Technological Change, Entry, and Stock-Market Dynamics: An Analysis of Transition in a Monopolistic Industry

By BIPASA DATTA AND HUW DIXON*

We consider the share-price dynamics induced by changes in technological progress (perhaps due to the introduction of a new technology or institutional reforms) and the resultant entry of firms. The focus is not so much in comparing the steady states before or after the change, but rather on the transitional dynamics of the industry or economy as it adjusts. The model is one with efficient markets and perfect foresight where fundamentals drive the stock-market value. Should we expect technological progress to lead only to increases in the level of the stockmarket (monotonic dynamics), or should we expect nonmonotonic behavior of boom followed by partial bust (a U-shaped or overshooting dynamic)? Is it possible to have share values falling even when the underlying technology is improving?

We model a stylized monopolistic industry or economy in a continuous-time general-equilibrium setting with no uncertainty and perfect foresight. We adopt a model of entry found in Sanghamitra Das and Satya P. Das (1997), Datta and Dixon (2000), and Marta Aloi and Dixon (2001), in which the cost of entry is increasing in the flow of entry (due to some congestion effect or other externality). The flow of entry is determined by an intertemporal arbitrage condition that equates the cost of entry with the present value of incumbency. This gives rise to a dynamic zero-profit condition: the present value of incumbents in each instant is equal to the cost of entry.

We first consider the case of a step increase in the level of technology with no other underlying growth. When an unanticipated technological improvement occurs, it causes a stock-market boom: there is a jump in the share value, the current profitability of incumbents, and an increase in the flow of entry. However, eventually entry drives the profit level back to zero, and shares decline back to the initial value. The initial boom is followed by a bust.

We next consider the case of an economy with constant exponential technology growth. What happens when the pace of technological change unexpectedly increases? There is an upward jump in the stock-market value of firms. This can overshoot the new balanced-growth path, with the possibility that there will be a U-shaped dynamic: the initial boom is followed by a slump before tracking back to the higher growth rate. If the initial jump overshoots the new balanced-growth path, there is a downward pull of share prices toward the new balanced-growth path, which may dominate.

This stock-market behavior reflects the behavior of entry: after an initial rush, there is a temporary slowdown before eventually getting back on track. A similar pattern can occur if the change is anticipated. We believe that this might be some part of the explanation of the behavior of the stock market in the late 1990's (although real life is much more complicated [see Jeremy Greenwood and Boyan Jovanovic, 1999]). The initial technological change causes a bonanza of profitable investment opportunities, resulting in high profits for incumbents and many new firms being set up. The increase in entry reduces profitability, and this may cause the flow of entry to reduce, if only in the short run. Finally, however, the long-run growth opportunities begin to come through, and the economy gets onto the new higher growth path.

I. Entry, Profits, and Share Valuation

We first introduce the basic model of entry developed, which presents the dynamic zero-profit entry condition which in turn relates the

* Economics Department, University of York, York YO10 5DD, United Kingdom. Address correspondence to Datta (e-mail: bd11@york.ac.uk). We thank Ray Rees, Gianni Defraja, and members of the July 2001 CESifo I.O. workshop in Venice, Italy, for their comments on an earlier draft. All proofs and background material can be found in Datta and Dixon (2001).

flow of entry to current profitability, stock-market valuation, and changes in market valuation. There is a monopolistic industry with a continuum of n firms. Profits per firm π is taken to be a function of the number of firms n and a technology parameter α: $\pi = \pi(n, \alpha)$, where $\pi_\alpha > 0 > \pi_n$. We can define the zero-profit number of firms as an implicit function of α, $n^*(\alpha)$, with $\pi(n^*, \alpha) = 0$ and $dn^*/d\alpha > 0$.

The entry model here is as simple as possible. Following Datta and Dixon (2000) and Das and Das (1997), we assume that at each instant t there is flow cost of entry $q(t)$, which is assumed to be proportional to entry flow $\dot{n}$: $q = \nu\dot{n}$ $(\nu > 0)$. This is based on the notion that there is a congestion effect: when more firms are being set up, the cost of setting up is higher. This might be because of a direct externality in the setting up of new firms, or due to the fixed supply of some factor involved in the creation of new firms (some specialized human capital or other input).

The flow of entry in each instant is determined by an *arbitrage condition.* There is some fixed return of r available elsewhere (this could be a government bond). The arbitrage condition requires that the return on investing a dollar in setting up a new firm is equal to r:

$$\frac{\pi(n, \alpha)}{q} + \frac{\dot{q}}{q} = r. \tag{1}$$

The left-hand side represents the return to investing a dollar in setting up a new firm. The first term is the price of a new firm (the number of firms per dollar, $1/q$) times the flow operating profits the firm will make if it sets up. The second term reflects the change in the cost of entry. If $\dot{q}/q > 0$, then it means that the cost of entry is increasing, which encourages earlier entry; $\dot{q}/q < 0$ implies that entry is becoming cheaper, thus discouraging early entry.

We have two equations (entry cost and arbitrage): this is a two dimensional system $\{n, q\}$, where n is a state variable and q a jump variable. We represent this as a second-order differential equation in n:

$$\nu\ddot{n} - r\nu\dot{n} + \pi(n, \alpha) = 0. \tag{2}$$

If we know the explicit form of $\pi(n, \alpha)$, we can investigate solutions to equation (2) using numerical methods. Instead, we seek to find more general results with analytical solutions to the linearized system.

A crucial feature of the entry model is that the dynamic arbitrage equation implies that the cost of entry q equals the net present value (NPV) of an incumbent firm at each instant.

PROPOSITION 1:

$$q(t) = \int_{s=t}^{\infty} \pi(n(s), \alpha(s))e^{-r(s-t)}\,dt.$$

This proposition creates the crucial link connecting entry, technology, and the stock-market value of firms in the industry. In an efficient stock market the value of firm shares will be equal to q in each instant. We can trace the dynamics of share prices and how they respond to technological innovations through q. We thus have an *intertemporal zero-profit entry condition:* the expected profits of any entrant at any time are zero. If this were not so, firms could revise the timing of their entry to coincide with entry when it is profitable.

II. Step Change in Technology

First we analyze the case where α is a constant: $\alpha(t) = \bar{\alpha}$. There is a steady state at $n^*(\bar{\alpha})$, so we can linearize around this steady state to obtain a linear nonhomogeneous second-order differential equation with eigenvalues λ_i:

$$\ddot{n} - r\dot{n} + \frac{\pi_n}{\nu}n = \frac{\pi_n}{\nu}n^* \tag{3}$$

$$\lambda_i = \frac{r}{2} \pm \sqrt{\left(\frac{r}{2}\right)^2 - \frac{\pi_n}{\nu}}. \tag{4}$$

Clearly, since $\pi_n < 0$, one eigenvalue is stable $(\lambda < 0)$, and one unstable $(\lambda^+ > 0)$, so that the steady state is saddle-path stable.

In the infinite-horizon case, we will want to rule out explosive paths, so we can define the solution in terms of the stable eigenvalue λ:

$$n(t) = n^* + (n_0 - n^*)e^{\lambda t} \tag{5}$$

$$q(t) = \nu\lambda(n_0 - n^*)e^{\lambda t}$$

where λ defines the speed of convergence to the

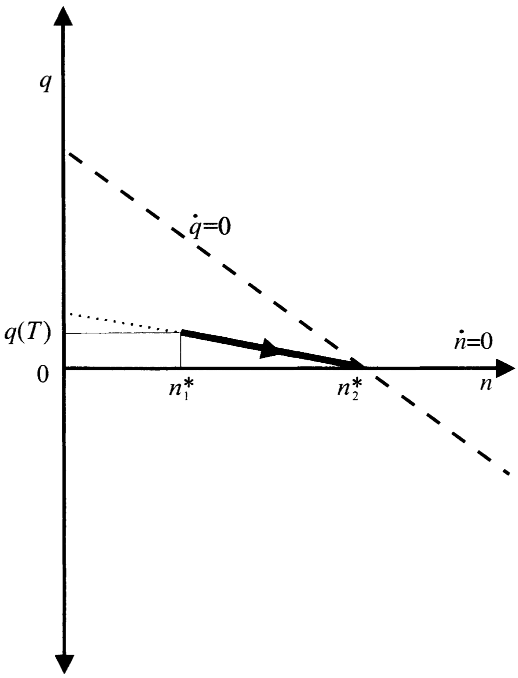

FIGURE 1. UNANTICIPATED TECHNOLOGY IMPROVEMENT

steady state. When $\nu \simeq 0$, then there is a very small adjustment cost, and the system converges rapidly to the steady state [from equation (4), λ becomes large]. When ν is very large, λ becomes close to zero, and convergence is very slow. Hence, the two cases of instantaneous entry ($\nu = 0$) and fixed n ($\nu = \infty$) are limiting cases of this entry process.

We will now look at a permanent unanticipated improvement in technology. Let α be a shift variable that can either be α_1 or α_2 with $\alpha_1 < \alpha_2$, with corresponding free-entry (and steady-state) values $n_2^* > n_1^*$. At $t = 0$ the system is in steady state with $n_0 = n_1^*$. There is a permanent increase at $t = T$ from α_1 to α_2. In this case, the $\dot{q} = 0$ line shifts rightward in $\{n, q\}$ space, and there is a new saddle path passing through the new steady state n_2^*. The dynamics are depicted in Figure 1: q jumps to the new saddle path, from 0 to $q(T)$. There is a positive flow of new firms into the industry, and the stock of firms increases toward the new equilibrium. The jump in q reflects the positive profits of the incumbents over the path to equilibrium: incumbents at $t = 0$ are able to earn positive profits throughout the adjustment path to the new equilibrium at n_2^*. Since the flow of profits falls over time, so does q.

The important point to note here is that share-price dynamics reflect both the technology and the entry process. Share prices overshoot the steady state, and bust follows boom as entry responds to technological advance.

III. Entry and Technological Growth

Next we analyze the dynamics of entry and stock-market valuation when α grows at an exponential rate d: $\alpha(t) = \alpha_0 e^{dt}$. For simplicity we adopt the linear functional form $\pi = \alpha - n$ so that $n^* = \alpha$ and $\pi_n = -1$: this can either be viewed as a linear approximation or as derived from an explicit model (see Datta and Dixon, 2001 [appendix]). The dynamic system can be written as a linear second-order differential equation with a time-varying constant:

$$\ddot{n} - r\dot{n} - \frac{1}{\nu} n = -\frac{1}{\nu} \alpha_0 e^{dt}. \tag{6}$$

The general solution to the homogeneous equation takes the standard form, with eigenvalues as given by equation (4). A particular solution $\bar{n}(t)$ for the nonhomogeneous equation is

$$\bar{n}(t) = \left[\frac{1}{1 + \nu d(r - d)}\right] \alpha(t). \tag{7}$$

We assume that $r > d$, a sufficient condition for the NPV of profits to be defined. The particular solution grows at a constant rate d and involves strictly positive profits when $\nu d > 0$, since the number of firms is less than the zero-profit number. If $\nu = 0$, then we have the instantaneous-entry case, with $\bar{n}(t) = n^*(t) = \alpha(t)$ at each instant. Along the particular solution, the share price is $\bar{q}(t) = \nu d \bar{n}(t)$. Note that an increase in the rate of growth of technological progress *always* causes the particular solution to the share price to increase.

Combining the general solution of the homogeneous linear second-order differential equation with the particular solution yields the general solution to the nonhomogeneous second-order differential equation: $n(t) = \bar{n}(t) + A_1 e^{\lambda t} + A_2 e^{\lambda^+ t}$. Ruling out explosive paths implies $A_2 = 0$, and the initial condition for $n(0) = \bar{n}(0)$ yields $A_1 = n_0 - \bar{n}(0)$:

$$n(t) = \bar{n}(t) + [n_0 - \bar{n}(0)]e^{\lambda t} \tag{8}$$

$$q(t) = \nu d\bar{n}(t) + \lambda\nu[n_0 - \bar{n}(0)]e^{\lambda t}.$$

There is a balanced-growth path, $\bar{n}(t)$, which grows exponentially. At the beginning, there is an initial deviation from the balanced-growth path. The equilibrium solution involves the deviation from the balanced-growth path diminishing over time. The speed of convergence is governed by the size of λ, which is in turn determined by ν.

Let us consider what happens if at some time T there is an unanticipated but permanent increase in the rate of technological progress, from $d \geq 0$ to $d' > 0$, with corresponding particular solutions $\bar{n}_1(t)$ and $\bar{n}_2(t)$. Before T, the economy is following its balanced-growth path: $n(t) = \bar{n}_1(t)$. The dynamics for $t \geq T$ are

$$n(t) = \bar{n}_2(t) + [\bar{n}_1(T) - \bar{n}_2(T)]e^{\lambda(t-T)}$$

$$q(t) = \nu d\bar{n}_2(t) + \lambda\nu[\bar{n}_1(T) - \bar{n}_2(T)]e^{\lambda(t-T)}.$$

We now turn to the question of whether the change in the value of firms $q(t)$ can be nonmonotonic after T, displaying a U-shaped dynamic. In particular, immediately after T the rate of change in the share-price is given by

$$\dot{q}(T) = \nu d'^2\bar{n}_2(T) + \lambda^2\nu[\bar{n}_1(T) - \bar{n}_2(T)]. \tag{9}$$

An increase in the rate of technological growth means that the underlying growth is faster (reflected in the balanced-growth path): this is captured in the first term on the right-hand side of equation (9). However, there is also the pull toward the balanced-growth path, reflected in the second right-hand-side term: if this pull is downward, then it can outweigh the underlying trend.

PROPOSITION 2: *U-shaped share-price dynamics,* $\{d' > d \geq 0\}$, *are as follows:*

(a) Let $d = 0$. *Then, there exists* $\bar{d}$ *such that for* $d' < \bar{d}$, $\dot{q}(\mathrm{T}) < 0$.

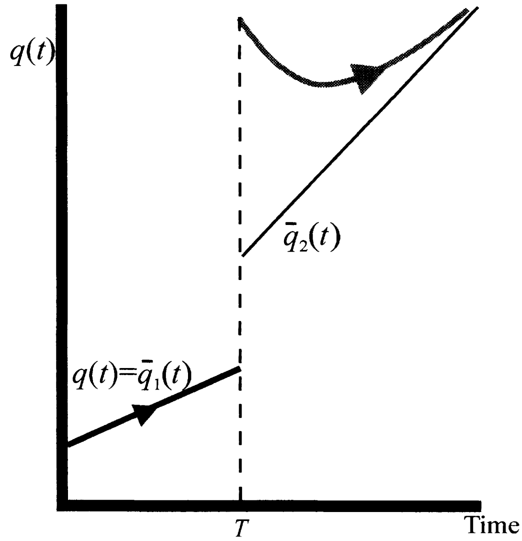

FIGURE 2. U-SHAPED SHARE-PRICE DYNAMICS

(b) Let $d' < \bar{d}$. *Then, there exists* $\hat{d}$ *such that for* $d < \hat{d}$, $\dot{q}(\mathrm{T}) < 0$.

(c) If $r(d' - d) + (d^2 - d'^2) \geq 0$, *then* $\dot{q}(T) > 0$.

Part (a) of Proposition 2 says that, if we start from a situation of no growth, $d = 0$, then a small increase to $d' < \bar{d}$ will lead to a U-shaped dynamic as in Figure 2. A corollary of this is part (b): given some small *ex post* growth rate $d' < \bar{d}$, a small level of initial growth ($d > 0$) will also result in a U-shaped dynamic. Taken together, the first two parts of the proposition mean that, if the growth rates are not too large, then there will be U-shaped dynamics. This makes sense, since high growth rates of underlying technology will tend to overpower any downward pull toward equilibrium. Part (c) gives a sufficient condition for there to be monotonic dynamics. Proposition 2 thus shows that both types of dynamic are possible in this setting.

IV. Conclusion

We have developed a simple model relating share valuation to entry and technological progress. Even with efficient markets and perfect foresight, we find that there can be interesting transitional dynamics. We have focused on situations where technological improvement can coexist with declining share valuation, the possibility of a short-run boom followed by a (possibly temporary) bust. We believe that this provides a new perspective on the phenomenon that acts as an alternative to notions of speculative behavior and behavioral models. While our model is very stylized, it can form the basis for a more complicated model with uncertainty and other features.

REFERENCES

Aloi, Marta and Dixon, Huw D. "Entry Dynamics, Capacity Utilization and Productivity in a Dynamic Open Economy." University of Nottingham (United Kingdom) Discussion Paper No. 01/09, October 2001.

Das, Sanghamitra and Das, Satya P. "Dynamics of Entry and Exit of Firms in the Presence of Entry Adjustment Costs." *International Journal of Industrial Organization*, April 1997, *15*(2), pp. 217–41.

Datta, Bipasa and Dixon, Huw D. "Endogenous Entry Dynamics in an Industry with Many Firms." Mimeo, University of York (United Kingdom), 2000.

______. "Technological Change, Entry, and Stock-Market Dynamics: An Analysis of Transition in a Monopolistic Industry." University of York (United Kingdom) Discussion Paper No. 01/18, December 2001.

Greenwood, Jeremy and Jovanovic, Boyan. "The Information-Technology Revolution and the Stock Market." *American Economic Review*, May 1999 (*Papers and Proceedings*), *89*(2), pp. 116–22.