Supplementary Material for

"Cumulative Investment and Spillovers in the Formation of Technological Landscapes"

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A. PROOF OF PROPOSITION 1

Step 1: Price in stage 2

Substituting (3) into the profit function yields:

$$\text{(A1)}\qquad \Pi_1 = (P_1 - C_1)\frac{P_2 - P_1 + \tau(x_2 - x_1)(x_2 + x_1)}{2\tau(x_2 - x_1)} - I_1,$$

and symmetrically for Firm 2. Using backward induction, we solve first for the price decision.

$$\frac{\partial \Pi_1}{\partial P_1} = 0 \qquad => \qquad P_1 = \frac{1}{3}\left(2C_1 + C_2 + \tau(x_2 - x_1)(2 + x_2 + x_1)\right),$$

$$\frac{\partial \Pi_2}{\partial P_2} = 0 \qquad => \qquad P_2 = \frac{1}{3}\left(2C_2 + C_1 + \tau(x_2 - x_1)(4 - x_2 - x_1)\right).$$

The concavity of $\Pi_1(P_1)$ is immediate so that these first-order conditions are necessary and sufficient for a maximum when $P_1 > C_1$ and $P_2 > C_2$. This solves for the second stage of the game. Prices can now be substituted into the profit function (A1). This implies:

$$\text{(A2)}\qquad \Pi_1 = \frac{\left(\tau(x_2 - x_1)(2 + x_2 + x_1) + C_2 - C_1\right)^2}{18\tau(x_2 - x_1)} - I_1.$$

and symmetrically for Firm 2.

Step 2: Location in stage 1

Regarding the first stage, the first-order conditions for profit maximization of Firm 1 with respect to both location and investment must be derived. The FOC for the maximization of (A2) with respect to location is

$$\text{(A3)}\qquad \frac{\partial \Pi_1}{\partial x_1} = \frac{1}{18}\left(2 + x_2 + x_1 + \frac{C_2 - C_1}{\tau(x_2 - x_1)}\right)\left(\tau(-2 + x_2 - 3x_1) + \frac{C_2 - C_1}{x_2 - x_1} + 2\left(\frac{\partial C_2}{\partial x_1} - \frac{\partial C_1}{\partial x_1}\right)\right).$$

Any symmetric equilibrium is such that $x_1 = 1 - x_2$ and $I_1 = I_2$. Equations (2), (2') and the symmetry of $C^{t-1}(.)$ imply that any symmetric equilibrium is also such that $C_1 = C_2$. Inserting these three equalities in (A3) implies:

$$\left.\frac{\partial \Pi_1}{\partial x_1}\right|_{\substack{x_1 = 1 - x_2 \\ I_1 = I_2}} = \frac{1}{3}\left(\frac{\tau}{2}(-1 - 4x_1) + \left(\frac{\partial C_2}{\partial x_1} - \frac{\partial C_1}{\partial x_1}\right)\right)$$

Using the derivatives of (2) and (2') with respect to x_1, after further simplifications, leads to:

(A4) $$\left.\frac{\partial \Pi_1}{\partial x_1}\right|_{\substack{x_1=1-x_2\\ I_1=I_2}} = \frac{1}{3}\left(-\frac{\tau}{2}(1+4x_1)-\frac{\partial C^{t-1}(x_1)}{\partial x_1}\right).$$

Depending on $C^{t-1}(.)$, three cases must be distinguished.

(i) When $C^{t-1}(.)$ is U-shaped and $\left.\frac{\partial C^{t-1}(x)}{\partial x}\right|_{x=0} \le \frac{-\tau}{2}$, there is a unique solution to

(A5) $$\left.\frac{\partial \Pi_1}{\partial x_1}\right|_{\substack{x_1=1-x_2\\ I_1=I_2}} = 0$$

and any symmetric equilibrium location is then uniquely determined by the shape of the initial cost profile

(A6) $$\frac{\partial C^{t-1}(x_1^*)}{\partial x_1^*} = \frac{-\tau(1+4x_1^*)}{2}.$$

(ii) When $C^{t-1}(.)$ is U-shaped and $\left.\frac{\partial C^{t-1}(x)}{\partial x}\right|_{x=0} > \frac{-\tau}{2}$, there is no interior solution to (A5) and any symmetric equilibrium location is such that $x_1^* = 0$.

(iii) When $C^{t-1}(.)$ is symmetric around 0.5 and increasing over $[0, 0.5]$, there is no interior solution to (A5) and any symmetric equilibrium location is such that $x_1^* = 0$.

This discussion defines a unique location.

Step 3: Investment in stage 1

The FOC for the maximization of (A2) with respect to investment is

(A7) $$\frac{\partial \Pi_1}{\partial I_1} = \frac{(\tau(x_2-x_1)(2+x_2+x_1)+C_2-C_1)\left(\frac{\partial C_2}{\partial I_1}-\frac{\partial C_1}{\partial I_1}\right)}{9\tau(x_2-x_1)} - 1.$$

For any symmetric equilibrium, we have $x_1 = 1 - x_2$, $I_1 = I_2$ and $C_1 = C_2$. Using these equalities in (A7) leads to

$$\left.\frac{\partial \Pi_1}{\partial I_1}\right|_{\substack{x_1=1-x_2\\ I_1=I_2}} = \frac{1}{3}\left(\frac{\partial C_2}{\partial I_1}-\frac{\partial C_1}{\partial I_1}\right) - 1.$$

Inserting the derivatives of (2) and (2') with respect to I_1, after further simplifications, implies:

$$\left.\frac{\partial \Pi_1}{\partial I_1}\right|_{\substack{x_1=1-x_2\\ I_1=I_2}} = \frac{1}{3}\frac{\partial R(I_1)}{\partial I_1}(1-\alpha(1-2x_1))-1.$$

Depending on $R(.)$, two cases must now be distinguished.

(i) When $R'(0) \geq 3/\left(1-\alpha\left(1-2x_1^*\right)\right)$, the concavity of $R(.)$ implies that there is a unique solution to

(A8) $$\left.\frac{\partial \Pi_1}{\partial I_1}\right|_{\substack{x_1=1-x_2\\ I_1=I_2}} = 0.$$

and any symmetric equilibrium location is then uniquely determined by

(A9) $$\frac{\partial R\left(I_1^*\right)}{\partial I_1^*} = \frac{3}{1-\alpha\left(1-2x_1^*\right)}.$$

(ii) When $R'(0) < 3/\left(1-\alpha\left(1-2x_1^*\right)\right)$, the concavity of $R(.)$ implies that there is no solution to (A8) and thus $I_1^* = 0$.

Thus any symmetric equilibrium is uniquely determined.

Step 4: Conditions for a local maximum

The second-order condition for the maximization of (A2) with respect to location is

$$\frac{\partial^2 \Pi_1}{\partial x_1^2} = \frac{1}{18}\left(\tau(-2+x_2-3x_1)+\frac{C_2-C_1}{x_2-x_1}+2\left(\frac{\partial C_2}{\partial x_1}-\frac{\partial C_1}{\partial x_1}\right)\right)^2 +$$
$$\frac{1}{18}\left(2+x_2+x_1+\frac{C_2-C_1}{\tau(x_2-x_1)}\right)\left(-3\tau+\frac{1}{x_2-x_1}\left(\frac{\partial C_2}{\partial x_1}-\frac{\partial C_1}{\partial x_1}\right)+\frac{C_2-C_1}{(x_2-x_1)^2}+2\left(\frac{\partial^2 C_2}{\partial x_1^2}-\frac{\partial^2 C_1}{\partial x_1^2}\right)\right).$$

Using $I_1^* = I_2^*$, $x_1^* = 1-x_2^*$ and the derivatives of (2) and (2'), implies for any symmetric equilibrium:

(A10) $$\left.\frac{\partial^2 \Pi_1}{\partial x_1^2}\right|_{x_1^*, I_1^*} = \frac{1}{18}\left(-\tau\left(1+4x_1^*\right)-2\frac{\partial C^{t-1}\left(x_1^*\right)}{\partial x_1^*}\right)^2 - \frac{1}{6}\left(3\tau+\frac{\partial C^{t-1}\left(x_1^*\right)}{\partial x_1^*}+\frac{\partial^2 C^{t-1}\left(x_1^*\right)}{\partial x_1^{*2}}\right).$$

The SOC for the maximization of (A2) with respect to investment is

$$\frac{\partial^2 \Pi_1}{\partial I_1^2} = \frac{1}{9\tau(x_2-x_1)}\left[\left(\frac{\partial C_2}{\partial I_1}-\frac{\partial C_1}{\partial I_1}\right)^2+\left(\tau(x_2-x_1)(2+x_2+x_1)+C_2-C_1\right)\left(\frac{\partial^2 C_2}{\partial I_1^2}-\frac{\partial^2 C_1}{\partial I_1^2}\right)\right].$$

Using again $I_1^* = I_2^*$, $x_1^* = 1-x_2^*$ and the derivatives of (2) and (2'), we find for any symmetric equilibrium:

(A11) $$\left.\frac{\partial^2 \Pi_1}{\partial I_1^{\,2}}\right|_{x_1^*, I_1^*} = \frac{1}{9\tau\left(1-2x_1^*\right)}\left(\frac{\partial R\left(I_1^*\right)}{\partial I_1^*}\left(1-\alpha\left(1-2x_1^*\right)\right)\right)^2 + \frac{1}{3}\left(1-\alpha\left(1-2x_1^*\right)\right)\frac{\partial^2 R\left(I_1^*\right)}{\partial I_1^{*2}}.$$

The cross derivative is

$$\frac{\partial^2 \Pi_1}{\partial x_1 \partial I_1} = \frac{1}{18\tau\left(x_2-x_1\right)}\left(\frac{\partial C_2}{\partial x_1}-\frac{\partial C_1}{\partial x_1}\right)\left(\tau\left(-2+x_2-3x_1\right)+\frac{C_2-C_1}{x_2-x_1}+2\left(\frac{\partial C_2}{\partial x_1}-\frac{\partial C_1}{\partial x_1}\right)\right)$$
$$+\frac{1}{18}\left(2+x_2+x_1+\frac{C_2-C_1}{\tau\left(x_2-x_1\right)}\right)\left(\frac{1}{x_2-x_1}\left(\frac{\partial C_2}{\partial x_1}-\frac{\partial C_1}{\partial x_1}\right)+2\left(\frac{\partial^2 C_2}{\partial x_1 \partial I_1}-\frac{\partial^2 C_1}{\partial x_1 \partial I_1}\right)\right)$$

For the candidate symmetric equilibrium, this implies

(A12) $$\left.\frac{\partial^2 \Pi_1}{\partial I_1 \partial x_1}\right|_{x_1^*, I_1^*} = \frac{1}{3}\frac{\partial R\left(I_1^*\right)}{\partial I_1^*}\left[2\alpha'\left(1-2x_1^*\right)+\frac{\left(1-\alpha\left(1-2x_1^*\right)\right)}{3\tau\left(1-2x_1^*\right)}\left(\tau\left(1-2x_1^*\right)-\frac{\partial C^{t-1}\left(x_1^*\right)}{\partial x_1^*}\right)\right].$$

Finally, from (A2), profits at the symmetric equilibrium are

$$\Pi_1^* = \frac{\tau\left(1-2x_1^*\right)}{2} - I_1^*.$$

To get sufficient conditions for a local maximum, four cases must be distinguished

(i) If $I_1^* = 0$ and $x_1^* = 0$, then it can be easily verified that $\Pi_1^* \geq 0$ so that we have a local maximum is obtained.

(ii) If $I_1^* = 0$ and $x_1^* > 0$, then again $\Pi_1^* \geq 0$. Besides, inserting (A6) in (A10) yields

(A13) $$\left.\frac{\partial^2 \Pi_1}{\partial x_1^{\,2}}\right|_{x_1^*>0, I_1^*} = -\frac{1}{6}\left(\tau\left(\frac{5}{2}-2x_1^*\right)+\frac{\partial^2 C^{t-1}\left(x_1^*\right)}{\partial x_1^{*2}}\right) < 0.$$

When (A13) is satisfied, this guarantees a local maximum.

(iii) If $I_1^* > 0$ and $x_1^* = 0$, then for $\Pi_1^* \geq 0$ we need $I_1^* < \tau/2$. In addition for a local maximum we also need $\left.\frac{\partial^2 \Pi_1}{\partial I_1^{\,2}}\right|_{x_1^*, I_1^*} \leq 0$. This is equivalent to

(A14) $$\frac{\partial^2 R\left(I_1^*\right)}{\partial I_1^{*2}} < \frac{-3}{\tau\left(1-\alpha(1)\right)}.$$

Condition (A14) and $I_1^* < \tau/2$ are needed to get a local maximum.

(iv) If $I_1^* > 0$ and $x_1^* > 0$, remark that (A6) and (A10) imply $\left.\frac{\partial^2 \Pi_1}{\partial x_1^{\,2}}\right|_{x_1^*, I_1^*} \leq 0$. Furthermore for

$\left.\frac{\partial^2 \Pi_1}{\partial I_1{}^2}\right|_{x_1^*, I_1^*} \le 0$, we need

(A15) $$\frac{\partial^2 R\left(I_1^*\right)}{\partial I_1^{*2}} < \frac{-3}{\tau\left(1-2x_1^*\right)\left(1-\alpha\left(1-2x_1^*\right)\right)}.$$

Using (A6), (A9), (A10), (A11), and (A12), it can be shown that the last SOC, i.e., $\left.\frac{\partial^2 \Pi_1}{\partial x_1{}^2}\right|_{x_1^*, I_1^*} \left.\frac{\partial^2 \Pi_1}{\partial I_1{}^2}\right|_{x_1^*, I_1^*} \ge \left(\left.\frac{\partial^2 \Pi_1}{\partial I_1 \partial x_1}\right|_{x_1^*, I_1^*}\right)^2$ is equivalent to

(A16) $$-\frac{2}{3}\left(\tau\left(\frac{5}{2}-2x_1^*\right)+\frac{\partial^2 C^{t-1}\left(x_1^*\right)}{\partial x_1^{*2}}\right)\left(\frac{1}{\tau\left(1-2x_1^*\right)}+\frac{1}{3}\left(1-\alpha\left(1-2x_1^*\right)\right)\frac{\partial^2 R\left(I_1^*\right)}{\partial I_1^{*2}}\right) \ge \left[\frac{1}{1-2x_1^*}+4\frac{\alpha'\left(1-2x_1^*\right)}{\alpha\left(1-2x_1^*\right)}\right]^2.$$

Finally, for profits to be positive we need: $2I_1^* \le \tau\left(1-2x_1^*\right)$. The last three conditions are sufficient for the interior candidate equilibrium to be a local maximum.

B. WELFARE

Since all consumers are served and buy one unit of the good, maximizing total surplus is equivalent to minimizing total costs. Total costs are:

(B1) $$TC^t\left(x_1, x_2, I_1, I_2, y\right) \equiv y C_1^t + (1-y) C_2^t + \int_0^y \tau\left(x_1-z\right)^2 dz + \int_y^1 \tau\left(x_2-z\right)^2 dz + I_1 + I_2.$$

Minimizing this function in the general case is beyond the scope of this paper as it involves five (non-separable) choice variables. Nonetheless, for a symmetric cost profile, it can be shown that the equilibrium welfare can be improved by having firms still located symmetrically but closer to the center and with larger investments. Indeed, if $y = 0.5$, the investment decision is such that:

(B2) $$\frac{\partial TC}{\partial I_1} = 0 \quad \Rightarrow \quad \frac{\partial R\left(I_1\right)}{\partial I_1} = \frac{2}{1+\alpha\left(x_2-x_1\right)}$$

A straightforward comparison with the equilibrium investment which is such that $\partial R(I)/\partial I = 3/\left(1-\alpha\left(x_2-x_1\right)\right)$ shows that firms have a tendency to invest less at the market equilibrium. (For any given locations, investment at the market equilibrium is sub-optimal.) Regarding the location choice we find

(B3) $$\frac{\partial TC}{\partial x_1} = 0 \quad \Rightarrow \quad \frac{\partial C^{t-1}\left(x_1\right)}{\partial x_1} = \frac{\tau}{2}\left(1-4x_1\right) - 2R\left(I_1\right)\alpha'\left(x_2-x_1\right).$$

Again, a comparison with the symmetric equilibrium shows that the latter induces too much differentiation.

Multiple sources of inefficiency, each corresponding to one decision variable of the game, are present. First, prices are too high (i.e., above the marginal cost). In our case, however, the deadweight loss of oligopoly pricing is zero due to our simplified demand function. Secondly, the level of investment is sub-optimal. Three effect are at stake. First in order to get a larger market share, firms may over invest. But this is more than offset by two other effects: (i) price competition between firms prevents them from receiving all the cost reduction originating from their investments and (ii) the presence of horizontal spillovers also aggravate this under-investment problem. Thirdly, the market equilibrium implies too much dispersion. The location decision generates this inefficiency because of the presence of the strategic (centrifugal) price effect and the absence of the (centripetal) joint-investment effect which is not internalized at the market equilibrium.

C. PROOF OF PROPOSITIONS 2 AND 3

In the beginning of period 1, firms face a flat cost profile. According to Proposition 1, any symmetric equilibrium implies that firms will locate at both ends of the market and that $I_1 \quad I \quad = I^*$. Inserting this into (1) implies for the of the first period

(C1) $C^1(x) = C^0 - (\alpha(x) + \alpha(1-x))R(I^*)$.

If $\alpha(.)$ is convex, $\alpha(x) + \alpha(1-x)$ is also convex and symmetric around 0.5. Then $C^1(x)$ is concave and symmetric around 0.5. Similarly if the initial cost profile in period *t*, $C^t(x)$ is concave and symmetric around 0.5, firms locate at $x_1 = 0$ and $x_2 = 1$. The cost profile in *t*+1 is symmetric and concave since it is equal to the sum of two functions, $C^t(x)$ and $-(\alpha(x) + \alpha(1-x))R(I^*)$, which are symmetric around 0.5 and concave. Thus firms keep locating at $x_1 = 0$ and $x_2 = 1$.

If $\alpha(.)$ is concave with $\alpha(1) > 0$, then $\alpha(x) + \alpha(1-x)$ is concave with a unique maximum at $x = 0.5$. Then $C^1(x) = C^0 - (\alpha(x) + \alpha(1-x))R(I^*)$ is convex symmetric around 0.5. In period 1, unless $C^1(x)$ is sufficiently steep (see Proposition 1), the firms locate again at $x_1 = 0$ and $x_2 = 1$. Their investment increases the steepness of the cost profile at $x = 0$ and $x = 1$.

Eventually, the latter becomes steep enough. Both firms locate such that $x_1 > 0$ and $x_2 < 0$. Using the same reasoning as above and Propositions 2 and 3, one obtains $x_1^{t+1} \geq x_1^t$ and $I_1^{t+1} \leq I_1^t$.

D. EXISTENCE ISSUES

The existence of the symmetric equilibrium is not automatically given. When the second-order conditions are not satisfied, firms have an incentive to deviate from the candidate symmetric equilibrium. Then no equilibrium exists in pure strategies altogether. This is a recurrent problem in differentiation models (see Anderson *et al.* [1992] for some developments on this issue). A first possible interpretation is that the non-existence result is a weakness of any game theoretical approach. Another possibility is to remark that there is no symmetric equilibrium when returns to R&D are large enough to potentially imply a decisive cost advantage for one firm. (In step 4 of Section A, it can be seen that a symmetric equilibrium fails to exist when the cost reduction function is not concave enough.) In this case there can be an incentive to relocate in the center of the market and make a large investment in order to capture the whole market. This non-existence result can then be interpreted as a limitation of our framework, which can only deal with incremental innovations and sets exogenously the number of firms. To deal with potentially drastic innovations (i.e., one firm may gain a decisive cost advantage and serve the whole market), another framework, maybe more Schumpeterian, is needed (Reinganum [1985]).

E. A NUMERICAL EXAMPLE

For Proposition 1, only necessary conditions for the equilibrium are given. Some examples for which the equilibrium exists can be analyzed. Set $R(I) = 4I/(1+I)$, $\alpha(|x_1 - x|) = Max\left(0, 1 - \psi(x_1 - x)^2\right)$ and $\tau = 2$. The simulations are conducted for different values of ψ, which is an inverse index of the intensity of spillovers (the higher ψ, the weaker the spillovers).

- If $\psi = 4$, for all *t*, it is the case $x_1 = 0$ and $I = 0.155$. The cost profile is as in Figure Ia and the costs of both firms are reduced by 0.54 at each period for the technologies they use.

- If $\psi = 2$, the results are exactly the same except that the cost profile is more complex as can be checked on Figure Ib.
- If $\psi = 1.2$, the cost profile is non-monotonic over $[0, 0.5]$ after one period (see Figure Ic). For $t = 1$, then $x_1 = 0$ and $I = 0.155$. In the beginning of period 2, there might be two potential equilibria. The first candidate is such that both firms locate at the ends of the market. The second is such that Firm 1 locates on the right of the first kink and Firm 2 on the left of the second kink of the cost profile. However, due to insufficient steepness, only the first candidate is equilibrium. However after three periods, the cost profile becomes sufficiently steep so that maximum differentiation cannot be sustained in equilibrium anymore and both firms locate according to Proposition 1 between the two kinks (Figure Id). This is a case of a 'complex landscape'.
- If $\psi = 1$, the first period equilibrium is characterized by $x_1 = 0$ and $I = 0.155$ (Figure Ie). Then over time, the process of diminishing differentiation and investments described in proposition 3 is observed. In period 2, $x_1 = 0.01$ and $I = 0.128$. In period 3, a steady-state is reached where $x_1 = 0.123$ and $I = 0$. This situation is represented graphically by Figure If. In all the above cases, it can be checked numerically that the candidate equilibrium is indeed equilibrium. However, if transport costs are significantly lowered or if returns to investments are substantially increased, then the candidate equilibrium can no longer be sustained. The reason is fairly simple. With a U-shaped cost profile, if transport costs are much lower, the centrifugal force is not strong enough to prevent a deviation whereby the firm would locate at the center of the market, benefit from the lower costs and grab all the market. This numerical example has simple and tractable results but always yields a high degree of product differentiation. This is due to the concavity of the cost reduction function. When choosing something like $R = A\sqrt{I}$, one can obtain asymptotic values for x_1 above 0.3 as firms keep investing even when they are very close. (Existence problems with this specification are nonetheless more complex to deal with, as nonexistence becomes more likely with time.)

F. RELATION TO THE THEORETICAL LITERATURE

This model is related to three different strands of literature. With respect to the large literature on endogenous horizontal product differentiation, it adds both a cost and a dynamic dimension as already argued in the introduction.

This model is also a contribution to the literature on industry dynamics. The dominant approach was initiated by Jovanovic [1982] and refined in later work by Jovanovic and MacDonald [1994] and Klepper [1996] among others. Their argument evolves around the idea of uncertain learning. A variable, be it the dominant technology or the idiosyncratic long-run cost of the firm, needs to be learned. In this purpose, firms make risky investments. Some firms succeed and thrive, whereas others fail and exit the industry. Those theories do well at replicating empirical regularities about entry and exit and the often observed slowdown over time of productivity growth. However, these theories have three main weaknesses. First they lack strategic interactions that seem pervasive in most industries and may potentially play a crucial role to explain industry evolutions. Secondly, they ignore product differentiation. And thirdly, the slowdown in productivity gains as industries mature stems directly from the exhaustion of learning opportunities given by the modeler.

The approach taken in this paper concentrates by contrast on the changes in product differentiation but ignores entry and exit. The levels of costs and the degree of product differentiation jointly evolve in a process where strategic interactions along with spillovers play a prominent role. Regarding the productivity slowdown, it provides an alternative view whereby productivity gains can slowdown despite a constant potential for cost reductions. This may be more in the spirit of the approach pioneered by Flaherty [1980]. The main result obtained here is that with sufficient spillovers and a concave diffusion function, a process of rising homogeneity takes place. As stated by Porter [1980], "products have a tendency to become more like commodities over time". This increased standardization reduces the incentive to perform independent cost-reducing investments although they are still feasible and socially desirable. In other words, the model proposed here is a model in which technological progress creates the conditions for its own demise. This stands in sharp contrast to existing theories.

This model can also be related to the strategic management literature. For instance, Porter [1980] writes that "every industry begins with an initial structure […] This structure is usually (though not always) a far cry from the configuration the industry will take later in its development. […] The evolutionary processes work to push the industry towards its potential structure, which is rarely known completely as an industry evolves. […] there is a range of structures the industry might possibly achieve, depending on the direction and success of research and development, marketing innovations, and the like. It is important to realize that instrumental in much industry evolution are the investment decisions by both existing firms in the industry and new entrants." He also underlines that overall cost leadership and differentiation are the two most important generic strategies for firms. What our model does is to embody these ideas in a formal framework, explore the welfare of some outcomes, relate dynamics to technological fundamentals and finally show how strategies are optimally chosen depending on the market structure.[1]

G. EMPIRICAL ASPECTS

Some empirical studies illustrate some of the properties of the model.

Shaw [1982] documents the gradual formation of clusters for the UK fertilizer industry between 1962 and 1978. As in the model, the clusters were composed of close but non-identical products. He concludes (p.86) "although identical competitive products were rare, there was a tendency for product clusters to emerge". He also argues that this clustering was unlikely to be the result of market demand. The second focus of his paper is about the existence of product relocation which is a key aspect of the model proposed above. Here the evidence is mixed with regards to our assumptions. Firms often relocated their products as assumed in the model but they also launched new products along with the old ones. This type of evolution with product proliferation is not considered in our model. This should be tackled in further work.

Swann's [1985] analysis of product competition in microprocessors over the 1971-1981 period is also relevant. Firstly, it documents the formation of some clustering in this industry. This clustering took place either through the development of original designs using the same base technology or even more obviously through 'second source' products which were in effect identical copies. The main difference with the set-up presented here is that competition in this industry seems to have followed a leader-follower pattern (instead of simultaneous R&D decisions). The second interesting aspect of his paper is that it provides evidence of spillovers in a fast-growing industry: "For a product subject to such rapid technical change, there are informational externalities about technical feasibility of production… Those who make the same product as other producers are in a position to exchange technical information… In

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[1] However, the vision of industry evolution proposed here is in some ways opposite to that of management theorists like Porter [1980]. In their vision of the world, strategies are the result of 'free decisions' by managers, whereas here the environment dictates the optimal strategy.

practice, there has been a high degree of cross-fertilization… It is evident from some law suits that have attempted to stop such cross-fertilization that it is information from firms making similar products that is especially valuable" (p. 50-51).

Another paper of interest is Mazzoleni [1997] on the comparison of numerically controlled machine tools in Japan and the US. He argues first that differences in initial market conditions led to different industry structures. In the US, more sophisticated users led to an exclusive focus on precision that brought about clustering: "many machine tool builders that entered the market adopted a strategic behavior that predominantly avoided the uncertainties inherent to the development of a new technology" (p. 417). In Japan by contrast, firms developed more differentiated products with a focus on flexibility. Japanese producers developed their niches and ended up dominating the world market thanks to lower costs. Mazzoleni [1997] quotes additional evidence suggesting that sectors with more differentiated products enjoy higher productivity growth as predicted by our model.

Finally Klepper and Simons [1997] document the evolution of some industries over long period. In three (out of four) of them, they show that after an initial shakeout (i.e., a large innovation), subsequent small innovations led to the domination of a dominant design, i.e., a set of characteristics common to all manufacturers in the industry like for instance electric starters, sliding gears transmission, four wheel brakes and closed steel bodies in the car industry. They conclude by stating that for the three complex assembled products they consider, "the gradual standardization on a dominant design seems a useful way to characterize technical change over the long run" (p. 453). Their inquiry also points at some regularities in the patterns of entry and exit which are not dealt with here.

SUPPLEMENTARY REFERENCES

Flaherty, T., 1980, "Industry Structure and Cost-Reducing Investment", *Econometrica,* 48, pp. 1187-1210.

Jovanovic, B., 1982, "Selection and the Evolution of Industry", *Econometrica*, 50, pp. 649-70.

Mazzoleni, R., 1997, "Learning and path-dependence in the diffusion of innovations: comparative evidence on numerically controlled machine tools", *Research Policy,* 26, pp. 405-428.

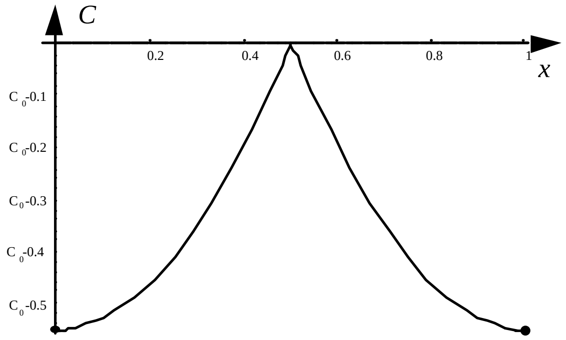
Porter, M., 1980, *Competitive Strategy*. (The Free Press, New York).

Reinganum, J., 1985, "Innovation and Industry Evolution", *Quarterly Journal of Economics,* 100, pp. 81-99.

GRAPHICAL REPRESENTATION OF THE NUMERICAL SIMULATIONS OF SECTION E

(Costs are on the vertical axis; the product space is represented by the horizontal axis; the bold dots give the equilibrium locations of the firms on the cost profile; ψ is an inverse measure of the intensity of diffusion for spillovers)

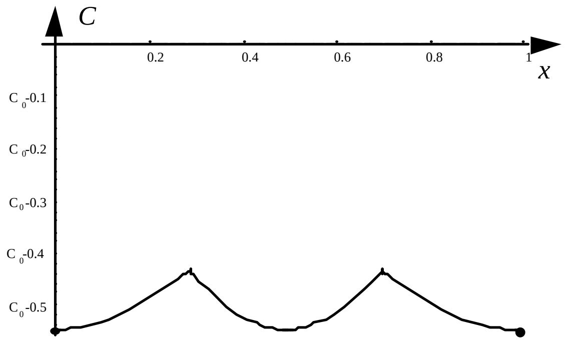
Case 1: $\psi = 4$ -- Cost profile for $t = 1$



$x_1 = 0, I = 0.155$

FIGURE IA

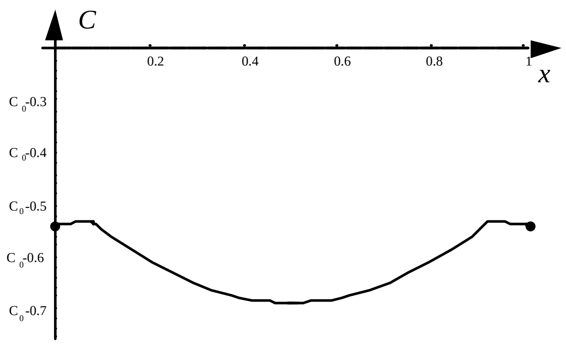
Case 2: $\psi = 2$ -- Cost profile for $t = 1$



$x_1 = 0, I = 0.155$

FIGURE IB

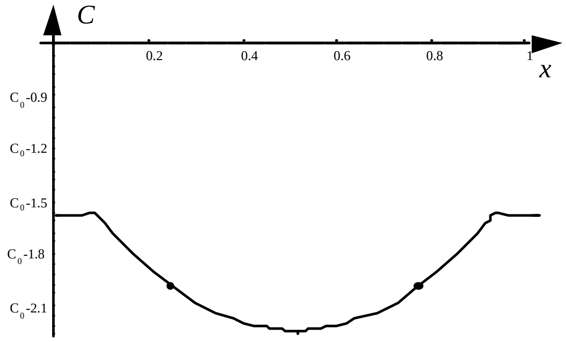
Case 3: $\psi = 1.2$ -- Cost profile for $t = 1$



$x_1 = 0, I = 0.155$

FIGURE IC

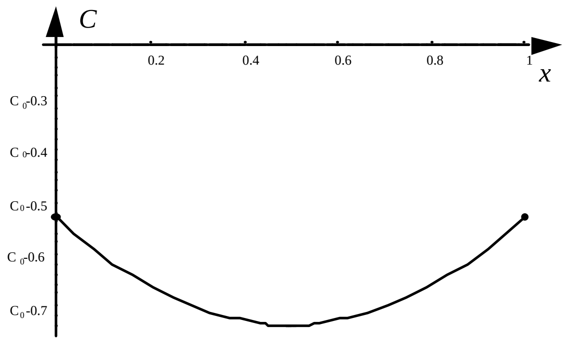
Case 3: $\psi = 1.2$ -- Cost profile for $t = 3$



$x_1 = 0.244, I = 0$

FIGURE ID

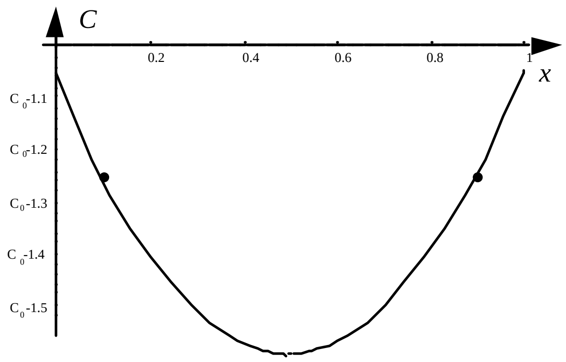
Case 4: $\psi = 1$ -- Cost profile for $t = 1$



$x_1 = 0, I = 0.155$

FIGURE IE

Case 4: $\psi = 1$ -- Cost profile for $t = 3,\ldots$



$x_1 = 0.123, I = 0$

FIGURE IF