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INTELLECTUAL PROPERTY & EXTERNAL CONSUMPTION EFFECTS: GENERALIZATIONS FROM PHARMACEUTICAL MARKETS

Tomas J. Philipson
Stéphane Mechoulan

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ABSTRACT

There is a long-standing literature that recognizes that an efficient solution in correcting a consumption externality is through applying subsidies and taxes that line up private incentives with social ones. An equally long-standing literature tackles the appropriate methods of generating the efficient amount of R&D into goods that only have private consumption effects, e.g. the analysis of the welfare effects of patent regulations. This paper analyzes the joint problem of the optimal provision of R&D and consumption incentives for goods that at the same time undergo technological change and have external consumption effects. For good with external effects, just as is the case for goods with only private effects, ex-post static efficiency may have to be sacrificed for dynamic efficiency. For goods with only private consumption effects, it is well-understood that efficient competition ex-post leads to insufficient R&D incentives ex-ante, which is of course the common rationale for patents. For external effects, this analogy has the important and unrecognized implication that classic interventions to solve externality problems, such as Pigouvian taxes and subsidies, may often be inefficient under technological change. In many cases, arguing for Pigouvian solutions in presence of technological change is analogous to arguing for competitive markets for new inventions (!), as both argue for ex-post efficiency rather than dynamic efficiency. The results are discussed in the context of the pharmaceutical industry which simultaneously is one of the most R&D-intensive industries and one for which consumption of its output often seems to involve external effects, e.g. through human rights-based access issues.

Tomas Philipson
The Irving B. Harris Graduate School
of Public Policy Studies
The University of Chicago
1155 East 60th Street
Chicago, IL 60637
and NBER
t-philipson@uchicago.edu

Stéphane Mechoulan
Department of Economics
The University of Toronto
150 St. George Street
Toronto, Ontario M5S3G7
Canada
s.mechoulan@utoronto.ca

Section 1: Introduction

It has long been recognized that an efficient solution in correcting a consumption externality is through applying subsidies and taxes that line up private incentives with social ones (Pigou, 1932). However, this classic problem, which we will label the *external consumption problem,* assumes that there is no technological change in the good that confers the external effects.

An equally long-standing literature tackles the appropriate methods of generating the efficient amount of R&D into goods that only have private consumption effects, *e.g.* the analysis of the welfare effects of patent regulations[2]. However, this classic problem, which we will refer to as the *private R&D problem*, assumes that there are no external effects in consumption of the good for which there is technological change.

Although both these problems are well analyzed, the combined problem of how to deal with technological change for goods with external effects seems less understood. More importantly, this seems to have led to substantial confusion about appropriate policy solutions for many important issues that implicitly seem to involve this joint allocation problem. To illustrate this point, consider the case of antibiotic resistance in which there has been great pressure to advocate "judicious use" to slow down the rising threat of antibiotic drugs becoming useless against many life-threatening diseases. In economic language, antibiotic use exhibits negative external effects, insofar as drug usage of current patients limits the benefit of drug usage of future patients[3]. However, taxing or limiting the demand for antibiotics ignores that such a policy at the same time discourages R&D into new antibiotics that will replace those to which bacteria have become resistant. Therefore, the costs of such judicious use of antibiotics may dominate the benefits even though such judicious use is the appropriate policy response in absence of technological change.

As another illustrative case, consider the pressing problem of providing drugs to third world nations for diseases such as AIDS, malaria, or tuberculosis. For example, about 90 percent of the prevalence of AIDS in

[2] There is of course a vast literature on the external effects of the R&D-process itself rather than external consumption effects of the final good, see e.g. Jones and Williams, 2000.

[3] For the purpose of this paper, we will assume that these negative external effects dominate the classic positive external effects of treatments for infectious diseases, see e.g. Philipson(2000).

the world is in third world nations but these populations cannot afford the new drugs for which R&D was undertaken in richer countries. As it appears that richer developed countries, for selfish - or altruistic reasons, care about expanding the demand for drugs by third-world countries for diseases such as AIDS, this problem appears in essence to be a problem of efficiently providing both technological change and the appropriate amount of consumption for a good with positive external effects[4]. An analogous issue arises for Medicare coverage of drugs in the US when the young care about drug consumption of the old. However, many current policy proposals seem to be Pigouvian in nature not taking into account technological change, *e.g.* such as those prescribing cost-based pricing under publicly financed demand, both for third world nations and Medicare[5]. When technological change is affected by such interventions, they may be inefficient. Under external effects in consumption, rewards to innovation should not be guided by potential *consumer* surplus, as under private goods, but the entire *social* surplus that includes the benefits to non-consumers as well as consumers as well.

Although the pharmaceutical industry, being both highly R&D intensive and often surrounded by human rights issues regarding access to its output, is a natural industry to illustrate our issues, many other industries appear to involve similar tradeoffs. For example, industries for goods with network-, peer-group-, or herd-effects, industries in which production induces pollution[6], or industries for which their output is used as inputs to externality-generating R&D, such as so called "research tools" industries, seem to involve similar issues of balancing externalities ex-post with R&D incentives ex-ante. Indeed, for health care generally, a central issue that falls under the problem at hand is the link between altruistic adoption of new technologies ex-post (society desires to finance nearly all available technologies with benefits) and the technological change induced by such altruism. As many observers have argued that technological change is the key source of recent growth in health care spending[7], the tradeoffs discussed may be of more general relevance.

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[4] For purpose of this paper, we assume that these positive external effects dominate the negative ones that may occur due to the fact that treatments may raise AIDS prevalence, see e.g. Anderson and May (1991).
[5] See Sachs et al (2001).
[6] See Parry et al (2000) for a discussion of technological change in pollution control.
[7] See e.g. Newhouse (1992).

This paper analyzes the appropriate joint treatment of externalities in consumption and provision for the right R&D incentives under technological change. We compare the efficient methods of solving the dual problem with the classic solutions proposed to the two separate problems represented by the external consumption problem or the private R&D problem.

First, we argue that classic Pigouvian solutions to the consumption externality problem are inappropriate under technological change. For goods with external effects, just as for those with only private effects, ex-post static efficiency is often inconsistent with ex-ante dynamic efficiency. In the private case, it is well-understood that efficient competition ex-post leads to insufficient R&D incentives ex-ante, which is of course the common second-best rationale for patents. Here, this analogy has the important and unrecognized implication that classic interventions to solve externality problems, such as Pigouvian taxes and subsidies, may often be inefficient under technological change. In many cases, arguing for Pigouvian solutions in presence of technological change is analogous to arguing for competitive markets for new inventions (!) as both argue for ex-post efficiency without regards to R&D incentives.

Second, we argue that optimal measures for the private R&D problem are inappropriate when those goods have external effects. In essence, such private measures go wrong because under externalities the entire social surplus to both non-consumers and consumers, as opposed to consumer surplus alone, needs to guide R&D efforts. We derive the efficient solutions to the problem of external effects in consumption under technological change. To illustrate our results, we consider the antibiotic resistance problem and the AIDS problem, and compare the efficient solutions to existing policy recommendations in these areas.

The paper may be briefly outlined as follows. Section 2 defines the problem of externalities under technological change. Section 3 considers how traditional solutions to the external consumption problem, such as Pigouvian taxes and subsidies, go wrong when there is technological change. This occurs because there are dual effects of Pigouvian measures when they not only affect externalities but also R&D incentives. Section 4 considers how traditional solutions to the private R&D problem, such as patents, go wrong when there are externalities. Section 5 discusses efficient solutions to the joint problem of technological change under external effects. Section 6 discusses the results as they apply to the provision of AIDS drugs in third-world nations[8]. Finally, Section 7 concludes.

Section 2: External Effects Under Technological Change

Let y denote the quantity of output, p(y) denote the private inverse demand curve of consumers, e(y) the monetary value of the external consumption effects to non-consumers, and c(y) the total cost function. Let the producer surplus (profits) of a monopolist be denoted:

$$(1) \qquad \pi(y) = p(y)y - c(y)$$

and let y_π denote the output that maximizes profits π. The surplus of the consumers engaged in consumption is denoted:

$$(2) \qquad s(y) = \int_0^y [p(q) - p(y)]dq$$

The social welfare W(y) is then defined by consumer and producer surplus together with the surplus of those affected by the externality

$$(3) \qquad W(y) = s(y) + \pi(y) + e(y) = \int_0^y [p(q) - (c_y(q) - e_y(q))]dq$$

The feasible level of technological change in the good consumed is represented by letting x(r) be an increasing, differentiable and strictly concave function representing the probability of discovering an invention as a function of the level of R&D, r, undertaken. The optimal level of R&D for that maximizes expected payoffs for any hypothetical ex-post prize z is denoted r(z) and is defined by

$$(4) \qquad r(z) = \text{argmax}_r \, x(r)z - r$$

We assume that the chance of discovery x(r) is increasing and concave function, which implies that r(z) is an increasing function.

To illustrate our results throughout the paper, we will consider a particular form of technology and preferences referred to as the *constant returns case*

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[8] Kremer (2002) summarizes a series of very interesting papers that deal with this issue, arguing for the benefits of prizes for R&D as commitment devices when external effects operate across countries.

in which the cost-function is of the form $c(y)=cy$, the externality of the form $e(y)=ey$, and in which demand is linear as in $p(y)=a-by$.

Section 3: Traditional Public Interventions for The External Consumption Problem

Traditional interventions designed to solve the externality consumption problem aim to maximize ex-post welfare, here denoted W. The output y_W that maximizes welfare W ex-post satisfies the necessary first-order condition

$$(5) \qquad W_y=0 \quad \text{if and only if} \quad p=c_y-e_y$$

This simply says that the efficient output involves prices above or below marginal costs depending on whether the externality is negative or positive.

However, aiming towards this ex-post optimal output level through public interventions ignores that R&D incentives may be affected. More precisely, consider a producer who maximizes the expected profits less the R&D expenditure as in

$$(6) \qquad E(\pi)=x(r)\pi(y)-r$$

The R&D undertaken by the innovator for a given amount of output is thus $r(y)=r(\pi(y))$. The expected dynamic welfare D defined in terms of the level of R&D and ex-post welfare is

$$(7) \qquad D(r(y),W(y))=x(r(y))W(y)-r(y)$$

Now consider attempting to achieve the output y_W, as when solving the externality consumption problem ex-post, e.g. through Pigouvian corrections. Simply specifying the welfare this way highlights a simple but unrecognized point; that with externalities, ex-post efficiency is often inconsistent with ex-ante efficiency, just as it is in the case of private effects.[9]

[9] This leads to the classic commitment issues of many R&D interventions, such as e.g. patents and prizes, where ex-post regulators want to lower rewards that are needed to be marked up to generate R&D ex-ante.

More precisely, if ones forces output to the ex-post efficient level y_W, the innovator undertakes an amount $r(\pi(y_W))$ of R&D. Can one do better by attempting to obtain some other output level than y_W ? The output y_D that maximizes D has the necessary first-order condition

$$(8) \qquad dD/dy = D_r r_y + D_W W_y = r_y [x_r W - 1] + x W_y = 0$$

This output only corresponds to the ex-post efficient solution to the externality consumption problem, y_W, if the first term is zero. That is, only under the rare conditions when dynamic efficiency does not depend on the R&D undertaken (D_r=0) or when optimal R&D is not affected by the output market (r_y=0). However, the optimal R&D investment of the firm that maximizes expected profits satisfies

$$(9) \qquad x_r \pi = 1$$

The output that maximizes expected welfare of an innovation does so by raising not only the value of the innovation conditional on discovery, W, but also the chance of discovering the innovation in the first place. This implies that a reduction in the chance of discovery must equal the gain in the ex-post welfare conditional on discovery. Therefore, the expected welfare involves having the value conditional on discovery being non-zero, an output level different from the one that maximizes ex-post welfare that has a zero marginal effect. This implies that the first term of (8) is non-zero whenever the social surplus differs from the profits; $W \neq \pi$ implies $W_y \neq 0$. In other words, when social welfare differs from profits, ex-post efficiency is sacrificed. As opposed to only private consumption effects, social welfare ex-post may be smaller than profits, but it is still true that divergence between social welfare and profits leads one to sacrifice ex-post efficiency to achieve ex-ante efficiency; y_W almost always differs from y_D.

This implication for our case of external effects, *i.e.* that ex-post static efficiency is inconsistent with ex-ante dynamic efficiency, is completely analogous to the case of goods with only private consumption effects. In the private case, it is well-understood that efficient competition ex-post leads to insufficient R&D incentives ex-ante, which is of course the common rationale for patents. Here, this analogy has the important and unrecognized implication that classic interventions to solve externality problems, such as Pigouvian taxes and subsidies, may often be inefficient under technological change. In many cases, arguing for Pigouvian solutions in presence of technological change is analogous to arguing for competitive markets for new inventions (!) as both argue for ex-post efficiency without regards to R&D incentives.

Pigouvian Tax Incidence and Dynamic Efficiency

Often governments cannot choose output levels directly but must attempt to induce them by various other measures. Perhaps the most commonly discussed of such measures for the external consumption problem is through so-called Pigouvian taxes and subsidies. The novel aspect introduced by such interventions in the case of externalities is that their *distributional impact*, in terms of the incidence of taxes or subsidies ex-post, matters for dynamic efficiency as profits drive R&D investments. Under static ex-post efficiency, however, the distributional impact of Pigouvian taxes are often irrelevant.

More precisely, consider the effects of tax-incidence results under the assumption of public budget neutrality, in the sense that the population considered gets paid back any taxes or pays for any subsidies. Without technological change in the good bearing an externality, define W(y,t) to be the ex-post welfare when the producer pays a budget neutral quantity tax t, and where the tax revenue is distributed to any party involved, as in

$$(10)\quad W(y,t)=ty+\pi(t,y)+s(y)+e(y)$$

Here the first term reflects the budget-neutral distribution of tax revenues to any party involved. However, as the taxes paid by the producer equals the tax-revenues distributed we have $ty + \pi(t,y) = \pi(y)$ for all t, and thus that the incidence of the tax, holding constant output, has no effect on ex-post welfare; $W_t=0$. An analog argument applies to other cases so that no matter who pays the tax or receives the subsidy and no matter who receives the tax revenues or pays for the subsidies, Pigouvian tax-incidence does not affect ex-post welfare.

However, when there is technological change in the good that confers external effects, Pigouvian tax incidence matters as it affects profits which in turn determine R&D. In the case above when producers pay the tax and it is distributed to non-producers, ex-ante welfare is

$$(11)\quad D(y,t)=x(r(\pi(t))W(y,t) - r(\pi(t))$$

Now, tax-incidence affects welfare because it affects R&D. That is, even holding output constant, changing the tax affects welfare: D_t is nonzero. Only in the case when all the collection and distribution is completely apart from the producer does tax incidence not affect ex-ante welfare. For example, when taxes are paid by consumers and distributed back to consumers and non-consumers, or when subsidies are received by consumers but again paid by non-consumers. To summarize, Pigouvian tax incidence does not matter without technological change but does matter with such change, in the sense that the partial W_t is always zero regardless of winners and losers while the partial D_t is non-zero when producers are affected.

Section 4: Traditional Public Interventions for The Private R&D Problem

The most common public intervention to stimulate R&D for private goods is of course through patents. It is well known that patents do not generate the first-best R&D incentives for private goods, because the social surplus is larger than the profits obtained due both to the fact that there is a dead-weight loss associated with the patent-induced markups and that consumers appropriate surplus not obtainable as profits. The social benefit generated by the invention is not fully appropriated by the producer who undertakes the cost to come up with the invention.

How do patents perform under external effects? Consider choosing the optimal patent length τ that may be interpreted as a quantitative measure of the extent of intellectual property protection. On the one extreme, with a zero patent life there is no protection and on the other extreme is a stream of monopoly profits forever as the patent length goes to infinity. For a given patent length the aggregate welfare consists of the welfare before patent expiration

$$(12)\quad W(\tau)=W_B(\tau)+W_A(\tau)$$

Where $W_B(\tau)$ and $W_A(\tau)$ denote the social welfare before- and after expiration. If we assume that cost-based pricing occurs after expiration its associated output is denoted y_c and defined by; $p(y_c)=c_y(y_c)$. This implies that the welfare before- and after-expiration is defined in terms of the static welfare according to

$$(13)\quad \begin{aligned} W_B(\tau)&=\Sigma_{0<t<\tau}\, \beta^t W(y_\pi)=v(\tau)W(y_\pi) \\ W_A(\tau)&=\Sigma_{t>\tau}\, \beta^t W(y_c)=[1/(1-\beta)-v(\tau)]W(y_c) \end{aligned}$$

Where $\beta\in(0,1]$ is the discount factor and $v(\tau)=(1-\beta^\tau)/(1-\beta)$ is the present value of a claim that pays one dollar a year as long as the patent lasts. A rise in the length of the patent life affects welfare according to

$$(14)\quad dW(\tau)/d\tau=(dv/d\tau)\ [W(y_c)-W(y_\pi)]$$

When there are no externalities, the last factor is of course positive as it represents the dead-weight loss of a patented monopolist. Hence, the derivative is negative; longer patents reduce ex-post welfare by simply extending monopoly protection; $dW(\tau)/d\tau < 0$. Consequently, the optimal ex-post patent length involves the corner solution of zero.

When there are positive externalities, our previous discussion implies the monopolist does more damage than the market by charging above costs that in turn are above the efficient price, so again the derivative is negative. However, when there are negative externalities, the patent holder may price the good better than a competitive market that prices the good at marginal cost. As we discussed in previous sections, this occurs when the over-pricing of a patent holder is less than the under-pricing of a competitive market. In such a case, the ex-post welfare function *rises* in patent length $dW(\tau)/d\tau>0$ and hence implies the corner solution of an infinite patent. The fact that negative external effects may imply that extending patents is beneficial ex-post, and that under positive externalities it is harmful, illustrates an important property used later on; that the interacting effect of the externality on the marginal effect of patent life is often negative.

This interaction between patent length and externalities is usefully illustrated by the constant returns case. In that case, it turns out that regardless of preferences and technology the competitive output is twice the patented monopoly output; $y_c=2y_\pi$. This implies that the dead-weight loss is half the monopoly profits so that the difference in the competitive and patented monopoly welfare reduces to

$$(15)\quad W(y_c)-W(y_\pi)=(½)\pi(y_\pi) + ey_\pi$$

When the patent expires, there is a social gain of half the monopoly profits (the dead-weight loss of the monopoly in the constant returns case) to consumers and producers and there is a change in the externality exposed proportional to the expansion of output. In the constant returns example this means that the ex-post welfare $W(\tau,e)$ has a negative cross-partial

$$(16)\quad W_{\tau e}=(dv/d\tau)y_\pi < 0$$

Moreover, the ex-post welfare *rises* with patent length whenever

$$W(y_c) < W(y_\pi) \Leftrightarrow e\, y_\pi < -(½)\pi(y_\pi) \Leftrightarrow$$
$$e < -(½)[p(y_\pi)-c] \Leftrightarrow e < -1/4\,(a-c)$$

Whenever the negative externality is larger in absolute value than half the markup, patents raise ex-post welfare. For a patent to be desirable ex-post, the magnitude of the negative externality must be large enough to overcome the social gain from eliminating the dead-weight loss of the patent.

The fact that ex-post welfare may fall or rise in the length of the patent has implications for the optimal dynamic patent life. The amount of R&D induced by a given patent length is $r(\tau)=r(v(\tau)\pi(y_\pi))$. Naturally, this implies R&D rises in the length of protection; $r_\tau >0$. The ex-ante optimal patent length that maximizes dynamic welfare D solves

$$(17)\quad \text{Max } D(\tau)=x(r(\tau))W(\tau)-r(\tau)$$

We are interested in how the size of an externality affects the optimal patent life, what $\tau(e)$ looks like.

Because of the fact that the ex-post welfare may be monotonic in the patent length, and hence involve corner solutions, first-order conditions are not as revealing of the difference between ex-post and ex-ante optimality as in previous sections. Consider first the case of positive externalities when the ex-post welfare function $W(\tau)$ is decreasing and thus has the optimal ex-post patent length of zero. As the R&D under no protection is zero, $r(0)=0$, and hence the chance of discovery, $x(r(0))=0$, ex-ante welfare is zero as well. Consequently, ex-post optimal protection is always smaller than ex-ante optimal protection as long as there is some patent length that yields strictly positive ex-ante welfare. Now consider the case of negative externalities, when the ex-post welfare function $W(\tau)$ may be increasing, and thus has the optimal ex-post patent life being infinite. Although both the chance of discovery and ex-post welfare rises with protection, they are optimally traded off against the cost of R&D.

More generally, how does the optimal patent length depend on the magnitude and sign of the externality? We consider this question for the case when the externalities are of the constant returns type $e(y)=ey$ and hence the parameter e is a measure of the size of the externality, whether positive or negative. The implicit function theorem applied to the implicit relationship $F(\tau,e)= dD/d\tau=0$ between the patent length and the size of the externality defined by the first-order condition for an optimal patent life yields

$$(19) \quad d\tau/de = -F_e/F_\tau = -\,[r_\tau x_r W_e + xW_{\tau e}]/F_\tau$$

where the denominator is necessarily positive as long as the second-order condition holds. This expression was obtained by noting that the optimal R&D level $r(\tau)$ does not depend on the size of the externality as the patented profits do not depend on the externality; $r_e=0$. As a consequence, the optimal chance of discovery as well as its derivatives do not depend on the externality either; $x_e=x_{re}=0$.

Evaluating the sign of the derivative $d\tau/de$, note that ex-post welfare rises with the externality as simply more people enjoy the output the larger the externality is; $W_e>0$. Thus the first term of the sum within the bracket is positive. Regarding the remaining term, which depends on the sign of $W_{\tau e}$, we need to sign the impact the externality has on the marginal effect of raising the patent length.

If the externality is non-negative we know that extending the patent is harmful, $W_\tau < 0$. Furthermore, the larger is the size of the positive externality, the more harmful it is to extend the patent

$$W_{\tau e} = (dv/d\tau)\, d[W(y_C)-W(y_\pi)]/de < 0$$

Under such an externality, it therefore follows that raising the size of the externality has an indeterminate effect on the optimal patent length. A larger positive externality both raises the social value of the invention, $W_e > 0$, but also the additional harm imposed by restricting its consumption through patents, $W_{\tau e} < 0$, making up two offsetting forces on the optimal patent life. In sum, starting from a positive externality or private good, it is ambiguous whether a rise in the externality should involve a shorter or longer patent; $d\tau/de <> 0$. If the externality is negative, then the cross-derivative $W_{\tau e}$ is positive, so that the effect of lowering the size of the externality has an unambiguous positive effect on the patent length.

Section 5: First-Best Allocations and Dual Interventions in Both R&D and Output Markets

The previous two sections reveal that single measures aimed at solving the external consumption or private R&D problem *alone*, fall short. In order to achieve the first best allocation one need to break the link between ex-ante R&D and ex-post output provision.[10] The inability of conventional solutions to either of the two traditional problems stems from that a single instrument is not sufficient to appropriately control both R&D incentives ex-ante and externalities ex-post. Appropriate policy must *simultaneously* solve the externality problem ex-post and the R&D problem ex-ante.

More precisely, the expected social welfare given R&D and output levels is

$$(20) \quad D(r,y) = x(r)W(y) - r$$

The *first-best* R&D and output (r^*,y^*) that maximizes this ex-ante welfare and implies the necessary first-order conditions:

$$(21) \quad D_y = xW_y = 0$$

$$(22) \quad D_r = x_r W - 1 = 0$$

[10] In this paper, we do not discuss whether public versus private production and financing of R&D would come closer to implement the "ideal" first-best policy, in particular how asymmetric information affects the optimality of such choice (see Wright (1983)).

Clearly, the ex-ante optimal output coincides with the ex-post-optimal: $y^* = y_W$. The corresponding optimal R&D is that which takes into account that highest level of ex-post welfare $r^*=r(W(y^*))$. Naturally, as the first-best allocation selects from the feasible set $\{(r,y): r\geq 0, y\geq 0\}$ that contains the feasible set $\{(r,y): r=r(y), y\geq 0\}$ selected from under a second-best allocation, the expected welfare is larger in the former case.

5. 1 The First-Best Optimality of Traditional Interventions

The previous section considered why traditional solutions to the consumption externality problem or the private R&D problem did not achieve second best optimality. We now consider how well these traditional solutions perform in a first-best sense.

Traditional Interventions to The Consumption Externality Problem

The traditional solution to the consumption externality problem, of only correcting output markets ex-post through Pigouvian transfers, generically does not generate the first-best allocation. To see this, note that if the allocation y y_W is achieved ex-post, then the R&D undertaken corresponds with the first-best level only whenever

$$r(\pi(y_W))=r(W(y_W))$$

which implies $s(y_W)+ e(y_W)=0$. This never holds under a positive externality, and never holds generically under a negative externality. This has the implication that, ex-post optimal Pigouvian externality solutions need to be accompanied with R&D corrections in order for them to induce first best outcomes. Classic solutions of internalizing externalities used *alone* never achieve dynamic efficiency.

Traditional Interventions to The Private R&D Problem

The first best optimality of the traditional solution to the private R&D problem, i.e. patents, is less obvious. When there are external effects without technological change, the markup of a patent holder acts as a Pigouvian tax and a patent may therefore be beneficial for ex-post efficiency under a negative externality, such as the antibiotic case, but is always harmful for ex-post efficiency under a positive externality, such as the AIDS drug case. In other words, the traditional welfare loss associated with patents, in that it restrict trade ex-post, may not be present under negative externalities but is exaggerated under positive externalities. More precisely, the ex-post efficient output y_W satisfies the markup/markdown condition

$$p = c_y - e_y$$

As opposed to the patented monopoly output y_π that satisfies the standard markup condition

$$(23) \quad p = [1/(1+\varepsilon)]\, c_y$$

where $\varepsilon \equiv p_y y/p$ is the elasticity of the inverse demand function. Naturally, under a positive externality, a patent always leads to an excessively high price as the patent holder charges above costs and cost-based pricing is too high. For a negative externality, the relative size of the elasticity of demand and the harm induced by the externality determines whether the patent monopolist under- or over-prices his output.

It may therefore appear that when a patent induces the monopolist to correct a negative externality correctly ex-post patents would be a first-best solution. To discuss this most apparently, consider a one period world in which a one period patent may be awarded. In this case it can be shown [11] that *the R&D and output under a patent generically differs from the first-best allocation (r^*, y^*).*

[11] This can be proved by noting that the optimal monopoly output y_π satisfies $\pi_y(y_\pi)=0$ as opposed to the ex-post optimal output y_W that satisfies $\pi_y(y_W) + s_y(y_W) + e_y(y_W)=0$. Hence those coincide only if $s_y(y_W)+ e_y(y_W)=0$. If the externality is positive, $e_y > 0$, this condition never holds, as consumer surplus rises with quantity as well, $s_y > 0$. If the externality is negative, $e_y < 0$, the condition never holds generically, only when marginal consumer surplus exactly offsets the marginal effect of the negative externality, $s_y = -e_y$. By monotonicity of $r(z)$, the R&D induced by the patent coincides with first-best R&D $r(\pi(y_\pi))=r(W(y_W))$, if and only if $\pi(y_\pi)=W(y_W)$, which in turn implies $s(y_W) + e(y_W)=0$, which never holds generically.

Put simply, when there are positive externalities, the markup of a patent holder induces an output that is not first-best. When there is a negative externality, the output may be first-best, but the R&D it induces is not, for similar reason why Pigouvian solutions do not induce the first-best R&D. In other words, when the markup of patent holder taxes a negative externality efficiently ex-post, just as under optimal Pigouvian interventions, there is still a surplus appropriations issue.

That patents do not generate first-best allocations under external effects mimics the result for the private R&D problem, and in essence both are due to the fact that part of the overall surplus of an innovation is not fully appropriated by the innovator. However, to highlight the unique aspects of patents under external effects, we consider the optimality of patents in an environment that allows for first-degree price-discrimination. In this case, it follows that R&D and output decisions are first best for the private R&D problem because the entire surplus is allocated to the innovator.

However, patents are never first-best when there is an externality even when such price discrimination is allowed. Under an externality, the producer charges each consumer her whole surplus. But the externality impacts *non-consumers,* and their surplus is not taken into account by the firm. This implies that under a positive externality, the monopolist always under-invests in R&D because the output is too low. Conversely, when the externality is negative he over-invests in R&D. Once again, the problem is that although the producer is appropriated the entire *consumer* surplus, he does not appropriate the entire *social* surplus when consumption affects non-consumers externally.

5. 2 Optimal Joint R&D- and Output Corrections

The optimal simultaneous correction of R&D and output can be derived from implementing the first-best allocation taking into account how corrective measures affects dynamic efficiency. Table 1 below illustrates the main characterization of the optimal joint determination of the R&D and output unit taxes (t_r ,t_y) which leads to the first best levels of R&D and output[12]. These taxes induce the monopolist to the efficient output and R&D and are defined by the condition:

$$(14)\quad [t_r + r(\pi(y(t_y)), y(t_y)]=[r^*, y^*]=[r(W(y_W)),y_W]$$

The characterization of the optimal taxes may be most easily understood by dividing up the analysis into the case of positive versus negative externalities. In the case of positive externalities, we know that the monopoly output in absence of intervention is below the ex-post efficient level, $y(0) < y_W$, so that the consumption intervention that restores the output to the level must be a subsidy; $y(t_y)= y_W$ implies $t_y < 0$. However, this consumption subsidy stimulates R&D too much or too little dependent on whether the condition

$$(15)\quad r(\pi(y(t_y)) + y(t_y)t_y) > r(W^*)$$

holds. This condition is in turn is equivalent to

$$(16)\quad \pi(y_W) + y_W t_y > W(y_W)$$

which states that the incidence of the tax on the full non-producer surplus, *i.e.* including consumers and non-consumers, is negative

$$(17)\quad s(y_W) + e(y_W) - y_W t_y < 0.$$

We say that the consumption tax is *Pareto Improving* (condition P in Table 1), whenever this fails. In that case, both non-producers and producers are better off ex-post under the consumption tax.

INSERT TABLE 1 HERE

In the case of a negative externality, the unregulated monopolist either produces above or below the optimal amount, as mentioned earlier. If the monopolist produces below the optimal amount, the case is similar to that of the positive externality (Case 1). In case the monopolist produces above the amount (Case 2), then the planner needs to impose a tax. Therefore, the

[12] These instruments implicitly rule out output rewards, see e.g. Wright (1983) for a discussion of their efficiency rationale. In a series of papers, Kremer (2001,2002) proposes to overcome the practical obstacles and the desirability of output rewards in the case of third world diseases.

optimal amount of R&D will be under provided privately, hence the need for a R&D subsidy ($t_r < 0$).

Section 6: International Healthcare Policy in Developing Countries

The previous analysis may be usefully illustrated by considering current policy proposals for the pressing problem of providing drugs or treatments for third-world diseases such as e.g. AIDS, TB, and malaria, a problem we interpret as providing efficient technological change under positive external effects.

Without externalities, its seems efficient that a disproportionate low share of the world private R&D is allocated towards third-world diseases even though these diseases may be more prevalent world-wide. However, under positive externalities induced by altruism, lack of R&D spending on third-world diseases may represent an under-investment in R&D. The problem is that consumption of third-world consumers do not only generate surplus to them, but also to non-consumers developed countries, and this part of the social surplus is not appropriated by a patent monopolist. An extreme case illustrating this would be when consumers are not willing to pay above *marginal* costs, as may be argued for the majority of the worlds population with AIDS or other third-world diseases. In this case, the social surplus may nevertheless be positive, and hence the first-best level of R&D positive, even though it should be zero with regards to consumer surplus alone.

Existing policy proposals to deal with this implicit externality problem have been *ad hoc* in the sense that the allocation problems that they intend to optimally solve have been left unspecified or non-explicit. Therefore, it appears useful to compare existing proposals to the combined taxes (t_r, t_y) implementing the first-best outcome (r^*,y^*) in our framework. For illustrative purposes, we discuss the proposals them in the constant returns case.

Sachs et al (2001) in a recent WHO report of a commission of experts in economics and medicine[13], entitled *Macroeconomics and Health: Investing in Health for Economic Development*, advocates cost-based pricing financed by donor country tax revenues for the drugs of third world diseases. This policy mimics a policy of having no IP-protection for innovations with a Pigouvian subsidy set to marginal cost; τ=0 and -t_y=c. The policy induces a producer price equal to marginal cost, p_P=c, and consumer price of zero,

[13] See Sachs et al (2001).

p_C=0. As the subsidy is financed by non-consumers in rich countries, the net external benefit of a given output level to non-consumers is

$$e(y)=ey-p_P y=(e-c)y$$

As the consumer price is zero, this will lead to full demand[14] at the maximum level which is $y_F=a/b$ under a linear inverse demand curve $p(y)=a-by$. The ex-post welfare of this output level is

$$W(y_F)=B(y_F)+s(y_F)+e(y_F)=0 + y_F\, [\, p(0)/2 + (e-c)]=(a/b)[a/2 + e-c]$$

Consequently, this ex-post welfare is positive as long as $a/2 + e > c$, which simply says that the average marginal value to consumers together with the marginal value to non-consumers is above marginal costs. This output level differs from the first-best output level in the constant returns case which satisfied $p(y_W)=c - e$ and hence

$$y_W=[a-(c - e)]/b= y_F -(c-e)/b$$

The two output levels y_F and y_W differ when the marginal benefit to non-consuming rich countries is less then the marginal cost. Otherwise, the two output levels coincide to be at the maximum output level as the rich countries would be willing to buy the maximum output just for their own sake. Thus, there is an output misalignment in between the Pigouvian solution and the WHO solution only when there is a marginal interest among donor countries relative to costs.

Naturally, the R&D induced by the WHO solution is never first-best as the producer surplus is zero. The important issue is that as the non-consumer surplus, e, will most likely dominate the consumer surplus, s, the first-best R&D level $r^*=r(W(y_W))$ should reflect the value to rich countries of combating third-world diseases[15]. The private R&D incentives induced by the WHO proposal misses this dominant benefit of third-world disease R&D. Although the Pigouvian intervention proposed by WHO may be optimal without technological change, it does not encourage R&D to reflect the altruism of donor countries, but discourages innovation by not capturing that altruism. For exclusively third-world diseases, R&D should be done for the rich, not the poor.

A similar argument may be applicable to the proposal of Lanjouw (2002) that advocates country- and disease-specific cut-backs in intellectual

[14] This analysis ignores issues of infrastructure, e.g. other capital and labor, needed to generate full demand at zero prices such as e.g. the availability of local health centers and doctors.

[15] The report advocates increased public R&D to potentially make up for the lack of private R&D incentives induced by its corrections in output markets.

property rights[16]. In some sense, this is the de facto, though not de jure, policies in place already as some countries for some diseases has relaxed IP rights. Lanjouw (2002) argues, correctly so it seems, that such country-specific IP rights may provide a solution to greater access while not affecting R&D incentives substantially for diseases whose R&D are affected by richer markets anyways. More precisely, if patents are weakened in poor countries when those countries do not make up a substantial share of world-demand, it is argued that overall R&D spending will not be much affected. This proposal is similar in spirit to the one of WHO in the sense that it advocates cost-based pricing in poor countries, through competition rather than regulation, when those countries make up a small share of world demand. Although these arguments seem correct, they advocate inefficient solutions. The problem is again that R&D *should* be affected by poor markets, but not by the consumer surplus, s, but by the non-consumer surplus from richer countries, e.

The basic conflict between these policy proposal and the first-best policy is that by limiting intellectual property rights of innovators, one is *reducing* benefits to innovators when those benefits should actually be *increased* to reflect the value to non-consumers. If donor countries care about access to drugs in poor countries, which indeed seems to be the whole rationale behind why there is a role for public intervention in the first place, efficiency dictates they should also pay for such greater access. As efficiency dictates that those who benefit pay, those gaining altruistically from the consumption of the poor should pay for it, as opposed to being paid by the producers through lower prices. In a sense, limiting property rights for producers of drugs implicitly involves asking innovators to not only come up with the new drugs that serves altruistic goals, but also to cover the bill for the distribution and consumption to achieve those goals.

The US Orphan Drug Act

The provision of AIDS drugs in poor countries mimics the problem of providing drugs for rare diseases in the US and it seems that international lessons can be learned from this domestic experience. Aimed at the purpose of stimulating R&D into markets that were privately unprofitable, The US Orphan Drug Act of 1983 both reduced the cost and raised the benefit of

[16] In a more general context, Grossman and Lai (2002) discuss the optimality of streamlining IP protection across countries.

R&D into drugs for diseases with sufficiently small prevalence[17]. Without external effects, it seems hard to justify such a policy because when consumption effects are only private, there should be no R&D for diseases that do not recoup this fixed investment cost. The market size and consumer surplus itself is not sufficient to generate the R&D, but a society which cares about those who are unlucky enough to catch uncommon diseases, the social surplus is larger than the consumer surplus. The Orphan Drug Act acts to make the R&D incentives larger than those represented by consumers, and hence market incentives, alone to reflect the positive external effects of non-consumers. The only difference seems to be that the third-world disease problem concerns an inverse demand curve that intersects the x-axis further out, although they both intersect with the marginal cost curve too early in order for the consumer surplus to be large enough relative to the fixed cost of R&D investment. It appears that The Orphan Drug Act seems inconsistent with the international proposals discussed above. While both seek to deal with provision of drugs to markets for which private incentives of provision would not be sufficient, The Orphan Drug Act correctly encourages R&D as opposed to international proposals that discourage R&D. The enormous growth in drugs for rare diseases generated by the Orphan Drug Act may contain important lessons for the correct international policy.

Section 7: Conclusion

The whole idea behind intellectual property protection for private goods in the first place is that ex-post efficiency, in terms of competitive cost-based pricing, is inconsistent with dynamic efficiency because competitive pricing ex-post does not generate the right R&D incentives. In one sense, what we have said for goods with external effects simply mimic this classic argument; although traditional Pigouvian measures are efficient ex-post, they do not generate the correct R&D-incentives ex-ante. Thus, arguing in favor of Pigouvian solutions in presence of technological change, which seems common in many applied contexts such as antibiotics and third-world drug provision, is like arguing in favor of competitive markets for new inventions. Recognizing the analogy between ex-post and ex-ante efficiency for goods with external effects seems important for many markets, particularly those such as health care, in which merit motives or "human-rights" issues so often seem to be present on the part of tax payers after an

[17] For a description of the main features of the act, see www.fda.gov/orphan.

invention has been discovered and since technological change is so often thought to be a key determinant in the expansion of the relative size of this sector.

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Negative Externality:	Case 1:	$y(t{=}0) < y_W \Rightarrow t_y < 0$	$t_r < 0$ (if P) or $t_r > 0$ (if not P)
	Case 2:	$y(t{=}0) > y_W \Rightarrow t_y > 0$ & $t_r < 0$	
Positive Externality:		$y(t{=}0) < y_W \Rightarrow t_y < 0$	$t_r < 0$ (if P) or $t_r > 0$ (if not P)

Table 1: Optimal R&D and Output Taxes & Subsidies