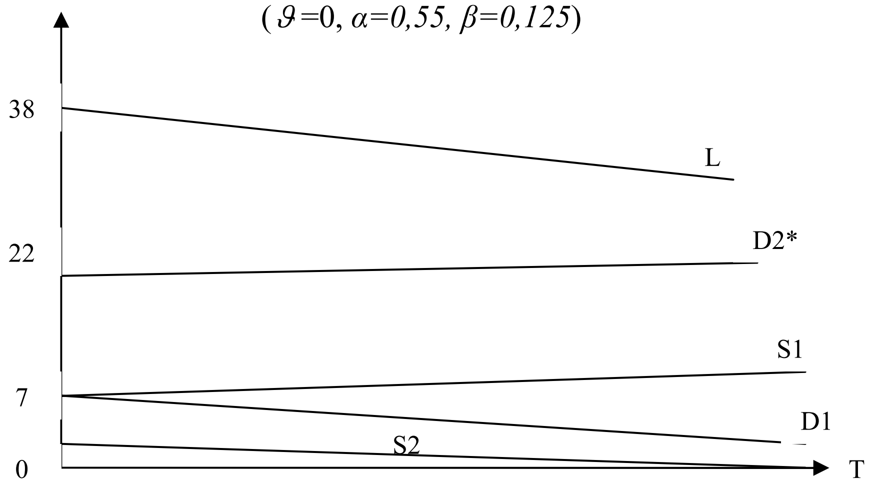
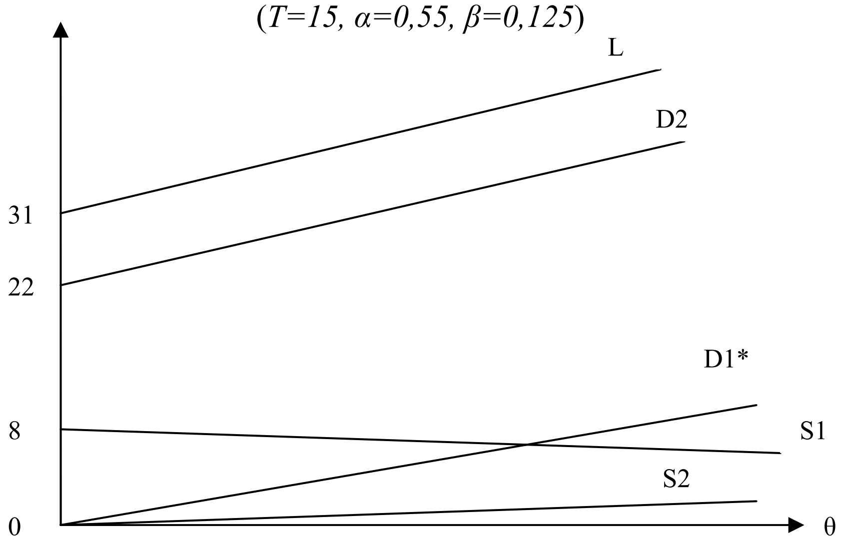


Diagram 3: Product-specific research; Effect of T
(ϑ=0, α=0,55, β=0,125)



*D2 is very slightly rising and then very slightly falling.

Diagram 4: Product-specific research; Effect of ϑ
(T=15, α=0,55, β=0,125)



* D1 is continuously falling for small T (T near one)

Table 4: Summary of Results				
	Non-product specific research		**Product specific research**	
	Effect of T	Effect of ϑ	Effect of T	Effect of ϑ
L	—	+	—	+
D	—	—	—	+
S	Depends on ε-α[1]	+	—	—
D1	—	—	— for small ϑ + for large ϑ	— for small T + for large T
D2	+	—	—	+
S1	—	—	+ for small ϑ — for large ϑ	—
VL or S2	+	+	—	0[2]
	Trade-Off depends on ε-α[1]	Trade-Off	No Trade-Off	Trade-Off

	Non-product specific research		**Product specific research**	
	Effect of α	Effect of β	Effect of α	Effect of β
L	+[3]	+	+	+
D	+[3]	+	+	+
S	+	+[4]	—	+

1. When *ε-α* is large, e.g. $\varepsilon=0.8$, $\alpha\leq 0.45$, then *S* is always falling with *T* (and so there is no trade-off between *D* and *S*). When *ε-α* is small (e.g. $\varepsilon=0.8$, $\alpha=0.55$), *S* is rising with *T* for large ϑ. Thus, when ε-α is small there will be a trade-off between *S* and *D* as *T* increases, for large values of ϑ.

2. The increase in the number of firms after the patents lapse in the simulation results is always less than one. Thus *S2* is approximately 0, or, exactly zero if we neglect increases in the number of firms that are less than unity

3. There is a very small decrease in *L* and *D* as α increases when T is very small.

4. *S* goes with β for small *T*;change either way is negligible.

7. Discussion of Results

7.1. General Comments

To start with, as in the homogeneous product case examined by Beath and Ulph (1990), in the present case too dynamic losses tend to exceed static losses under product specific research. However, with non-product specific research, dynamic and static losses are much more evenly balanced, and with large ϑ it is static losses that exceed dynamic ones. Underlying the latter result is the relatively large value of *VL* (the loss from the wrong number of products in the market equilibrium) under non-product specific research. (As in the homogeneous product case, *S1*, the Harberger-type loss is always relatively small). It is straightforward to see the reason for this large value of *VL*: in both non-product specific and product-specific research cases the number of varieties introduced in the market equilibrium before patents lapse is the same. But the social optimum number of varieties in the non-product specific case is much larger than the product-specific case, as we would expect from the fact that in the former case the social planner has to incur research costs just once irrespective of the number of varieties he decides to introduce. This explains the relatively large value of *S* in the non-product specific research as opposed to the product specific research case. (Of course, the number of varieties in market equilibrium increases after the patents lapse but the increase is very small relative to the gap between social optimum and the market equilibrium number of varieties).

Secondly, as in the homogeneous product case, under non-product specific research *D2* is not at all significant (whilst *D1* is). This is as it should be since what matters in determining *D2* is the number of research laboratories in the market equilibrium relative to the optimum and this depends on the product-specificity of research paths rather than product differentiation per se. This intuition is confirmed by noting that with product specific research paths *D2* is very significant – it is the dominant component of the overall social welfare loss. It is again fairly straightforward to see the reason for this: in both non-product specific and product specific research cases the number of research laboratories introduced in the market equilibrium is the same (equal to the number of varieties introduced before the patents lapse). Whilst however with non-product specific research (with homogeneous products or under product differentiation) the social planner only needs to operate one laboratory (and *D2* arises from excessive duplication of research effort), in the product specific research case the social planner, in order to satisfy society's taste for variety, has to introduce a large number of research laboratories (one for each variety introduced). Thus, here, the large *D2* value is the result of a lack of research laboratories in the market equilibrium. In this respect note that as α increases (products become less good substitutes), so society's taste for variety is reinforced, *D2* also increases as the social planner must respond with an even larger number of product varieties.

Thirdly, as in the homogeneous product case, there will be (in most cases) no trade-off between static and dynamic efficiency as patent life *T* increases. This is always the case with product specific research and will usually be the case with non-product specific research. However, unlike the homogeneous product case, with product differentiation there is a trade-off with respect to ϑ (irrespective of whether research is product specific or not). Whilst we offer a detailed discussion of the effects of policies on the various welfare losses below, here is a short explanation of this. As we would expect, as ϑ increases and price is driven towards marginal cost less firms find entry into the market attractive. In the non-product specific research case (where there is excessive duplication) this reduced *D*. However, because now, unlike the homogeneous case, *VL* increases with ϑ, this dominates the reduction in *S1* as ϑ increases, and *S* increases – so we have a trade-off. In the product specific case, on the other hand, the effect of ϑ on *D* is dominated by the effect on *D2*: this now goes up with ϑ (as explained below) making *D* to go up too. The effect on *S* is normal: *S* is reduced because *S1* is (with *S2* negligible and hardly changing with ϑ)-thus creating a trade-off again.

7.2 Policy effects on each welfare loss component

Policy effects on *D1*

(a) Effect of patent life

As *T* increases, for any given number of firms, each firm will wish to do more research and this tends to reduce *D1*. But more firms enter to do research when *T* increases and this, by reducing expected returns to each firm, tends to reduce research per firm and to increase *D1*. The first effect dominates, leading to a reduction in the D1 in the non-product specific research research case but only dominates in the product specific case when ϑ is large.

(b) Effect of competition policy

As ϑ increases and price is driven towards marginal cost returns to research, for any given number of firms, are depressed and so is research investment so that *D1* tends to increase. But less firms find it attractive to enter the market as ϑ goes up and this tends to increase returns from research, to stimulate research investment, and to reduce *D1*. The second effect dominates with non-product specific research but only does so with product specific research when *T* is large.

<u>Policy effects on *D2*</u>

(a) Effect of patent life

As *T* increases more firms enter the market and engage in research so with non-product specific research duplication increases and thus so does *D2*. But *D2* is reduced with product specific research as the introduction of additional laboratories now <u>reduces</u> the gap between the social optimum and the market equilibrium.

(b) Effect of competition policy

As already noted, as ϑ increases, less firms enter the market. Thus this reduces duplication, and hence *D2* too, in non-product specific research case, but increases gap between social optimum and market laboratories and hence *D2* in product specific research case.

<u>Policy effects on *S1*</u>

(a) Effect of patent life

As *T* increases and more firms enter to engage in research the increase in competition drives down and this tends to reduce *S1*. However, the increase in *T* leads to a delay in getting imitators into the market and this tends to increase *S1*. The former effect dominates the latter in non-product specific research case but only dominates when ϑ is large in the product specific research case.

(b) Effect of competition policy

As ϑ increases there is a direct effect of price being driven towards marginal cost tending to reduce *S1*. In both our cases this effect dominates the indirect effect form a reduction in the number of firms, mentioned above, that tends to increase the price-cost margin and thus *S1*.

<u>Policy effects on *VL* or *S2*</u>

(a) Effect of patent life

As *T* is increased, as already noted, more firms enter the market, more varieties are introduced, and this tends to reduce *VL*. However there is an increased delay in society getting new varieties from imitators and, with non-product specific research, the latter effect dominates so we get an increase in *VL*. With product specific research new firms cannot enter with new varieties after the patents lapse so, having to compete with the same varieties as existing firms, very few firms decide to enter. Thus in this case the first effect dominates and we get a reduction in *S2*.

(b) Effect of competition policy

As ϑ increases the reduction in the number of varieties, because lee firms find it attractive to enter the market, leads to a reduction in *VL* in the non-product specific research case. With research product specific *S2* captures the loss from the wrong number of <u>firms</u> in the market equilibrium after the patents lapse: as already noted, in this case, the number of firms in the market equilibrium changes very little after the patents lapse. Indeed, if we neglect the case where the increase is less than the unity, our results indicate that *S2* will be zero, in the product specific research case, for all ϑ and/or T.

7.3 Effects of parameter changes

The effect of changes in β

The main effect of an increase in β, that we may interpret as an increase in the productivity on research, is to increase *D* and thus to increase *L* in both our cases. The reason is that, whilst an increase in β has a beneficial impact on market research it leads to an even greater increase in the social optimum value of research.

The effect of changes in α

An increase in the parameter α implies a reduction in the degree of substitutability between products. This enhances society's taste for varieties and leads the social planner to introduce more varieties at lower output per variety. The latter reduces *S1* in both our cases. However, in the non-product specific research case the former leads to an increase in *VL* which outweighs the reduction in *S1* so *S* is increased. (Remember that, under product specific research, *S2* measures loss from inappropriate number of firms in post-patents equilibrium, so in this case the first effect is sufficient to lead to a reduction in *S*).

An increase in the optimal number of varieties when α is increased implies, in the product specific case, an increase in the optimal number of research laboratories. Thus the main effect of an increase in α in this case is to increase *D2* and thus D. In the non-product specific case the effect on *D* is negligible. Taken together these effects explain why an increase in α is likely to increase *L* in both our cases.

Effect of an increase in *s* or reduction in *F*

Such changes increase *D* in both our cases by increasing optimal research by more than research in the market equilibrium. Further by increasing the optimal number of varieties, each produced at a smaller output, such changes tend to reduce *S1* but they increase *VL*. The latter effect will not always dominate the reduction in *S1* so that *S* may be reduced even with non-product specific research-where the change in the optimal number of varieties counts. With product specific research *S* will be reduced. However the reduction in *S* is not sufficient to outweigh the increase on *D* so that *L* is increased.

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