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INTELLECTUAL PROPERTY RIGHTS, THE POOL OF KNOWLEDGE, AND INNOVATION

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ABSTRACT

The pace of innovation is related both to the level of investment in innovation and the pool of knowledge from which innovators can draw. Both of these are endogenous: Investments in innovations are affected by the pool of knowledge and the ability of firms to appropriate the returns to their innovative activity, itself affected by the intellectual property rights (IPR) regime. But as each firm engages in research, it both contributes to the pool, and takes out from it. The strength and design of IPR affects the extent to which any innovation adds to or subtracts from the pool of ideas that are available to be commercially exploited, i.e. to the technological opportunities. We construct the simplest possible general model to explore the resulting dynamics, showing that, under plausible conditions, stronger intellectual property rights may lead to a lower pace of innovation, and more generally, that long run effects may be the opposite of the short run effects.

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Intellectual Property Rights, the Pool of Knowledge, and Innovation

Advocates of stronger intellectual property rights argue that stronger intellectual property rights, *ceteris paribus*, lead to higher levels of investment in R & D, and therefore more innovation. But empirical research provides at best ambiguous support for a simple relationship between the strength of intellectual property rights and the level of innovation—or even higher levels of investment in R & D or learning.[2] The reason is that much is hidden in the assumption of *ceteris paribus* (all other things being equal). There are many other ways of appropriating returns from research, and thus the *incremental* benefit from stronger IPR, at least in many industries, is less than it otherwise would be.[3]

What seem to be *more* important are the "opportunities," the potential for discoveries, related to the pool of knowledge to be exploited, i.e. the pool of ideas that awaits translation into processes and products that are valued in the market.[4] But the size of that pool is *endogenous.* As each individual or firm engages in research and learning, it both contributes to the pool, and takes out from it. The "enclosure of the intangible commons of the mind"[5] that is associated with patenting, i.e. with the exercise of intellectual property rights, diminishes the size of the pool available to others. At the same time, each innovation that is not patented may contribute to the pool of ideas that others can build on.

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[2] See for example Bessen and Meurer (2008). That said, it should not be surprising that there have been a large number of attempts at finding correlations between some measure of the strength of a country's intellectual property regime and economic growth, or some variable purportedly related to economic growth, such as inward bound foreign direct investment. As most scholars engaged in this research have recognized, these studies are bedeviled by a large number of econometric problems, e.g. of identification. With global harmonization, there is a dearth of natural experiments; and even when such experiments exist, long lags and the influence of a multiplicity of other factors affecting innovation and growth make it difficult to establish definitive, or even convincing, results.

Historical studies are suggestive of the multiplicity of influences on the level of innovation: several European countries with weak intellectual property rights had flourishing innovative sectors—more flourishing than others with stronger intellectual property rights. (Chang 2001, 2002). See also David (1993, 2002).

More recent critiques of IPR regimes have focused on "flaws" in the IPR regime, arising from the patent thicket, the bias for excessive patenting (as opposed to the incentives for fighting patents), hold-ups, incentives for evergreening, etc. Whether it is possible to adequately "correct" these flaws, so that the net effect on the pace of innovation (as opposed to the level of investment in R & D, taking into account the distortions associated with these flaws) of the IPR regime is positive remains contentious. It is clear, however, that the relationship between IPR and innovation depends on fundamental rules of the IPR regime, governing what can be patented, the breadth and standards of patenting, how patents are enforced, and so forth.

More narrowly focused studies have identified areas where particular patents have had adverse effects on follow-on research. In particular, evidence presented in the Myriad BRAC gene patent litigation detailed adverse effects both on the development of tests and further research. (See *Association for Molecular Pathology v. Myriad Genetics*, 569 U.S. 12-398 [2013], Huang and Murray, 2008; Williams, 2013).

The discussion of this paper abstracts from the details of the patent system, which are discussed at length extensively in the large literature on intellectual property. So too, we ignore the details of the patent system that affects the welfare impacts, e.g. the consequences of IPR regimes for access to life-saving medicines.

The state of the current debate around IPRs is surveyed by the contributions to the Winter 2013 *Journal of Economic Perspectives* symposium (Boldrin and K. Levine; Moser; Hagiu and Yoffie; and Graham and Vishnubhakat.)

[3] Dasgupta and David (1994) also argue for the importance of other non-pecuniary motivations for research. See also David (2004a, 2004b).

[4] See Dosi and Stiglitz (2013) and the references cited there.

[5] To use Boyle's evocative phrase. See Boyle (2003). See also Heller (1998) and Heller and Eisenberg (1998).

The strength and design of IPR thus affects the extent to which any innovation adds to or subtracts from the pool of ideas that are available, i.e. to the technological opportunities.[6]

In this paper, we construct the simplest possible general model to explore the resulting dynamics. We show that, in this quite general model, stronger intellectual property rights may well lead to a lower pace of innovation. This is in spite of the fact that *at any level of opportunities* it leads to more investments in R & D. The reason is that stronger IPR, by tilting the balance between additions to and subtractions from the pool of opportunities, *at any level of investment in R & D or learning*, leads to a diminution in the size of the knowledge pool. The effect on investments in R & D over the long run is ambiguous; that is, once the adverse effect on the size of the technological pool is taken into account, stronger IPR may in the long run actually lead to less investment. But with a small knowledge pool, even a given investment in R & D leads to less innovation. Thus, even if stronger IPR leads to more investment in R & D, taking account of the adverse effects on the knowledge pool, the adverse effect on innovation is so strong that the level of innovation may be reduced. Obviously, the magnitude of the adverse effects depends critically on the impact of stronger IPR on knowledge externalities (the positive externalities arising from additions to the knowledge pool, and the negative externalities associated with subtractions from the knowledge pool) as well as the availability of alternative mechanisms for appropriating returns to innovation.

Thus, the purpose of this paper is not to parse out the empirical literature of the effects of IPR in general, or specifically, of particular IPR provisions, on the level of investments in R & D or on outcomes, on the pace of innovation, but rather to provide insights into why, there may be an ambiguous relationship between the strength of intellectual property rights and innovation, and even why, under plausible circumstances, in the long run, "tighter" IPR regimes may be associated with a reduced level of innovation. An understanding of the underlying mechanisms by which such seemingly perverse results may arise provides some guidance into how one might construct innovation systems (which include, as a component, an IPR regime), which do lead to higher levels of innovation.

Beyond this introduction, this paper is divided into four sections. We begin by examining an analogous problem, fishing from a renewable common resource pool, showing that changes in the legal or institutional environment which lead to more investment *at any given size of fishing stocks* can lead to steady states with a lower flow of fish catches. A distinctive aspect of the "commons" problem is that in the long run, the general equilibrium effect of a policy change can be of opposite sign to the short-run,

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[6] We should emphasize the importance of the word "design": There are many details to the IPR system, such as the breadth of the patent, which affect the extent to which knowledge is added to or "subtracted" from the pool. Knowledge that is not available for others to use is, in effect, "subtracted" from the pool. Broad patents "subtract" more from the available knowledge pool than more narrowly defined patents. Matters are, of course, far more complicated than this simple arithmetic analogy would suggest: knowledge that can be used, but at a price, is in a sense "partially" available; and even knowledge that cannot be used directly can trigger research. By the same token, some, perhaps much, of the investment in R & D in a poorly designed IPR regime is devoted to inventing around a patent or to increasing the rents that can be extracted out of a patent (e.g. by evergreening); in such circumstances, even if tighter IPR leads to more investment in R & D, it may not lead to faster real innovations, i.e. an increased pace of increases in standards of living.

partial equilibrium effect (in contrast to many other areas in economics, where, in a stable equilibrium, general equilibrium effects alter the magnitude but not the sign of the partial equilibrium effects).

The following section shows that analogous results hold in the context of a knowledge pool. Stronger intellectual property rights may lead to a lower level of innovation. The third section shows that entry (an increase in the number of firms) can lead to lower innovation, and, analogous to the fishing model, the marginal entrant in a world with free entry is likely to have a negative marginal effect on innovation. The final, concluding section argues that there are reforms in the design of intellectual property regimes which may result in a higher flow of innovations.

I. The common resources problem

The problem of a large number of private firms drawing upon a common resource has been well studied in the environmental economics literature (For an early treatment, see Dasgupta and Heal (1974)). In reduced form, there is, say, a population of fish, P, which reproduces at the rate H(P) which depends on the size of the population, as depicted in figure 1. Below P_{min}, the population is not self-regenerating, i.e. dP/dt < 0 and the species becomes extinct. In the absence of fishing, the population reaches a self-sustaining asymptote of $\overline{P}$.[7] There is a maximum reproduction rate, $\dot{P}_{\max}$, achieved at $\hat{P}$.

A fishing fleet consists of n symmetric firms, each of which invests *i*, a function of P and n, with the amount of fish caught being Q(i(P,n),n,P)= $\mathcal{Q}$ (P,n), which we refer to as the fishing function.

It is easy to derive Q(i(P,n),n). Each firm takes the level of investment of the n- 1 others as given and ignores the effects of its fishing on the size of the fishing stock P[8], as it maximizes its profits

(1) $\underset{\{i\}}{\text{Max}}\ pQ_j\,[i, i^{-j}, P] - c(i)$

where p is the price of fish, c(i) is the cost of an investment of i, and $Q_j\,[i, i^{-j}, P]$ is the level of fish caught by the *j*th firm when the other n-1 firms invest i^{-j}.[9] The symmetric Nash equilibrium gives rise to the investment function described earlier, i(P,n), and that in turn gives rise to the fishing function, $\mathcal{Q}$ (P,n), depicted in figure 2 for a fixed n.

The long equilibrium size of the stock of fish is given by the solution(s) to

(2) $dP/dt = H(P) - \mathcal{Q}(P,n) = 0$,

that is, the values of P for which

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[7] P_{min} is defined by the lowest value of P for which H(P) = 0.

[8] This would obviously not be the case if the number of firms is very small (say n=1 or 2). In this simple formulation, the price of fish, p, is given exogenously.

[9] It is easy to generalize (1) to include situations where there is imperfect competition among the firms (i.e. we generalize pQ to a more general revenue function R). The model is consistent with alternative interpretations of how additional investments in fishing fleets affect the marginal catch. For our purposes, these details are irrelevant.

(3) $H(P) = \mathcal{Z}(P,n)$.

This can be seen diagramatically by superimposing Figures (1) and (2). We see in figure 3 that, for fixed n, there are three equilibria (i.e. three solutions to equation (3)): $P = 0$; $P = P_1$, $P= P_2$, with the first and third stable. The equilibrium fish-catch is given by $H(P^*)$.

Assume now that there is a change in the economic (legal or institutional) environment that leads firms, at any level of P, to invest more. The business community would celebrate the improved business environment, and the increased income derived from fishing. But soon, the fishing stocks would start to deplete, and the new stable equilibrium would shift from P_2 to $P_2' < P_2$, so that the flow of fish would actually be lower in the new equilibrium than in the old (see figure 4). This would be true whether or not investment is lower in the new equilibrium. That is, in the obvious notation, letting θ and θ' represent the two states of nature (the two different "business environments"), $i(P_2, n, \theta)$ may be > or < than $i(P_2', n, \theta')$.

There is an exception. It is possible that with an excessively large fishing population, crowding actually interferes with reproduction, i.e. as we noted earlier, $H' < 0$ for $P > \hat{P}$. If $P_2 > \hat{P}$, then the upward shift in the fishing curve leads to a lower level of P, but a higher sustainable flow of fish. (Figure 5)

Similar results hold for the effect of new entry. New entry leads to more competition and more fishing—normally thought of as positive for welfare. But here, if the initial equilibrium entails $P_2 < \hat{P}$, the upward shift in the $\mathcal{Z}$ curve leads to a lower level of equilibrium fish caught (and lower profits). While normally, we would expect that each individual enterprise will reduce its level of investment ($i(P,n') < i(P, n)$ for $n' > n$), we might have hoped that the effect of more firms outweighed the diminution of investment of each firm. But it is well known that there can be overfishing. Increased entry may reduce the size of the catch whether or not aggregate investment has increased or decreased (i.e. whether or not $n'i(P,n')$ < or > $ni(P,n)$ or indeed, whether or not $n'i(P_2',n')$ < or > $ni(P_2, n)$). (Figure 6)

On the other hand, if the equilibrium initially entails excessively large fish stocks—in the sense that the equilibrium value of P is greater than $\hat{P}$, then the new equilibrium that emerges entails a higher annual catch.

It is well known that in the case of common pools, the entry decision will not be efficient: firms enter so long as profits are positive, not taking into account the (adverse) effects that their entry has on the size of the catch of other firms. This has led to the presumption that there is excessive entry. But the entrants also fail to take into account the effect that their entry has on the size of the fishing stock, both directly (which is negative), and indirectly (because their entry discourages investment on the part of other firms.) It is clear that if, at the free entry equilibrium, $P < (>)\hat{P}$, the flow of fish would be increased if entry were taxed (subsidized).[10]

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[10] The full welfare calculation is more complicated, because of the effects of externalities, even if markets are competitive. Ignoring the effect on P and the cross firm externality associated with the increase in fishing costs for

It may be possible, however, to change the regulatory environment in ways which allow a higher sustained catch, and possibly with a lower level of expenditure on fishing. Let us denote the set of fishing regulations by ζ. There are some regulations which allow fish to be caught without as large an adverse effect on the growth of the fishing stock, e.g. regulations that ensure that small fish are not caught. We now write

(4) $dP/dt = H(P) - \mathcal{Z}(P,n,\zeta)M(\zeta)$

with $M' < 0$. In other words, tighter regulations mean that the adverse effect of a given level of fishing is reduced, but $\mathcal{Z}_3 < 0$, tighter regulations increase costs, and hence, at fixed P and n, lead to less fishing and a smaller catch. It follows that with tighter regulation, the equilibrium level of P, denoted P_2'', is increased. But that means that the flow of fish, H, has increased: tighter fishing regulations (in the sense defined) leads to an increased flow of fish, and this is true whether there is more or less investment in the fishing fleet. (That is, other things being equal, the increase in P results in a larger fishing fleet; but the increase in regulations leads to reduced investments, so the net effect is ambiguous.)(Figure 7)

What is striking about these results, as we have noted, is that they reverse normal presumptions. Usually, general equilibrium responses diminish the magnitude of partial equilibrium responses, but do not reverse the sign. Here (and in the analysis of the knowledge pool below) they do.

In the next section, we show that the same logic holds for innovation. Changes in the environment which lead to more investment *given a level of P,* the size of the “knowledge pool,” may so diminish the equilibrium pool of knowledge (the set of technological opportunities) that the flow of innovations is reduced. This is true whether or not at the new equilibrium level of P, there is more or less investment in R & D.

II. Knowledge Pools

In this section, we denote the set of technological opportunities, the knowledge pool, which can be drawn upon by innovators, by P. Each innovation both adds to the knowledge pool, and, especially in the presence of strong IPR, subtracts from P, the set of ideas that can be drawn upon for subsequent innovations. (In the absence of IPR, in a technological sense, an innovation would not reduce the pool of technological opportunities. In another sense—in terms of the set of *profitable* opportunities that are available, given the technological opportunities—it does, given the first-mover and other advantages discussed elsewhere in the literature.[11] The analysis below is unaffected by which interpretation we give to the diminution in P.)

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each firm, the marginal value of resources used by each firm are then equal to the marginal costs, and the value of the benefits of the marginal firm equals its marginal costs. The fact that the cross-firm externality effect (at fixed P) is negative implies that if the pool effect is small (P is only slightly greater than $\hat{P}$) it is still desirable to tax entry.

[11] Matters are, of course, more complicated than this discussion might suggest: In the long term, the innovation may be "enabling," even if it takes away economic opportunities in the short term, because it provides the

At the same time, government and university-funded basic research adds to the pool of knowledge that can be drawn upon. We denote the level of public investment in basic research by K. We assume that the additions to knowledge, H, that flow from K depend upon the pool of knowledge that is in the public domain, P, i.e. we assume that H(K,P), with

$H_K > 0$, $H_P > 0$,

An increase in investment in basic R & D leads to an increase in the flow of contributions to the knowledge pool, and the larger the knowledge pool, the larger the flow of contributions resulting from any level of investment in basic research.[12] (Figure 8 depicts H(K,P) as a function of P. It looks much as Figure 1, except we assume that the larger the pool of knowledge, the greater the increment in knowledge from any investment K. Figure 8 is drawn under the assumption that H approaches a constant. That is, at any moment of time there is an upper bound to the pace of knowledge creation resulting from any given level of investment in basic research, K.[13] We also assume that there is a non-convexity in the production process—at least for small P, the marginal return to an increase in P is increasing.[14])

Thus, we can write

5) $dP/dt = H - [\alpha(\xi) - \beta(\xi)]I(i, P; n)$

where I is the level of innovation[15], $\alpha(\xi)I$ is the diminution in the available set of technological opportunities as a result of an innovation level of I, when the "tightness" of the IPR regime is ξ, $\beta(\xi)I$ is the addition to the available set of technological opportunities as a result of an innovation level of I, when the "tightness" of the IPR regime is ξ, and where I(i, P; n) is the level of innovation, an increasing function of i, the level of investment in R & D (learning) of each of the fixed n firms (we focus on symmetric equilibria in which all firms engage in the same level of R & D), and P, the size of the technological pool:

(6a) $I_i > 0$, $I_P > 0$.

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knowledge base on which further innovations can eventually be built. See for example the various contributions to the Winter 2013 symposium on patents in the *Journal of Economic Perspectives.*

[12] Notice that this formulation explicitly rejects the view that there is a fixed stock of knowledge to be discovered. If that were the case, then it is possible that a large value of "discovered" knowledge would diminish the set of knowledge to be discovered, and it is possible that $H_P < 0$, or even more, that $H_{PK} < 0$, i.e. the marginal return to research investments diminish as the size of the knowledge pool increases.

[13] All that the analysis below requires is that d H/dP not increase too much, for then there may not be a stable equilibrium pool of knowledge. If there were a fixed stock of ideas to be discovered, a larger P might mean that there were fewer ideas to be discovered, so that dH/dP could be negative beyond some point, resulting in a figure looking more like that depicted earlier for fishing stocks.

[14] This is consistent with general results showing a fundamental non-convexity in the value of information. See Radner and Stiglitz (1982).

[15] We can think of I as the pace of, say, labor augmenting technological change. For purposes of this paper, however, we do not have to specific about how we parameterize the level of innovation.

A tighter ("stronger") IPR regime means that, for others, access to the knowledge created by an innovation for others is smaller, and that every innovation represents more of an enclosure of the knowledge commons[16], so that

(6b) $\alpha'(\xi) > 0, \beta'(\xi) < 0$.

For simplicity, we define $\gamma(\xi) = \alpha(\xi) - \beta(\xi)$, with $\gamma' > 0$.

The steady state: knowledge inflows and outflows

In steady state, $dP/dt = 0$, or

(7) $H(K,P) = \gamma(\xi)I(i, P; n)$

We can solve (7) for P as a function of K and i[17], for any given ξ and n:

(8) $P = \phi(i, K; \xi, n)$,

with[18]

(9a) $\partial P/\partial i = - \gamma I_i / (\gamma I_P - H_p)$

(9b) $\partial P/\partial t = -\gamma' I / (\gamma I_P - H_p)$

ϕ is the *steady-state locus,* giving the equilibrium level of P as a function of the level of investment in innovation of the representative firm, i, for a fixed level of {K, ξ, n}. P, as we have discussed, is the pool of technological opportunities available for commercial exploitation, which is why we expect that the flow of innovations to be more sensitive to P than is the contribution of publicly funded basic research, In other words, we assume

Assumption A: $\gamma I_P > H_p$.

In that case, it follows that (using (6a) and (6b))

(10a) $\partial P/\partial i < 0$

(10b) $\partial P/\partial \xi < 0$.

Thus, we have established

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[16] See, e.g. Boyle [2003].

[17] Throughout this section, we hold n constant.

[18] Implicitly differentiating (3) .

Lemma 1. Under Assumption A, an increase in the strength of the IPR regime leads (in steady state, with a fixed level of investment in R & D, public and private) to a smaller pool of technological opportunities; and an increase in the steady-state level of investment leads to a smaller steady-state pool of technological opportunities.

Profit-maximizing R & D investments

To determine the level of investment in R&D in the representative industry, we assume that there is a single firm in each industry[19] (so that we do not have to worry about interactions among the firms except through the knowledge pool P[20]). Each firm maximizes profit by choosing the level of investment in R&D, i, taking the set of technological opportunities as given. Let $R(I(i,P), \xi)$ be the flow of revenues for the representative firm associated with an innovation level of I, under an IPR regime of tightness ξ; then the flow of profits is

$$R(I(i,P), \xi) - i,$$

Profit is maximized at[21]

$$(11) \quad R_I I_i(i,P) = 1.$$

(11) can be solved for i as a function of P and ξ:

$$(12) \quad i = \Psi(P, \xi)$$

with

$$(13) \quad \partial i/\partial P = -[R_{II} I_p I_i(i,P) + R_I I_{iP}(i,P)]/D.$$

where

$$D \equiv R_{II} (I_i(i,P))^2 + R_I I_{ii}(i,P)$$

D is unambiguously negative, by the second-order condition. The sign of the numerator is ambiguous: a larger pool increases the marginal return to investment, and normally, we would expect this effect to dominate, so that a larger P leads to more investment. But it is possible that there is sufficiently large decreasing profitability to an increased flow of innovations (i.e. R_{II} is sufficiently negative) , that the normal presumption is reversed. We will refer to the case where $\partial i/\partial P > 0$ as the *normal* case.

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[19] In the next section, we shall show how these results can easily be generalized.

[20] We are explicitly assuming that knowledge is *not* industry specific.

[21] This formulation allows us to avoid the more complicated intertemporal maximization problem that would arise if each firm's current innovation level depended not only on the current pool of publicly available knowledge, but on a pool of privately available knowledge. Qualitative results for this more general problem would, however, be similar to those described here.

This will be true if

$$(14)\ d\ln I_P/d\ln i > -\,d\ln R_I/d\ln i,$$

which will be true if there is not rapidly diminishing marginal profitability to innovations.

Similarly,

$$\partial i/\partial t = -R_{I\xi} I_i / D > 0,$$

so long as

Assumption B: $R_{I\xi} > 0$,

In other words, stronger intellectual property rights increases the *marginal* return to an innovation. Thus, this model grants to the advocates of stronger IPR the notion that, *given the set of technological opportunities*, stronger intellectual property rights does lead to more investment. But to assess the overall effect, both on investment in R & D and innovation, we have to take into account the endogeneity of P.

Solving for the steady state

We can solve for the equilibrium (steady-state) value of the knowledge pool by solving simultaneously (8) and (12), the steady-state equation (SS), giving P as a function of I, and the profit-maximizing equation (PM), giving the equilibrium value of i as a function of P. The steady-state values of i and P, $\{i^*, P^*\}$ thus solve, for given $\{n, \xi, K\}$

$$P^* = \phi\,(i^*, K; \xi, n)$$
$$i^* = \Psi\,(P^*, \xi).$$

Because under assumption A, the SS curve is downward sloping, and in the "normal" case, the PM curve is upward sloping, there is a unique steady state. (See Figure 9a) (But in the more general case, though, the PM curve can have an upward-sloping segment, in which case it is possible that multiple steady-state equilibria exist. See figure 9B. In the ensuing discussion, we will ignore this possibility.)

Once we have solved for the equilibrium value of P, P*, the steady-state flow of innovations can easily be solved for, using (7):

$$(15)\ I^* = H(K, P^*)/\,\gamma(\xi).$$

The effect of tighter IPR

Earlier calculations established that a tightening of IPR shifts the steady-state curve down (i.e. under assumption A, for a fixed value of i, the equilibrium P will be smaller—equation 10b), and that a tighter intellectual property regime shifts the profit-maximizing locus to the right. In other words, *normally* a tightening of intellectual property rights leads to more investment in R & D, at a fixed opportunity set. It follows that that the steady state level of the knowledge pool will be smaller. P* is diminished as a result of a tighter intellectual property regime.

Under our assumptions that $H_P > 0$ and $\gamma'(\xi) > 0$, it follows directly from (15) that[22]

Proposition 1. In the normal case, and under assumptions A and B, tighter intellectual property rights leads to less innovation.

There is an alternative formulation where the analysis is more parallel to that of Section I. By substituting (12) into (7) we obtain

$$(16)\ H(K,P) = \gamma(\xi)I(\Psi (P, \xi), P).$$

We can now calculate the total derivative with respect to t of the size of the innovation pool:

$$(17)\ dP /d\xi = \gamma'(\xi)I + \gamma(\xi)I_i\Psi_t /[H_P (K,P) - \gamma(\xi)(I_i\Psi_P + I_P)].$$

Under assumption A, $\gamma I_P > H_p$. In the normal case, $\Psi_P > 0$. The result that

$$(18)\ d^*P/d\xi < 0$$

follows directly: stronger intellectual property rights diminishes the size of the opportunities pool. But it is then easy to show that the flow of innovation is diminished.

Notice that this result holds whether i increases in equilibrium or diminishes. Earlier, we showed that *given the set of technological opportunities,* i increases with the strength of IPR. But we also showed that i diminishes with P, and we have now shown that P diminishes with the strength of IPR. Thus, the net effect of the strength of IPR on investment in R&D remains ambiguous:

$$(19)\ di/d\xi = \Psi_t (P,\xi t) + \Psi_P (P,\xi)\, dP/d\xi$$

the sign of which is that of

$$- R_{I\xi} I_i [H_P (K,P) - \gamma(\xi)(I_i\Psi_P + I_P)] - [R_{II}\, I_p\, I_i(i,P) + R_I\, I_{iP}(i,P)][\gamma'(\xi)I+ \gamma(\xi)I_i\, \phi\Psi_\xi].$$

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[22] $d\ln I/d\xi = (d\ln H/dP)dP/d\xi - d\ln \gamma(\xi)/d\xi < 0$.

If investment in R & D is very sensitive to technological capabilities, especially relative to the sensitivity to IPR, then investment in R & D is likely to be decreased. For instance, if $R_{It} \approx 0$, then

$$di/d\xi \approx (\partial i/\partial P)_{|PM} \quad \gamma'(\xi)I / [H_P(K,P) - \gamma(\xi)](I_i\Psi_P + I_P) < 0,$$

(where $(\partial i/\partial P)_{|PM}$ is the change in investment from an increase in P along the profit-maximizing curve), under our assumption that the contribution of public investments to the knowledge pool is not too sensitive to the size of the pool itself and our "normal" case that an increase in technological opportunities leads to an increase in the profit-maximizing level of investment in R & D.[23]

Diagrammatic exposition

We can reframe the above analysis using the diagrammatic techniques used in the first section to analyze equilibrium fishing and fishing stocks. H(K,P) is the flow of knowledge into the knowledge pool, $\gamma(\xi)I(\Psi(P, \xi), P)$ is the flow out. In equilibrium, the two are equal, as depicted in figure 10A. A tighter intellectual property regime represents an increase in the net outflow out of the pool at any given P, and thus results in a lower level of P and a lower flow of innovations. (Figure 10, Panel B).

III. The effect of entry on innovation

We can extend the model slightly to ask what happens if the number of firms, n, increases. The model is exactly the same, except now we assume the revenue flows to the jth firm in the representative industry from a given level of innovation for that firm, I^j, are diminishing in n: $R^j(I^j, n)$ with $R^j_n < 0$. The level of innovation for each firm I^j is a function of the number of other firms, their level of investment in R &D, and the opportunity set P: $I^j = I^j(i^j, - i^{-j}, n, P)$. We assume for simplicity that all firms are identical. The Nash equilibrium investment in R & D is found by:

$$\underset{\{i^j\}}{\text{Max}}\; R^j(i^j, \xi, n, P, i^{-j}) - i^j,$$

This generates the reaction function

$$i^j = z(i^{-j}, n, \xi, P),^{24}$$

which leads to the symmetric equilibrium where $i^j = i^{-j}$ (in the natural notation)

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[23] These results can be seen directly in Figure 9a, where while the effects on P* are unambiguously negative, that on i* are indeterminate.

[24] Notice that this formulation is consistent with there being many firms in each industry. The profits of any firm are a function of its own innovations and those of others in the industry.

(20) $i^j = Z(P, \xi, n)$.

Normally, we expect that an increase in the opportunity set, given the legal and economic environment and the number of firms, will increase the marginal return to investments in innovation, and hence

(20a) $Z_P > 0$.

On the other hand, more competition means that there is, say, a smaller probability of winning the patent race. Average and marginal returns to investment in R & D will be lowered, and so investment (by each firm) may be lowered (though aggregate investment, ni^j may be increased.) Hence, we assume

(20b) $Z_n < 0$.

The aggregate flow of innovations I is a function of Z, the level of investment of the representative firm, and n, the number of firms:

(21) $I = I(Z(P, \xi, n), P, n)$.

The steady state is now described by

(22) $H(K,P) = \gamma(\xi)I(Z(P, \xi, n), P, n)$.

We can solve (22) for P as a function of t, n and K:

(23) $P = \Omega(\xi, n, K)$

and as before, aggregate innovation is simply H/γ, so we can solve for the pace of innovation as a function of t, n, and K:

(24) $I = H(\Omega,K)/\gamma(\xi) = \Lambda(\xi,n,K)$

From (22)

(25) $dP/dn = \gamma(\partial I/\partial n)_{|P} / [H_P(K,P) - \gamma(\xi)(I_i Z_P + I_P)]$

which implies that, in the normal case

$\text{sign } dP/dn = - \text{sign } (\partial I/\partial n)_{|P}$

and if that is so, it implies (since $I = H/\gamma$) that

$\text{sign } dI/dn = - \text{sign } (\partial I/\partial n)_{|P}$

More precisely,

(26) $dI/dn = H_P\,(\partial I/\partial n)_{|P}\,/[\,H_P\,(K,P) - \gamma(\xi)(I_i Z_P + I_P)]$

The results are parallel to those of the previous section, where we showed that improved intellectual property rights led to more research, at any given size of knowledge pool, but this so drained the knowledge pool (the set of opportunities), that the full effect was to lower the equilibrium pace of innovation. The full effect of more competition is just the opposite of the "partial effect": more firms may lead, at any P, to more innovation, but this so drains the pool of opportunities that the steady-state flow of innovation is actually reduced. (Figure 11)

We now take a more careful look at (26), and in particular, at the numerator. Normally, we expect that *at any size of technological pool*, more researchers will lead to more innovation:

(26) $\partial I/\partial n|_P = I_i\, Z_n + I_n > 0.$

More researchers, taking the level of investment of each researcher as given, are likely to lead to more innovation (at a fixed P), i.e. $I_n > 0$; and more investment, by each researcher, will lead to more innovation, i.e. $I_i > 0$. But more competition (larger n) is likely to discourage each firm from investing in R & D[25] ($Z_n < 0$).

In our earlier discussion of (26), where we had assumed that more firms lead to more innovation, we had implicitly assumed

$$I_{n/}\, I_i > -\, Z_n$$

But that may not be so, and if $- Z_n > I_{n/}\, I_i$, then an increase in n leads to a smaller level of overall innovation, given P, but a larger level of *equilibrium* innovation, once we take into account the effect on the opportunity set.[26]

The literature has emphasized that (essentially at a fixed P) the effects of the number of firms on innovation are ambiguous, partly because the benefits of having more researchers may be small,

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[25] By analogy, in section I, more fishing firms *given a stock of fish,* will discourage investment by each of the fishing firms, as the marginal return to investment (at a given level of i and P) is reduced. In the context of innovation, see Aghion and Howitt, 1993, 1998, Greenwald and Stiglitz, 2014, and Stiglitz, 2013a, 2013b.

[26] But the analysis shows equally that if more competition should lead to lower innovation *at a fixed P,* then it will lead to more innovation in equilibrium. And that may well be the case. It is possible that more competition (large n) so lowers the marginal return to investments in R&D at any given level of research of others (and P), that investment by each firm is so diminished, that the depletion of the knowledge pool is actually reduced as competition increases. See Greenwald and Stiglitz (2014) for a more extensive discussion of the issues.

beyond a small n (and especially so if research strategies are correlated), and the adverse effects on the investment of each may be large, because of a decrease in the marginal returns to investment (and especially so if the investment of each firm is highly sensitive to slight changes in marginal returns).[27]

By the same token, there may be significant externalities associated with the decision to enter: lower profitability associated with other firms contemporaneously engaged in research, a lower profitability associated with future firms engaged in research, because of the net drawdown in P, *but* a higher profitability associated with future firms engaged in research, because of the effects on other firms' R & D. In a sense, this is a classic problem of the second best. It should not come as a surprise that in such situations, the net welfare effects are ambiguous.

Our analysis has noted that these partial equilibrium results (given P) may be reversed, once account is taken of the long-run effects on P.[28] More generally, the effect of an increase in n on innovation here is different from that in much of the conventional literature, which has emphasized the role that competition has in spurring innovation. Here, we have observed that even if that is the case, so that at a fixed opportunity set an increase in n increases innovation, under not implausible conditions related to the intellectual property regime, the long-run general equilibrium effects may be the opposite of the short-run partial equilibrium effects.

IV. Concluding Remarks: Pro-innovation intellectual property regimes

There are reforms in the IPR regime that might lead to a greater pool of knowledge upon which innovators could draw and yet still incentivize research.[29] Provisions of the patent system that make it easier to “enclose the knowledge commons,” i.e. take out from the pool more than one contributes are

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[27] There is a huge literature on the subject, some of which suggests an inverted U shaped relationship (see Aghion, Bloom, Blundell, Griffith and Howitt(2005)), some of which suggests that innovation may decline monotonically with n. The empirical literature is bedeviled with the problems noted in earlier footnotes, and even the theoretical literature does not always separate clearly the effects of entry *given* a particular opportunity set, vs. the effects with an endogenous opportunity set. The literature in which prior innovation affects returns to current investments in R & D typically emphasizes the benefits that arise from the increase in the “baseline” knowledge, from which current research efforts depart, rather than the negative effects of the draw down in the knowledge pool that has been the focus of this paper. See, e.g. Romer(1990), Aghion, P. and P. Howitt (1993, 1998), Aghion, Akcigit, and Howitt, (2013), Greenwald and Stiglitz, 2014, and Stiglitz, 2013a, 2013b.

28 Thus, an increase in n, especially beyond a certain critical level, may lead to lower I, keeping P fixed, and thus to a higher level of innovation taking into account the effect of entry on the size of the opportunity set (P).

[29] There is, by now, a large literature discussing these and other similar reforms to the intellectual property regime. For a brief review, see Greenwald and Stiglitz (2014), chapter 15. Boldrin and Levine (2013) present a set of eight policy proposals including: shorter patent durations, reducing the set of what can be patented, strengthening antitrust policies, reversing the “idea mercantilism” of the TRIPS agreement, adjusting patent protections according to sector, an “economic test” for patent protection, reversing patent protection for results derived from federally sponsored research, and the adjustment of non-patent-related policies disincentivizing innovation in sectors such as pharmaceuticals (Boldrin and Levine, 2013, p.19) .

particularly harmful; disclosure requirements, rigorously enforced, can increase innovators contributions to the knowledge pool, with only limited effects on incentives.

So too, an intellectual property regime that provides less scope for holdups, less scope for impediments imposed by patent thickets, etc. may lead to a higher equilibrium knowledge pool.

The "liability system,"[30] in which anyone can use an idea, upon the payment of an appropriately designed fee, leaves more knowledge in the pool to be used by others, but, of course, the price is a two-edged sword: the higher the price the greater the incentives for innovation (at a fixed P), but the lower the price, the larger the *effective* P. In an appropriately parameterized model, one could analyze the optimal price. The patent system can be thought of as associating an infinite price[31]; the absence of a patent system a zero price. In analyzing the optimal price, it should be observed that even at a zero price, firms have an incentive to innovate, because knowledge does not diffuse costlessly and instantaneously to others. In many sectors, in fact, there is little recourse to the patent system. Thus, it is possible that in some sectors, the optimal price is zero (i.e. all knowledge should be freely available). The analysis of this paper, highlighting the adverse effect of patents on innovation, suggests that in general, we should expect a price lower than the (admittedly temporary) "infinite" price associated with the current system.

The effect of such changes can be shown diagrammatically in figure 12 as a downward shift in the net pace of knowledge extraction (more contributions to the knowledge pool, less "enclosure" of the knowledge commons) at any level of P. The result is a higher steady state level of knowledge production and a larger equilibrium knowledge pool. The new knowledge extraction locus is shown as a dotted curve, with $\gamma = \gamma_{1.}$

The central message of this paper is simple: We began by noting that some observers of innovation have claimed that a more important determinant of the levels of investment in R & D and the pace of innovation than the intellectual property regime is the "opportunity set," the knowledge pool from which applied researchers can draw. Knowledge, it is has long been recognized, is a public good—a common resource from which all can draw (see, e.g., Stiglitz 1987).[32] Intellectual property provides a way of appropriating the returns to investments in knowledge, but in doing so, effectively privatizes a public good. But every innovation draws upon prior knowledge, and the boundaries of "new" knowledge are inherently imprecise. Patents inevitably enclose what would otherwise have been in the public domain. In doing so, not only do they impede the efficient use of knowledge, but because knowledge itself is the most important input into the production of further knowledge (innovations), they may even impede the flow of innovations.

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[30] As advocated, for instance, by Lewis and Reichman (2005).

[31] This is not quite correct, since while the holder of the patent has the right and ability to set the price arbitrarily high—and in some cases (such as in the Myriad patent cited earlier, where Myriad clung to its "right" to prevent others from building on their patent, even by developing better and cheaper tests) firms do so, in other cases, they provide a license at a fee.

[32] See, for instance, Stiglitz (1987, 1999).

We have provided a simple way of modeling additions to and subtractions from the technological opportunity set from which innovators can draw. We have shown that tighter intellectual property regimes, by reducing the newly available set of ideas from which others can draw and by increasing the extent of the enclosure of the knowledge commons, may lead to lower levels of innovation, and even lower levels of investment in innovation, as a result of the diminution in the size of the knowledge pool. Advocates of stronger intellectual property rights, while noting the positive partial equilibrium effects, have ignored the even more important general equilibrium effects. The real lesson is that considerable care is needed in designing intellectual property regimes, with particular focus on the extent to which any particular regime increases or diminishes the technological opportunities upon which others can draw.

Figures

Figure 1. The rate of increase in fishing stocks as a function of fishing population (P). Below a critical threshold level, the population is not viable. In the absence of fishing, there is a maximum sustainable population.

Figure 2. Equiibrium fish extraction as a function of fishing population (Symmetric Nash equilibrium of n profit maximizing firms.)

Figure 3. Equilibrium fishing stocks. Superimposing Figures 1 and 2, we can ascertain values of P such that the rate of fish extraction equals the rate of reproduction. In the figure, there are three equilibria, two of which are stable—0 and P_2.

Figure 4. Effect of improved investment environment. At each P, there is more fish extraction, so the equilibrium P (and the equilibrium rate of fishing) is lowered.

Figure 5. An exception. If, beyond a critical level of P, increased P leads to lower rates of growth of the fishing population, an improved investment environment may lead to a lower P but higher levels of "catches."

Figure 6. Increased competition has similar effects to an improved investment environment—leading to a lower equilibrium P and levels of fish extraction (if $P^* = P_2$ is less than $\hat{P}$).

Figure 7. Better regulation can lead to a larger equilibrium fishing stock, and a higher level of fishing catches (if $P^* = P_2$ is less than $\hat{P}$).

Figure 8. Increase in knowledge pool from basic research. As depicted here, as P increases, with fixed K (investments in basic research), H approaches a constant.

Figure 9. Equilibrium knowledge pool. Equilibrium is given by the intersection of the steady state locus (SS) and the profit maximizing locus (PM).

Panel A Normally, there is a unique equilibrium. Tighter IPR leads to more investment at any level of P (a shift to the right in the PM curve) and a lower steady state P at any given level of P (a shift down in the SS curve). Thus P* shifts down.

Panel B. The PM locus may, however, not be upward sloping, in which case there can exist multiple steady state equilibria.

Panel 10. In equilibrium, the flow of knowledge (available to others) into the knowledge pool, H, equals the flow out. There may be multiple equilibria, but in the figure there is a unique steady state, P_2 (besides the no-innovation equilibrium $P= 0$). Panel B. Tighter intellectual property rights shift the level of knowledge exploitation up (at each P), resulting in a lower level of the equilibrium knowledge pool and a small flow of innovations.

Figure 11. An increase in the number of researchers has an analogous effect in reducing the equilibrium size of the knowledge pool and the equilibrium flow of innovations

Figure 12. A better-designed intellectual property regime can lead to a larger knowledge pool and a higher rate of innovation.

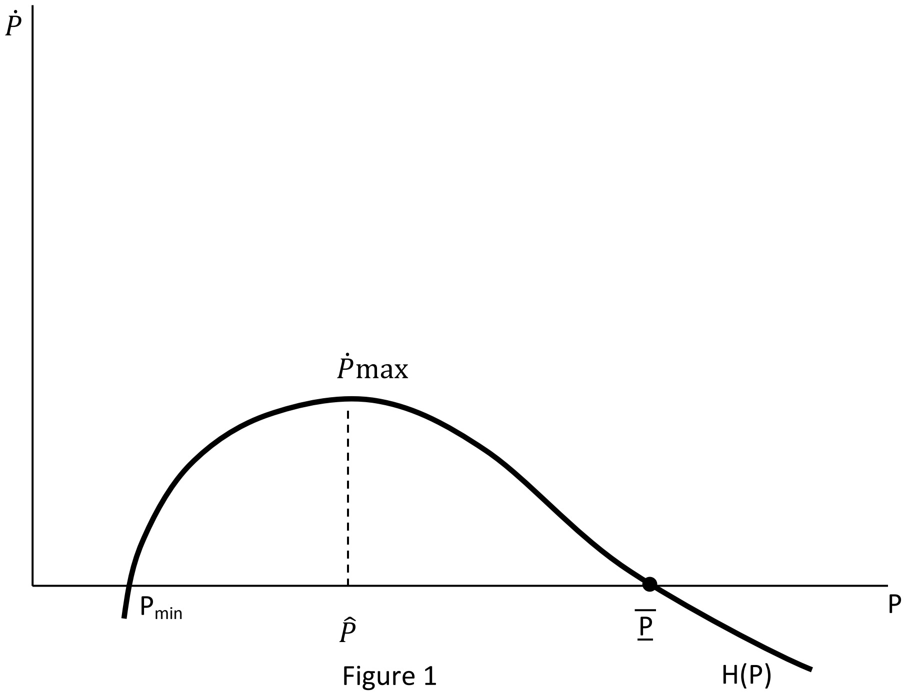

Figure 1

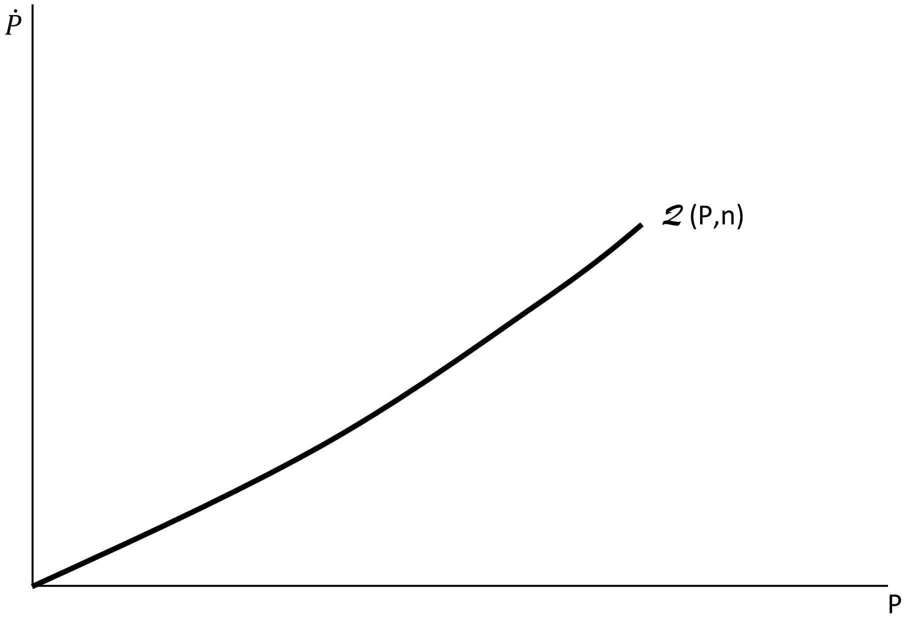

Figure 2

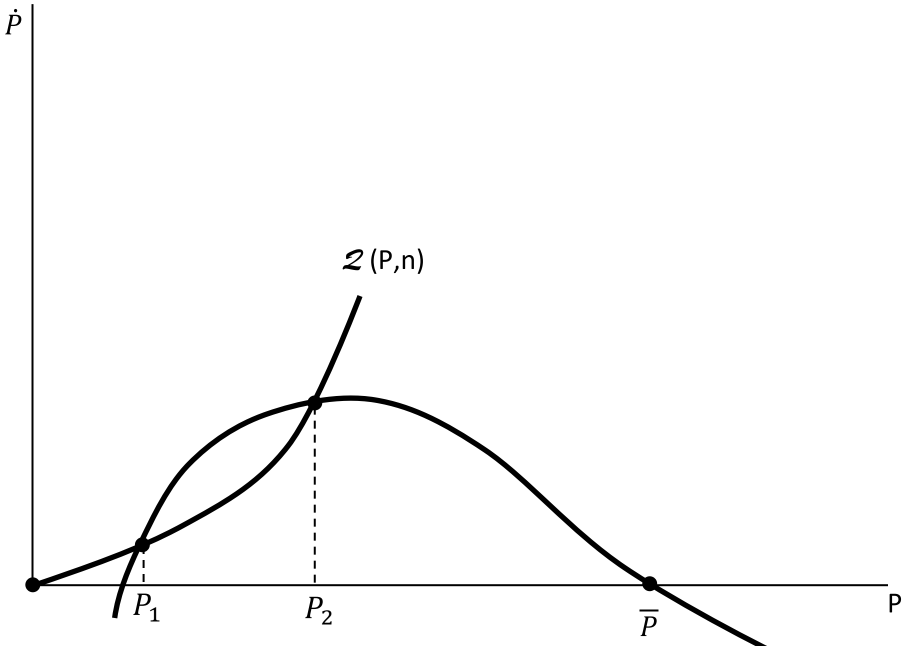

Figure 3

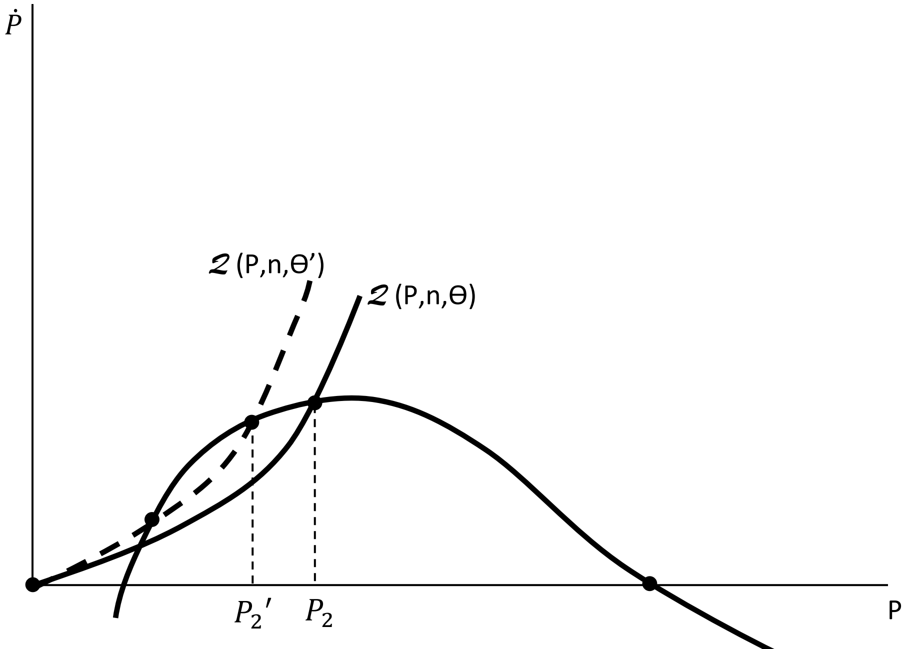

Figure 4

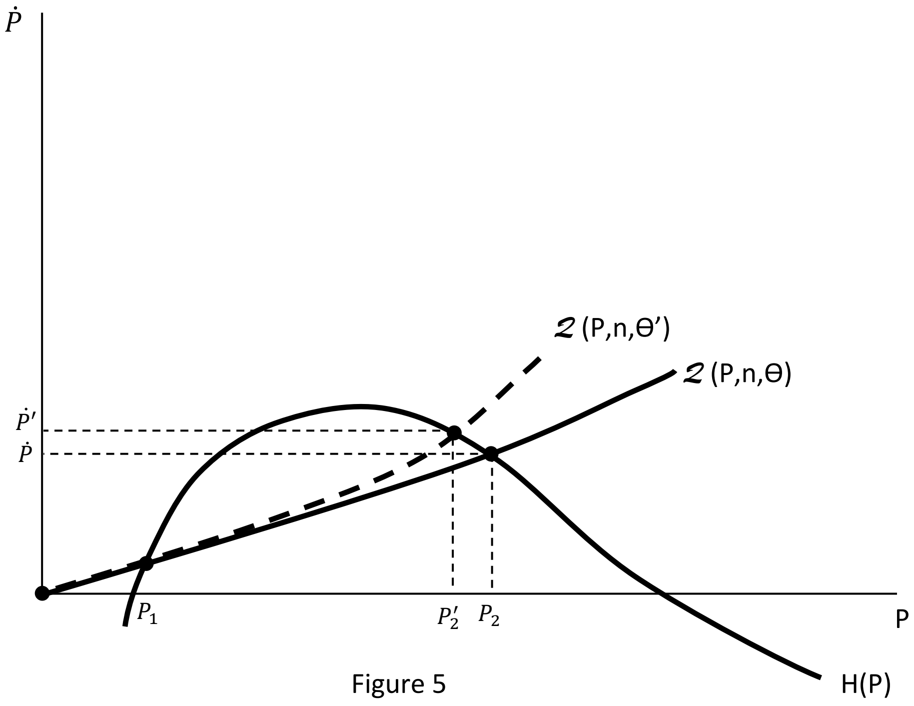

Figure 5

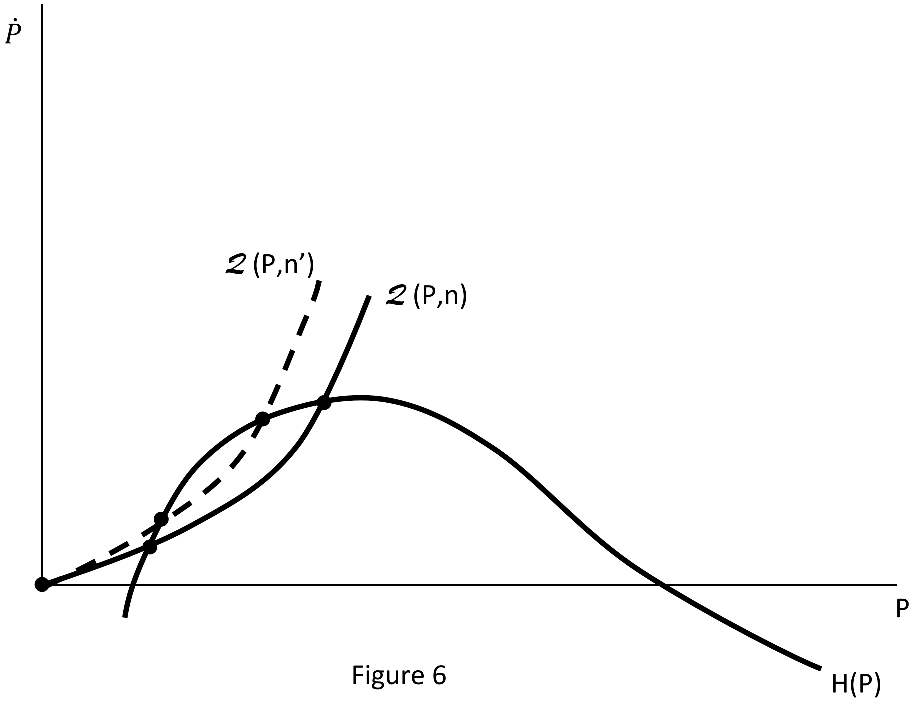

Figure 6

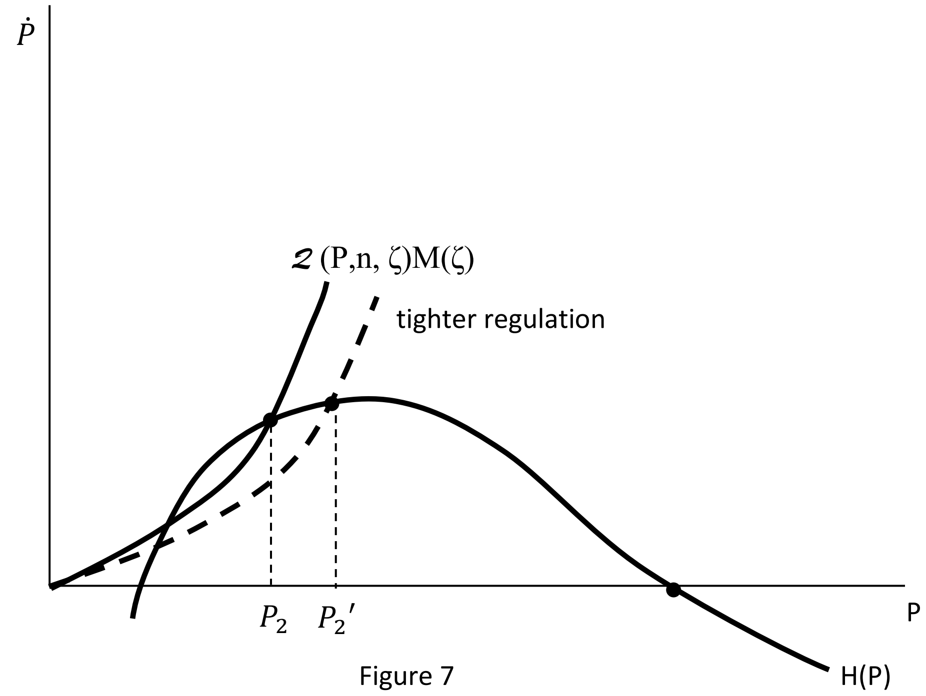

Figure 7

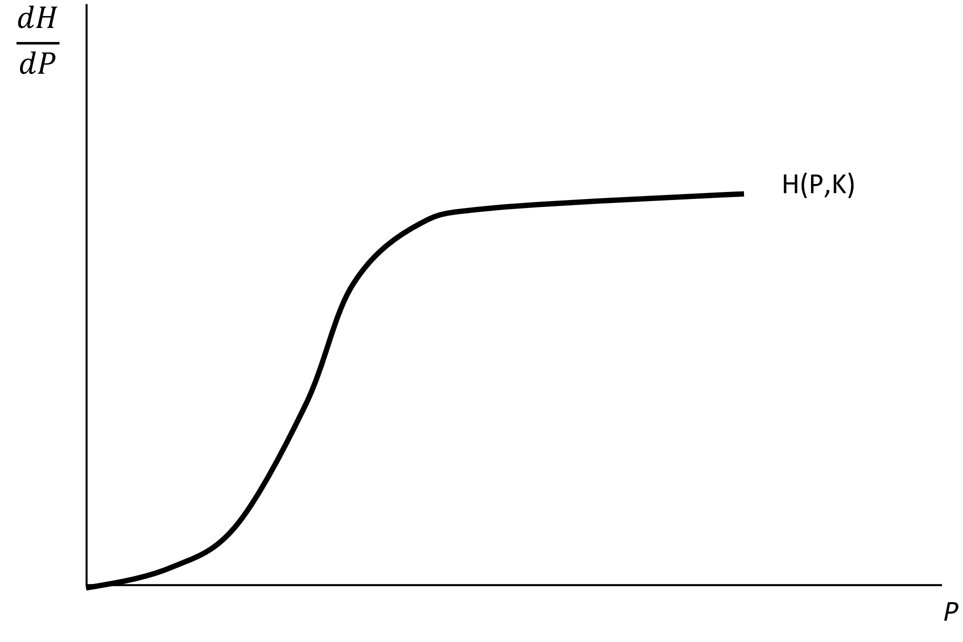

Figure 8

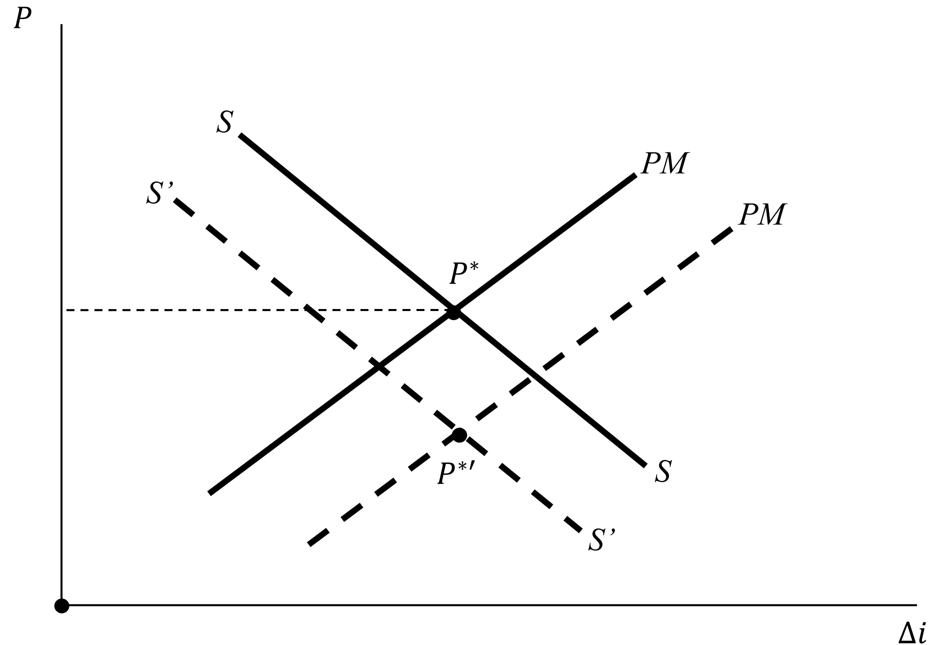

Figure 9A

SS: Eq. 8. PM: Eq. 12

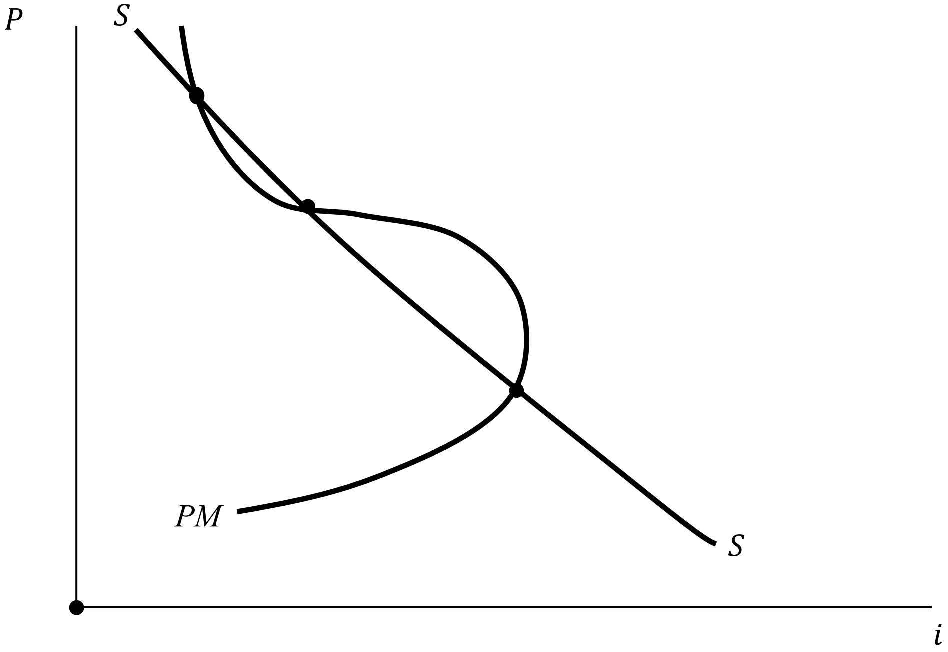

Figure 9B

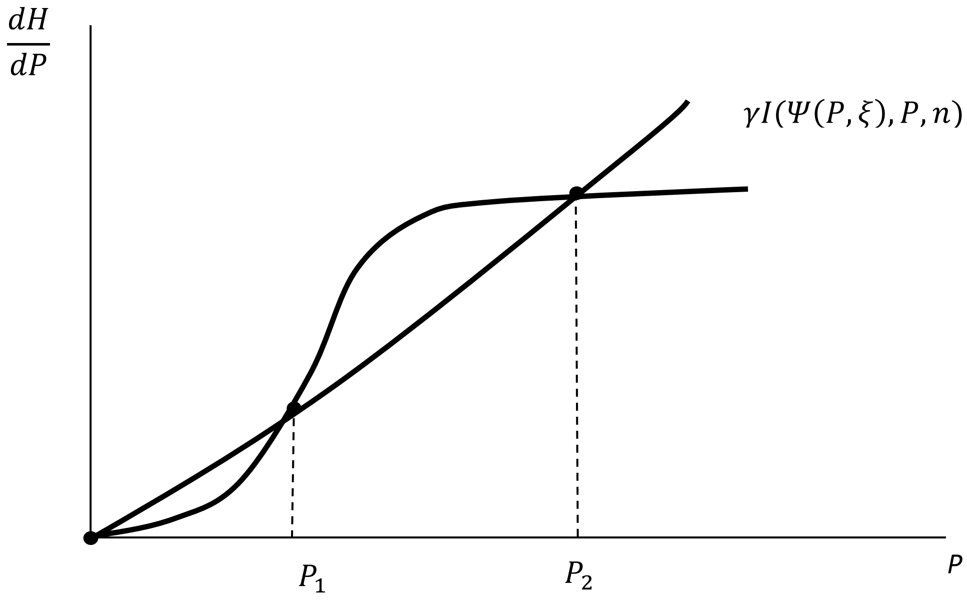

Figure 10A

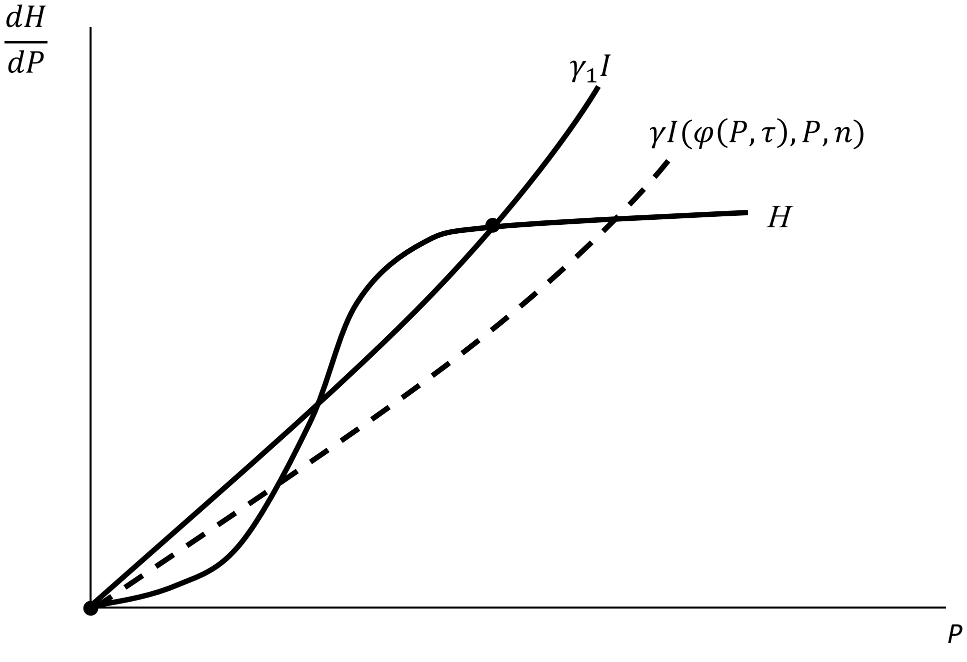

Figure 10B

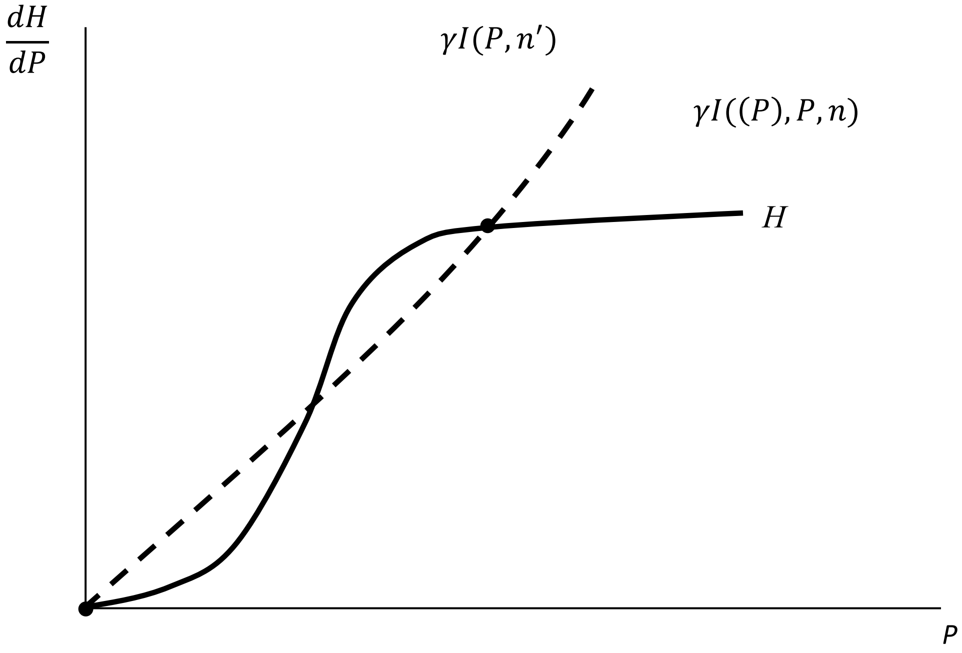

Figure 11

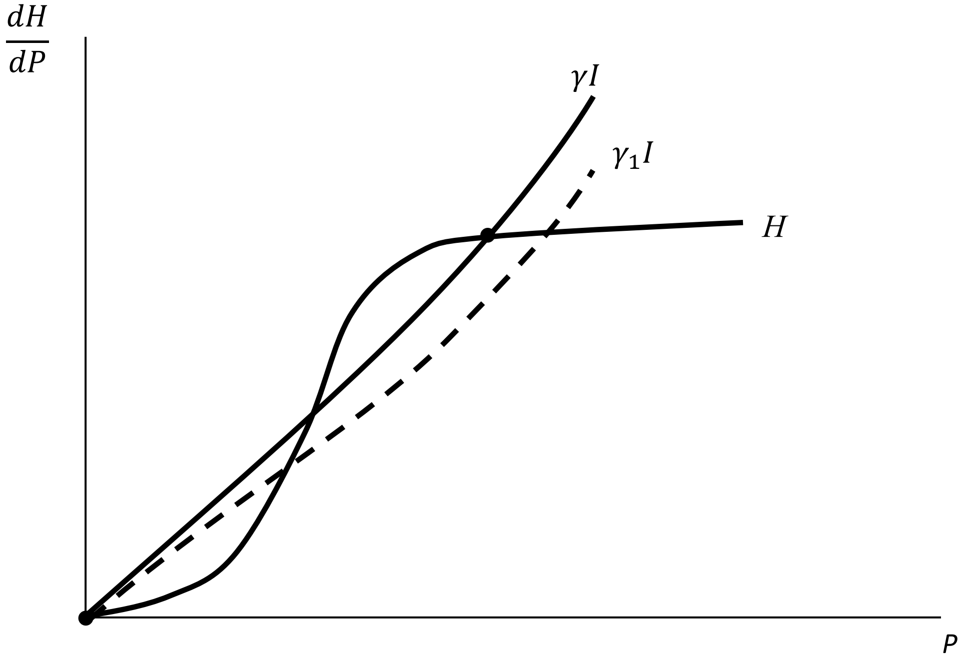

Figure 12

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