NBER WORKING PAPER SERIES

MERGERS AS REALLOCATION

Boyan Jovanovic
Peter L. Rousseau

Working Paper 9279
http://www.nber.org/papers/w9279

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
October 2002

We thank the NSF for support, A. Faria, R. Lucas, R. Shimer and N. Stokey for useful comments, and Tanya Colmant-Donabedian for help with obtaining some of the early data on mergers. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

Mergers as Reallocation
Boyan Jovanovic and Peter L. Rousseau
NBER Working Paper No. 9279
October 2002
JEL No. O3, L2, N8

ABSTRACT

We argue that takeovers have played a major role in speeding up the diffusion of new technology. The role that they play is similar to that of entry and exit of firms. We focus on and compare two periods: 1890-1930 during which electricity and the internal combustion engine spread through the U.S. economy, and 1971-2001 . the Information Age.

Boyan Jovanovic
Department of Economics
New York University
269 Mercer St.
New York, NY 10002
and NBER
bj2@nyu.edu

Peter L. Rousseau
Department of Economics
Vanderbilt University
Box 6182, Station B
Nashville, TN 37235
and NBER
peter.l.rousseau@vanderbilt.edu

Mergers as Reallocation

Boyan Jovanovic and Peter L. Rousseau*

October 2002

Abstract

We argue that takeovers have played a major role in speeding up the diffusion of new technology. The role that they play is similar to that of entry and exit of firms. We focus on and compare two periods: 1890-1930 during which electricity and the internal combustion engine spread through the U.S. economy, and 1971-2001 – the Information Age.

1 Introduction

It has been said that new technology replaces and therefore "destroys" old technology. But if we think further about the process by which this replacement takes place, it becomes clear that much of "creative destruction" would more aptly be named *reallocation*. In trying to adopt a new technology, a firm may re-train some of its workers and replace others, and it can re-fit its buildings and equipment, where possible, and replace the rest. If it fails in the attempt to reorganize internally, the firm will probably disappear and its assets will be reorganized *externally*. In that case the firm will either liquidate, or it will be taken over. Either way, however, the existing human and physical capital is no more likely to be "destroyed" than during an episode of internal reorganization. It will simply change management. Indeed, a new technology cannot spread quickly economy-wide unless these reallocation mechanisms work smoothly. This paper studies these mechanisms.

We study and measure, in particular, the two external adjustment mechanisms – mergers and entry-and-exit (E&E) – using the stock-market capitalization of the firms involved. In Figure 1, the U-shaped top line is our estimate of the total amount of capital that has been reallocated on the U.S. stock market over the past 112 years. Its components are the stock market capitalization of entering and exiting

*NYU and the University of Chicago, and Vanderbilt University. We thank the NSF for support, A. Faria, R. Lucas, R. Shimer and N. Stokey for useful comments, and Tanya Colmant-Donabedian for help with obtaining some of the early data on mergers.

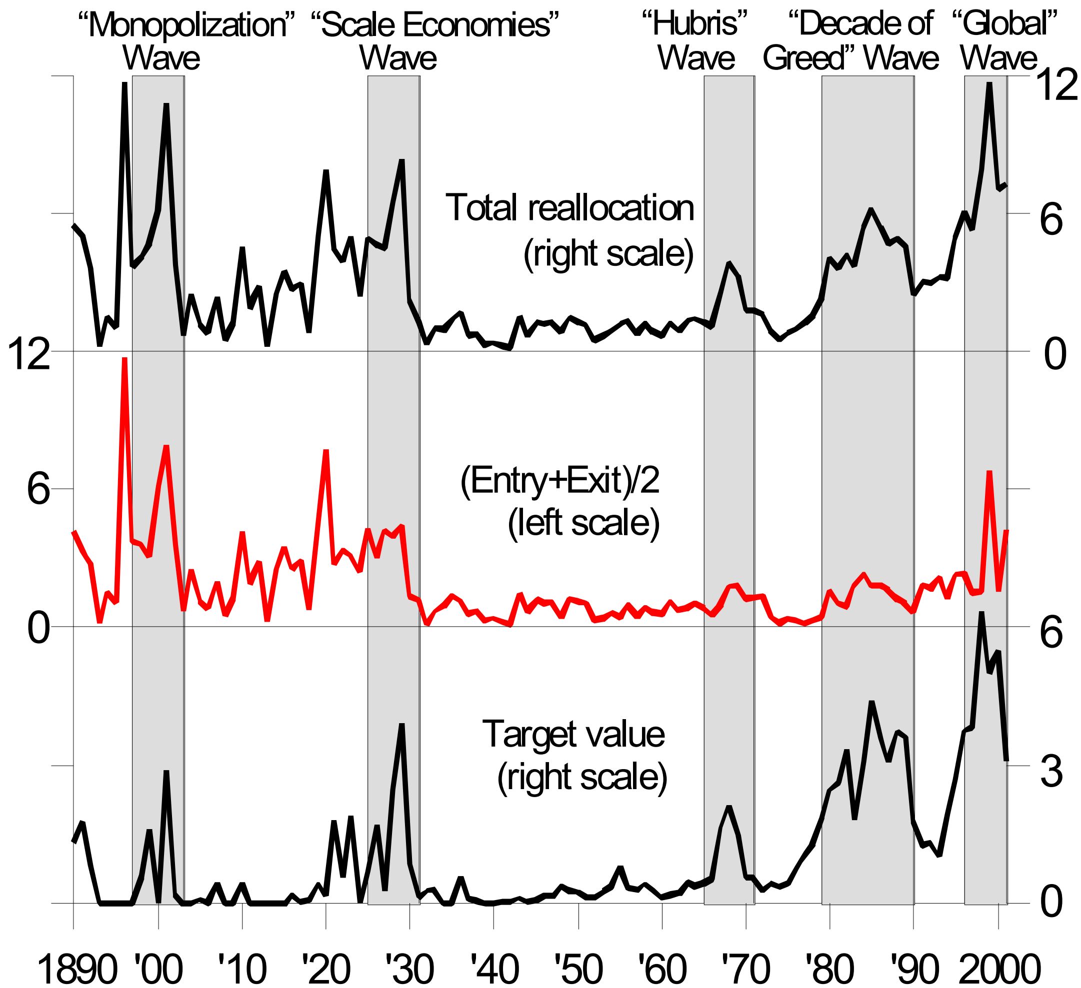


Figure 1: Reallocated capital and components as percentages of stock market value, with merger waves shaded, 1890-2001.

firms divided by two, and the value of merger targets.[1] E&E, given by the center

[1] We identify targets for 1926-2001 using the stock files distributed by the University of Chicago's Center for Research on Securities Prices (CRSP) and various supplementary sources. We use worksheets for the manufacturing and mining sectors that underlie Nelson (1959) for 1890-1930. The target series includes the market values of exchange-listed firms in the year prior to their acquisition, and reflects 9,030 mergers. Stock market capitalizations after 1925 are from CRSP. Prior to that they are from our extension of CRSP backward through 1885 using contemporary newspapers. Entries and exits are also drawn from CRSP and our newspaper sources. Before assigning a firm as an "exit" we check the list of hostile takeovers from Schwert (2000) for 1975-1996 and individual issues of the *Wall Street Journal* from 1997-2001 to ensure that we record firms taken private under a hostile tender offers as mergers. See footnotes 1 and 4 of Jovanovic and Rousseau (2001) for a detailed description of these data and their sources.

line, is a rough measure of how much capital exits from the stock market and comes back in under different ownership, or at least under a different name. The lower line is the stock-market value of merger targets.

The bottom panel shows the five merger waves and at the very top we list the names most commonly given to these waves.[2] This paper will argue, however, that the first two waves represent a form of external reallocation of resources in response to the simultaneous arrival of two general purpose technologies (GPTs) – electricity and (to a lesser extent) internal combustion – and that the last two represent reallocation in response to the arrival of the microcomputer and information technology (IT). The middle "Managerial Hubris" wave was composed mainly of conglomerate mergers and does not seem to fit our story. Two specific points emerge in Figure 1:

1. Each merger wave was accompanied by a rise in E&E. The deviations from trend are positively related – the correlation is 0.46.

2. Total reallocation has no significant trend, but mergers have grown relative to E&E – the ratio rises by a factor of 9, from 0.18 in the 1890's to 1.63 in the 1990's.

Fact 1 arises, we argue, because society will use both margins of external adjustment in response to a technological shock. Fact 2 arises, we believe, because of the increased importance of teamwork and organization capital which also has caused market values of companies to rise relative to their book values.

Our contrast of two periods of major technological change – electrification (1890-1930) and IT (1970-2002) is in the spirit of David (1991).

2 Model

First we describe a standard one-technology "Ak" model; we then add a second technology with its own capital that suddenly and unexpectedly becomes available.

2.1 One-technology model

Preferences are

$$\frac{1}{1-\sigma}\int_0^\infty e^{-\rho t} c_t^{1-\sigma} dt,$$

aggregate output is

$$y = zk,$$

[2] We define the shaded merger "waves" as starting when the series for target value stays above a tightly-specified HP trend (λ=100 in the RATS filter program) for two or more consecutive years. The wave "ends" when the series falls below trend for two consecutive years.

capital evolves as

$$\dot{k} = -\delta k + x,$$

and the income identity is

$$y = c + x.$$

Equating the marginal product of capital, z, to the user cost of capital, $r + \delta$, and substituting into the consumer's first-order conditions for optimal consumption $\dot{c}/c = (r - \rho)/\sigma$ gives us the constant-growth-rates of income and consumption

$$\frac{\dot{y}}{y} = \frac{\dot{c}}{c} = \frac{z - \delta - \rho}{\sigma}.$$

This model has no transitional dynamics because it has a single state variable, k.

2.2 A second technology arrives

Starting from a state in which all its capital embodies a technology z_1, how does the economy transit to a state in which all its capital embodies technology z_2? If the arrival of z_2 at $t = 0$ was unexpected, the growth rate before the transition would have been $(z_1 - \delta - \rho)/\sigma$, and after the transition is over at date T the growth rate will be $(z_2 - \delta - \rho)/\sigma$. For the intervening T periods, two kinds of capital coexist, k_1 and k_2. This is the era of reallocation.

De novo investment and upgrading New capital can be produced from the consumption good, or from old capital.

De novo entry of k_2.—As is usual in one-sector growth models, the production function for new capital (not counting depreciation) is

$$\dot{k}_2 = x_2 \tag{1}$$

where x_2 is the consumption foregone for the purpose of creating k_2.

Two technologies for converting k_1 *into* k_2 *or into* c.—We shall model these upgrading costs as convex costs of adjustment. We assume two distinct upgrading activities, one of which involves only k_1 while the other requires both k_1 and k_2. The intuition is easiest if we imagine that k_1 and k_2 must reside in different firms – call these z_1-firms and z_2-firms

1. *Conversion via "Exit".* Let Δ_1 be amount of k_1 that the z_1-firms retire and convert into an equal number, Δ_1, of units of the consumption good. In so doing, they forego

$$\psi\left(\frac{\Delta_1}{k_1}\right) k_1$$

units of output. Assume that ψ is increasing, convex and differentiable with $\psi'(0) = 0$. This adjustment cost is homogeneous of degree 1 in (Δ_1, k_1).

2. *Conversion via "Acquisition".* Let Δ_2 be the total amount of k_1 that the z_2-firms acquire from z_1-firms and convert into Δ_2 units of k_2. In so doing, they forego
$$\phi\left(\frac{\Delta_2}{k_2}\right)k_2$$
units of output. Assume that ϕ is increasing, convex and differentiable with $\phi'(0) = 0$. This adjustment cost is homogeneous of degree 1 in (Δ_2, k_2).

Output and the evolution of k_1 and k_2. During the transition, $t \in [0, T]$, both k_1 and k_2 are used. Net of upgrading costs, output is

$$y = (z_1 - \psi[\varepsilon])\,k_1 + (z_2 - \phi[m])\,k_2, \tag{2}$$

where
$$\varepsilon \equiv \frac{\Delta_1}{k_1}$$
is the exit rate of k_1, and
$$m = \frac{\Delta_2}{k_2}$$
is the acquisitions rate relative to k_2. Consumption is

$$c = y - x_1 - x_2.$$

The two capital stocks evolve as follows:

$$\dot{k}_1 = -\delta k_1 + x_1 - (\varepsilon k_1 + m k_2) \tag{3}$$
$$\dot{k}_2 = -\delta k_2 + x_2 + \varepsilon k_1 + m k_2 \tag{4}$$

These two laws of motion are standard but for the reallocation term $\varepsilon k_1 + m k_2$, which is subtracted from the right-hand side of (3) and added back in (4).

2.3 Equilibrium

Equilibrium consists of m, ε, $x_1$and x_2 such that firms maximize and such that the representative agent consumes optimally. The initial conditions are $k_{1,0} = 1$, $k_{2,0} = 0$, and the aggregate laws of motion (3) and (4) hold with the added restriction that $k_{1,t} \geq 0$. The model has neither external effects nor monopoly power and the Appendix uses the planner's problem to derive the equilibrium formally. In this section we shall give the market-economy interpretation.

Upgrading.—Let q be the price of k_1, and Q the price of k_2. Optimal upgrading by z_1-firms implies that
$$\psi'(\varepsilon) = Q - q. \tag{5}$$

and optimal upgrading by z_2-firms implies that

$$\phi'(m) = Q - q. \tag{6}$$

In both cases the replacement cost for k_1 is q, and the upgraded capital has a price of Q. The difference between the two is equated, in (6) and (5) to the marginal cost of adjustment.[3]

Investment.—We assume that $x_2 > 0$. Then

$$Q = 1.$$

On the other hand, it will turn out that $q < 1$ for all $t \in [t, T)$, and therefore $x_1 = 0$ throughout the transition.

Output and upgrading rents.— k_1 and k_2 play a dual role here. Each produces output, and each assists in the upgrading process. Upgrading is subject to increasing marginal costs and so, in equilibrium, entails a rent. The per-unit upgrading rent that k_1 draws is

$$\pi^{\varepsilon}(q) \equiv \max_{\varepsilon} \{\varepsilon - (q\varepsilon + \psi[\varepsilon])\},$$

and the per-unit rent that k_2 draws is

$$\pi^{m}(q) \equiv \max_{m} \{m - (qm + \phi[m])\}.$$

Consumption growth during the transition is

$$\frac{\dot{c}}{c} = \frac{1}{\sigma}(z_2 + \pi^m(q) - \rho - \delta) \tag{7}$$

and the rate of interest is

$$r = z_2 - \delta + \pi^m(q).$$

Output in (2) rises monotonically because, by (5) and (6), ε and m both decline monotonically. This is driven by the monotonic rise in q that we are about to show.

The monotonic rise in q during the transition If we can solve for q, we shall be able to infer ε, m, $\pi^{\varepsilon}(q)$, $\pi^m(q)$, $\dot{c}/c$, and r. The price of k_1 must be such that the marginal product of k_1 equals its user cost:

$$z_1 + \pi^{\varepsilon}(q) = (r - \delta)q - \dot{q}.$$

Since $\dot{Q} = 0$, the corresponding condition for k_2 is

$$z_2 + \pi^m(q) = r - \delta.$$

[3] In our partial-equilibrium treatment of takeovers as an investment (Jovanovic and Rousseau 2002), the equivalent of (6) is eq. (8). That paper also assumes adjustment costs on x which we have suppressed here in order to keep the analysis manageable.

Combining these two conditions and eliminating r we are left with[4]

$$\frac{\dot{q}}{q} = z_2 + \pi^m(q) - \frac{(z_1 + \pi^{\varepsilon}[q])}{q}. \tag{8}$$

Let q^* be the largest value of q at which

$$z_2 + \pi^m(q) = \frac{(z_1 + \pi^{\varepsilon}[q])}{q}$$

for all $t \in [0, T]$. Since $\pi^m(q) = \pi^{\varepsilon}(q) = 0$ when $q \geq 1$, we have $0 < q^* < 1$. This rest-point q^* is unstable from above:

$$q > q^* \quad \Longrightarrow \quad \dot{q} > 0.$$

But q must approach unity at $t \to T$ because as of date T, $k_{1,t}$ becomes zero and ε_t and m_t must both become zero. That is, since $\phi'(0) = 0$, a unit of k_1 is at date T as valuable as a unit of k_2 because it can be upgraded costlessly. It must therefore be that

$$q_0 \in (q^*, 1) \text{ and } q_T = 1$$

and, from (8), that $\dot{q} > 0$ all through the transition, . Finally, $\dot{q}_T = z_2 - z_1$. Figure 2 illustrates the solution for q_t.

2.4 Summary of implications

The qualitative implications are as follows:

1. At $t = 0$, output falls from $z_1 k_1$ to $(z_1 - \psi[\varepsilon_0]) k_1$ and then starts to rise monotonically.

2. The value of capital also falls from 1 to q_0. Wealth falls from $k_{1,0}$ to $q_0 k_{1,0}$.

3. Thereafter, q_t rises monotonically to 1, and k_1 falls monotonically to zero at date T, as do ε and m.

4. Total exits, $q\varepsilon k_1$, decline monotonically, whereas total acquisitions, qmk_2 start and end at zero and are, essentially, inverted U-shaped during the transition.

5. The rate of interest jumps from $z_1 - \delta$ to $z_2 - \delta + \pi^m(q_0)$ and then declines monotonically to $z_2 - \delta$ where it remains thereafter.

6. Consumption falls at date zero. After that consumption growth declines monotonically. More precisely,

$$g_c = \begin{cases} \frac{z_1 - \delta - \rho}{\sigma} & \text{for } t < 0 \\ \frac{z_2 + \pi^m(q_t) - \delta - \rho}{\sigma} & \text{for } t \in (0, T) \\ \frac{z_2 - \delta - \rho}{\sigma} & \text{for } t \geq T. \end{cases}$$

[4]This equation is derived for the planner's shadow price of k_1 in (17) of the Appendix.

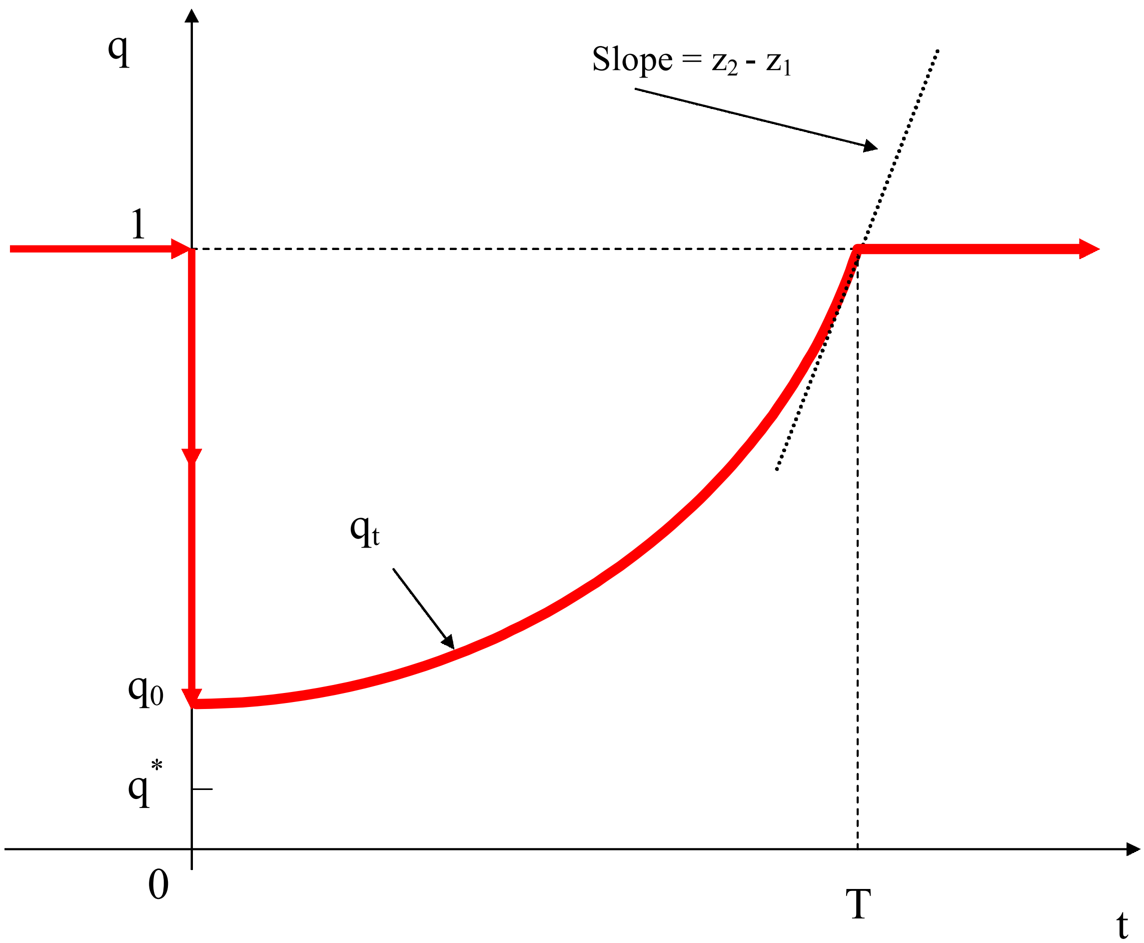


Figure 2: The solution for q_t.

2.5 Simulations

We now simulate the model. We assume that $\sigma = 1$ and that adjustment costs are quadratic:

$$\phi(m) = \frac{m^2}{2\mu} \quad \text{and} \quad \psi(\varepsilon) = \frac{\varepsilon^2}{2\nu}. \tag{9}$$

The date-0 initial conditions are

$$k_1 = 1 \quad \text{and} \quad k_2 = 0$$

and the other boundary conditions are

$$k_{1,T} = 0, \tag{10}$$

and

$$q_T = 1. \tag{11}$$

Finally, because the shock is unforeseen, the present value of consumption as of date zero (just *after* the shock) equals wealth, which is just $q_0 k_{1,0}$. Since $k_{1,0} \equiv 1$, the last condition is

$$q_0 = \int_0^T \exp\left(\int_0^t r_s ds\right) c_t dt + e^{-rT}\frac{c_T}{\rho}. \tag{12}$$

Parameter choices are reported in Figures 3 and 4. If we assume that discounting is at a rate of five percent per year, the value of $\rho = 0.10$ determines the period-length at 2 years. In both of the simulations we have assumed that the new technology doubles the rate of growth from $z_1 - \rho = 0.015$, or three-quarters of a percent per year before the transition, to $z_2 - \rho = 0.03$, or 1.5 percent per year after the transition. The adjustment-cost parameters, μ and ν, are set much higher implying a far smaller adjustment cost than the micro evidence (see below) suggests. Our main interest is in how the diffusion of the new technology is implemented. The three ways in which k_2/k_1 grows are:

1. *Acquisitions.* Relative to market capitalization, acquisitions are

$$M = \frac{qmk_2}{k_2 + qk_1}. \tag{13}$$

2. *Exits.* Relative to market capitalization, exit is

$$E = \frac{q\varepsilon k_1}{k_2 + qk_1}, \tag{14}$$

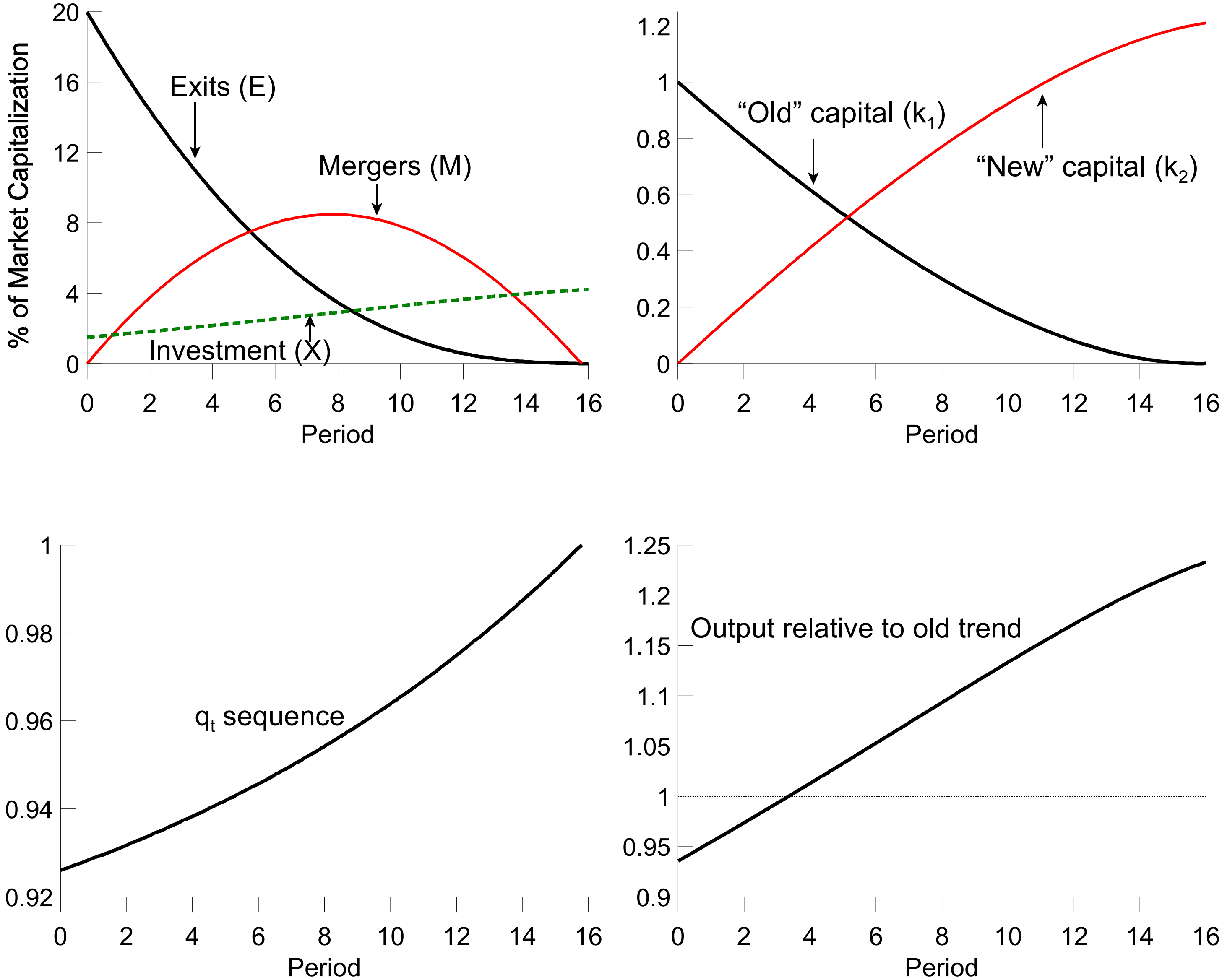
and E must decline on average from ε at $t = 0$ to zero at date T.

3. *De novo investment.*

$$X = \frac{x_2}{k_2 + qk_t}$$

These three series are plotted in the upper left panels of Figures 3 and 4. During the electricity period, exits were several times as important as acquisitions, and this is the main fact that we obtain in Simulation 1 (Figure 3), along with a transition that lasts 32 years. If teamwork and organization capital have indeed become more important and the cost of destroying them has risen, this implies a fall in ν. Simulation 2 (Figure 4) raises the ratio μ/ν by a factor of 10, and although it achieves the needed substitution of acquisitions for exits, the transition still takes 32 years.

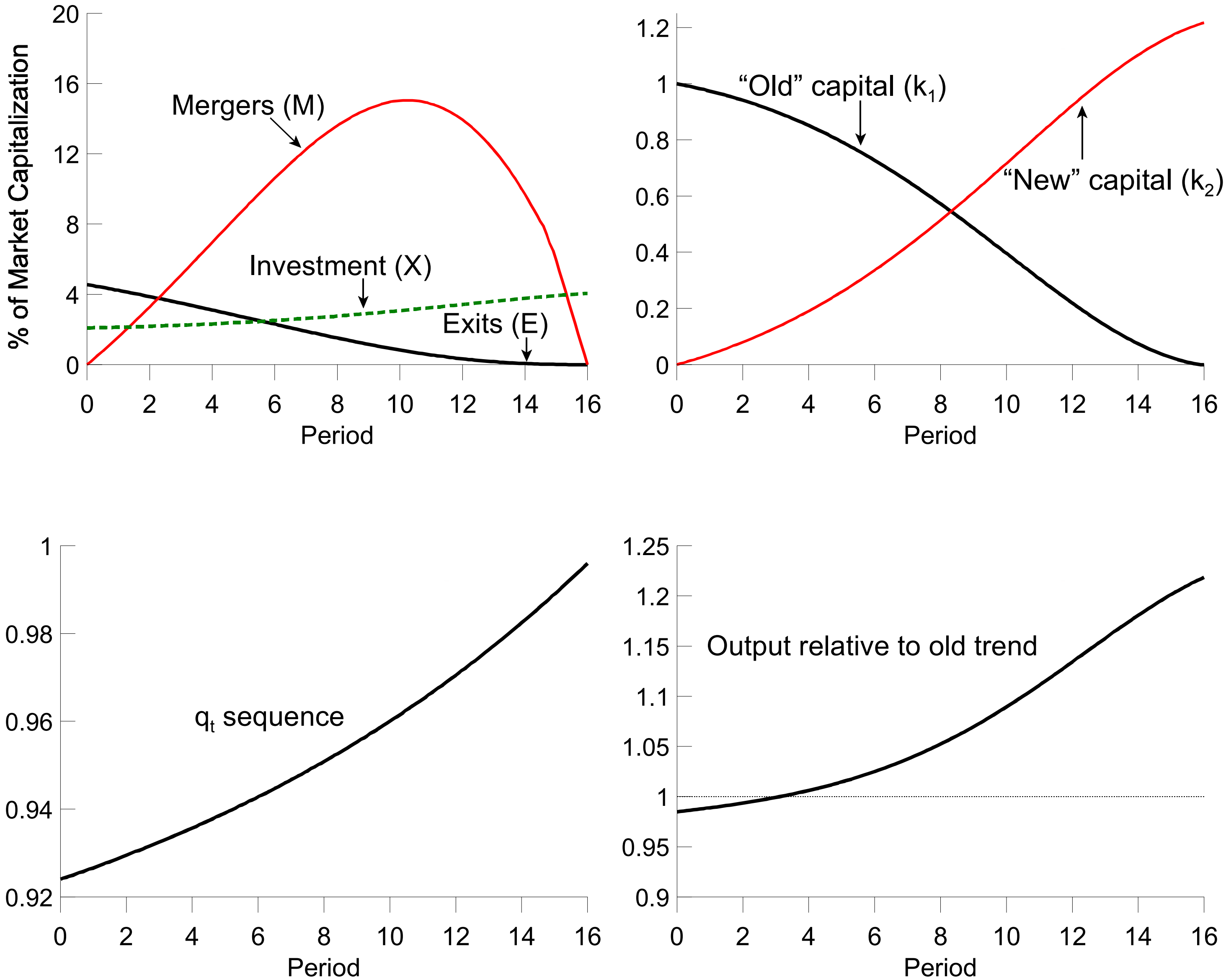
Simulation 1 shows k_2 overtaking k_1 after 10 years (i.e., 5 periods). When we raise the adjustment costs in simulation 2, Figure 4 shows that overtaking does not occur until the 17th year. Since, in Simulation 2, ϕ and ψ are much higher than in Simulation 1, it is surprising that we do not see more substitution towards X. Exits lead acquisitions in both simulations. Finally in the last panel we plot the new productivity relative to old trend and find that the productivity slowdown lasts about 7 years in both simulations.



Model settings:

$z_1 = 0.115$, $z_2 = 0.130$, $\mu = 2.7$, $\nu = 2.7$, $\rho = 0.1$, $\sigma = 1$, $\delta = 0$.

Figure 3. Transitional dynamics for "Electricity" model.



Model settings:
$z_1 = 0.115$, $z_2 = 0.130$, $\mu = 0.60$, $\nu = 0.06$, $\rho = 0.1$, $\sigma = 1$, $\delta = 0$.

Figure 4. Transitional dynamics for "IT" model.

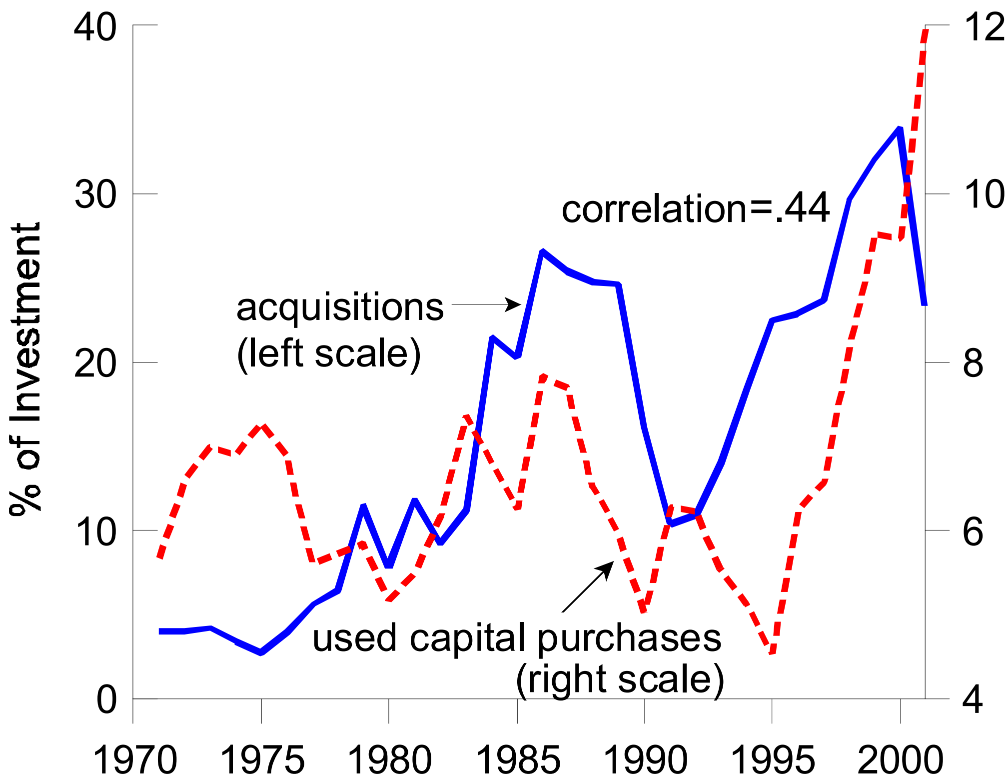


Figure 5: Used and Acquired Capital as Percentages of Total Investment, 1971-2001

3 Evidence

We begin with our assumption that the transition is technological and that takeovers and exits are reallocative. First, we know from McGuckin and Ngyen (1995) and Schoar (2000) that the productivity of acquiring firms' plants falls and that the productivity of the targets' plants rises following a takeover. Also, Lichtenberg and Siegel (1987) find that plants changing owners had lower initial levels of productivity and higher subsequent productivity growth than plants that did not change hands. These findings support our assumption that a takeover implies that k_1 is transformed into the more productive k_2, and that the acquirer faces an adjustment cost.

Second, the trading of used capital is correlated with mergers.

Our model treats M&As like purchases of used capital at the price of q. In fact, trading in the two kinds of used capital – bundled and disassembled – has moved together over the last thirty years. Figure 5 shows this fact. It plots acquired capital and direct purchases of used capital among exchange-listed firms as percentages of their annual investment from 1971 to 2001. We derive the series using all firms common to CRSP and Standard and Poor's Compustat.[5] The two series do not overlap in coverage, and thus if we add them, we have the fraction of investment spent on used capital. The correlation coefficient between the two series is 0.44.

3.0.1 Acquisitions and sectoral exposure to GPTs

If 1890-1930 and 1970-2002 are technological transitions, then we should have seen more upgrading and reallocation in the sectors that were absorbing more of the two GPT's. Figure 6 reports, for each epoch, a measure of sectoral absorption of the two GPTs at the tail end of the two episodes. The figures are comparable, and are constrained by the sectoral investment data that we could find for the first epoch.[6] The acquisitions that we report are for 1925-30 and 1997-2000 (the waves as defined in Figure 1).[7] That is, we look at the growth of the GPT shares over the 10-year periods and then report acquisitions during the end-of-period wave.

The relation is positive in both epochs, but more so for the electrification era. The correlation coefficients are 0.74 and 0.22 respectively.

3.0.2 Acquisitions, exits and IPOs by sector

If m and ε are performing the same sort of reallocative function, then they should be positively correlated over sectors. It turns out that they are. The rank correlations between IPOs and exits on the one hand and acquisitions on the other, with ranks based upon the percentage of each in total sector value (with the merger samples as defined in fn. 7) are given below.

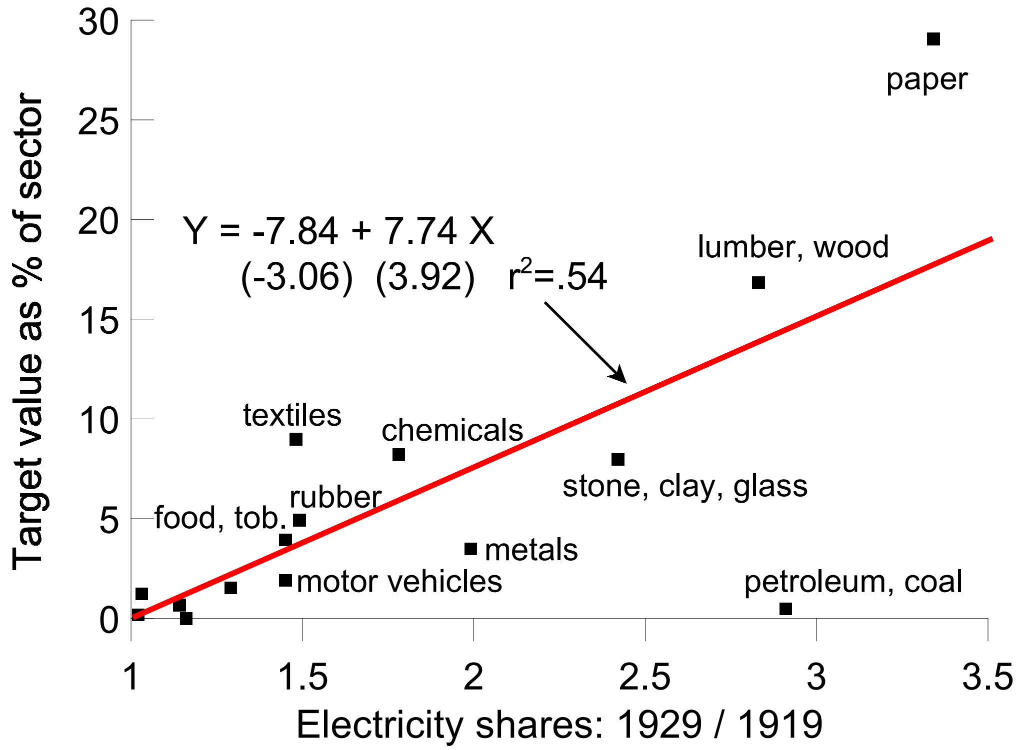
Period	rank correlation	significance	# of sectors
	Mergers and IPOs		
1925-1930	0.718	1%	15
1997-2000	0.227	10%	53
	Mergers and Exits		
1925-1930	0.343	10%	15
1997-2000	0.123	NS	53

Once again, the electricity era seems to fit the model better.

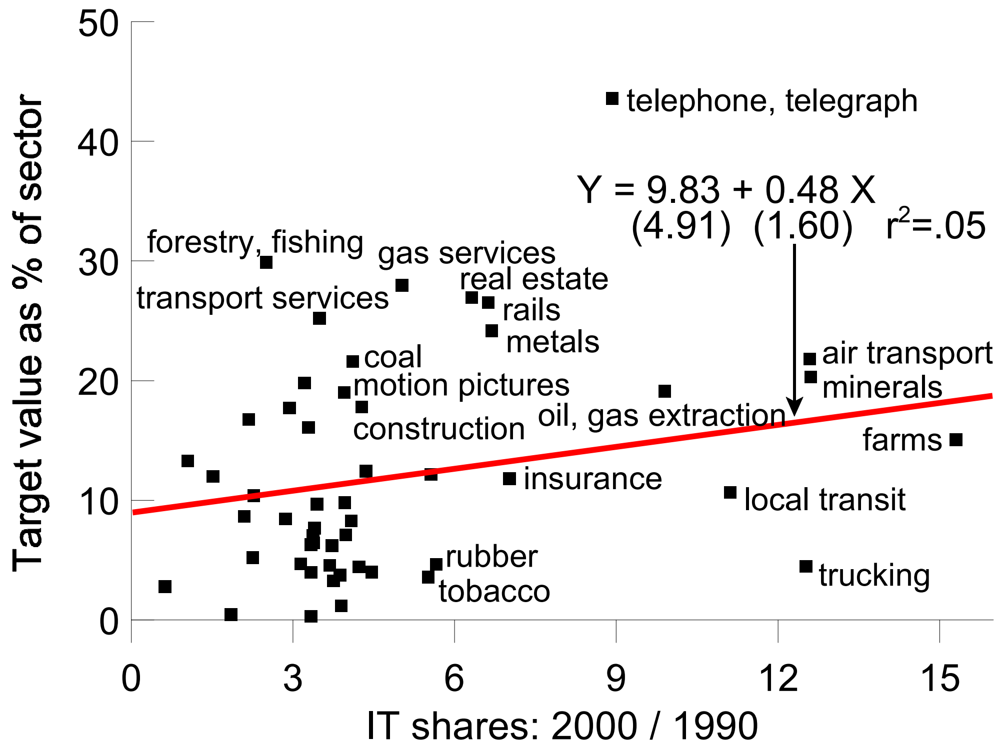
[5] Capital sales include property, plant, and equipment (Compustat item 107). Acquisitions include funds used for and costs related to the purchase of another company in the current year or an acquisition in a prior year that was carried over to the current year (item 129). Investment is the sum of acquired capital (item 129) and direct capital expenditures (item 128). We compute the ratios in Figure 5 after summing each data item across active firms in each year.

[6] The sectors and electricity shares shown in the upper panel of Figure 6 are from David (1991).

[7] A good deal of U.S. merger activity took place outside of the stock exchange over the 1890-1930 period, and a sectoral breakdown would not be possible unless we use these off-exchange transactions. Panel (a) of Figure 6 therefore uses all targets and sector designations recorded in the worksheets underlying Nelson (1959), and then divides by the total value of exchange-listed firms belonging to a given sector to form the vertical axis quantities. Panel (b) of Figure 6 reflects activity among exchange-listed firms only.



(a) electricity revolution



(b) IT revolution

Fig. 6. Target values vs. changes in GPT shares over 10-year periods by sector.

3.0.3 Acquisitions and exits over time

Now we compare the simulations with the aggregate data. In the upper left panels of Figures 3 and 4 we simulated M, E, and X, and now we look at their actual behavior. Figure 7 is the empirical counterpart.

Acquisitions should be inverted-U in that a merger wave must begin and end at zero. Figure 7 shows that mergers crest during the second half of each transition.

Since k_1 is decreasing, total exits should fall over the transition. Figure 7 shows that exits have a slight negative trend, though the T-statistics in a regressions of exits on trend are only 1.27 for the electricity era and 0.90 for the IT era.

We also simulated X in Figures 3 and 4, but in practice we do not know the investment for firms that actually traded on the stock market. For the economy as a whole, investment net of residential structures averaged 10.5% of GDP for 1890-1930 and 11.5% for 1970-2001.[8] Of course, these shares are much higher than in our simulations, but the units are not the same. If the aggregate capital stock was about three times nominal output from 1890-1930 and about two and a half times output from 1970-2001, we can divide each average by these multiples to express investment as shares of stock market capitalization, assuming of course that listed firms form their capital stocks in the same way as unlisted ones. The resulting investment shares of 3.5% for 1890-1930 and 4.6% for 1970-2001 are much closer to the simulations. Panel (b) of Figure 7 shows the upward trend in investment that the model predicts for the transitions, but panel (a) does not.

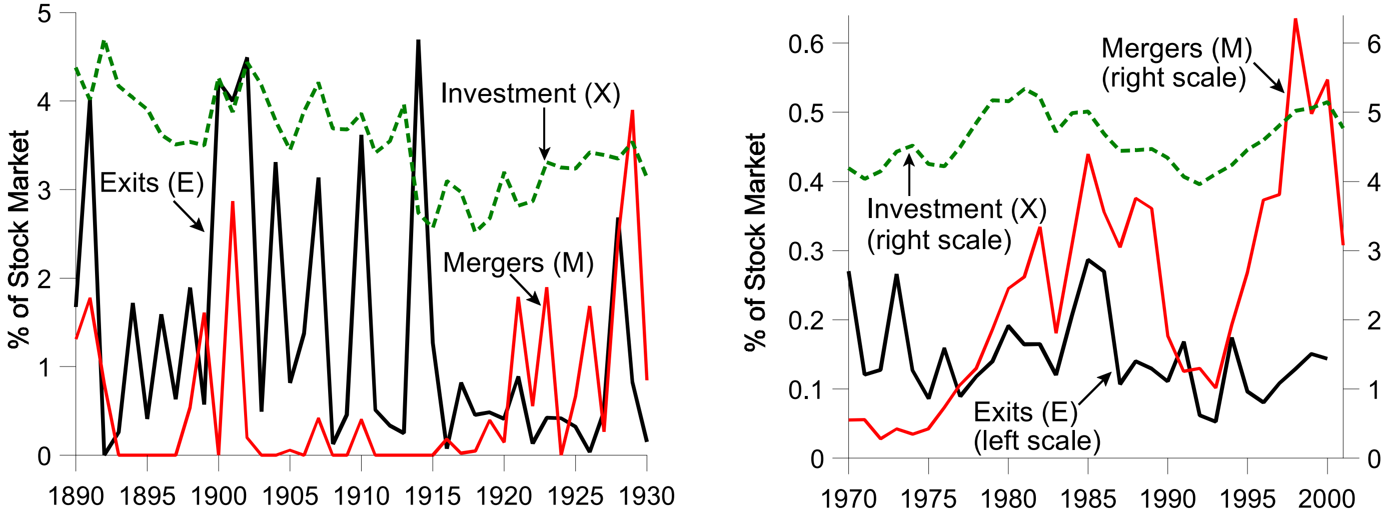
3.0.4 A rising q

Using the average market-to-book ratios of exiting and target firms as a proxy for q, panel (a) of Figure 8 shows that q has been rising during the IT episode. But so has Q when measured as the average market-to-book values of acquirers, and this flatly contradicts the implication that $Q = 1$.[9] The model could explain values of Q in

[8] We obtain private domestic fixed investment and its price deflator for 1970-2001 from the August 2002 issue of the *Survey of Current Business* (Table 1, pp. 123-4, and Table 3, pp. 135-6) and exclude non-farm residential investment. We use Kendrick (1961, Table A-IIa, column 7) for 1890-1930, and then subtract residential nonfarm construction from worksheets underlying Kuznets (1961, Table T-11).

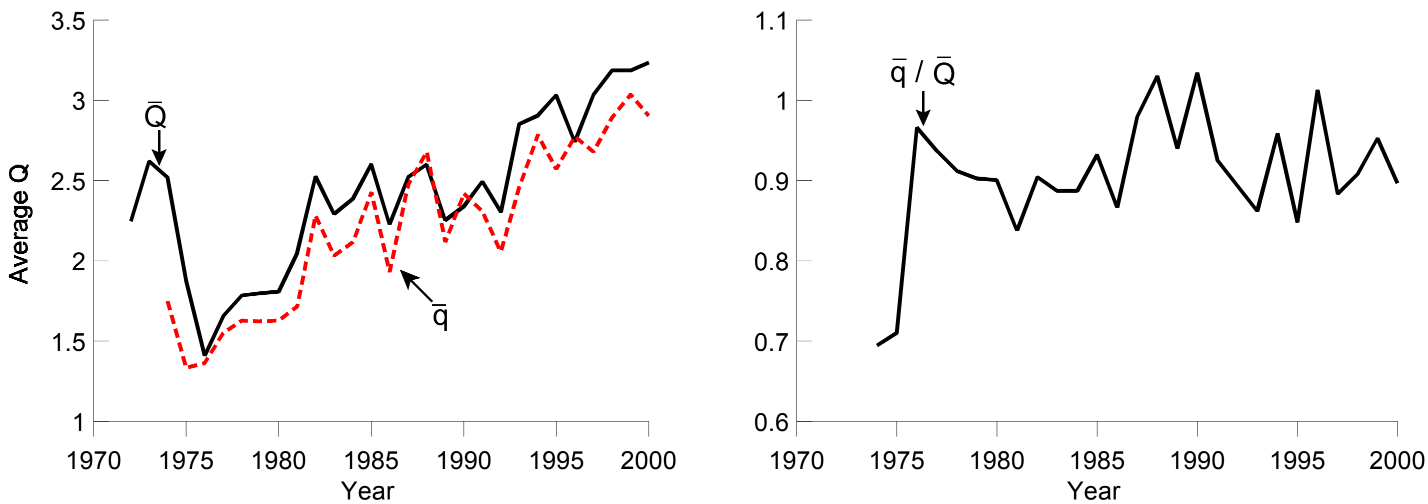
[9] We use the Compustat files to compute firm q's, and define market value as the sum of common equity at current share prices (the product of items 24 and 25), the book value of preferred stock (item 130), and short- and long-term debt (items 34 and 9). Book values are computed similarly, but use the book value of common equity (item 60) rather than the market value.

Since the company coverage within Compustat is very thin before 1972, we begin to compute Q's at this time. We count firms that disappear from Compustat as targets or exits, but only if the firm has been on the files for at least two years. Thus, the series for $\bar{q}$ and $\bar{q}/Q$ begin in 1974. We omitted q's for firms with negative values for net common equity from the plot since they imply negative market to book ratios, and eliminated observations with market-to-book values in excess of 100, since many of these were likely to be serious data errors.



(a) electricity revolution (b) IT revolution

Figure 7. The values of exiting firms and merger targets in two technological epochs.



(a) Q's by investment subgroup (b) the ratio of exiting and target firm q's to acquirer Q's

Figure 8. Prices of the two types of capital in the IT transition.

excess of unity if x_2 also imposed convex adjustment costs on the firm, but the algebra loses its simplicity and results are hard to prove. Moreover, a part of the rise in both q and Q may be due to the rising importance of unmeasured components of k_2 which are not on the firms' books. It is better, therefore, to concentrate on the ratio q/Q. In the theory, Q is unity and so

$$q = \frac{q}{Q}.$$

The theory predicts a monotonic rise in this ratio. Panel (b) of Figure 8 shows that the ratio has indeed risen, but much faster than the simulations in the third panel of Figure 4.

4 Other evidence and puzzles

In this section we report other, less favorable evidence, and other material that is somehow incongruous with the model and the logic.

4.0.5 The secular rise of acquisitions relative to exit and entry

Figure 1 shows a nine-fold increase in the ratio of acquisitions to E&E. We do not explain the trend here, but we can re-formulate the puzzle in terms of our two adjustment costs. Assume they are quadratic as in (9). Then (6) and (5) read $m = \mu(1-q)$ and $\varepsilon = \nu(1-q)$. Note that

$$\frac{m}{\varepsilon} = \frac{\mu}{\nu}.$$

If, for some reason, the ratio ν/μ were to fall, ε would fall relative to m. The nine-fold rise in the ratio of mergers to E&E over the past century suggests that the ratio μ/ν has risen by an order of magnitude over this period (which is also the difference between the first and the second simulations in Figures 3 and 4). "Team capital" or "organization capital" may today be more important than it was in 1900, and this makes it worthwhile to preserve the healthy parts of an underperforming firm and fix only the part that works poorly. If a firm is taken over, its teams and its organization can remain intact, whereas if it were to exit through bankruptcy its assets and people will disperse, and this will destroy its team-specific capital.

4.0.6 The stock-market drop

Initial stock-market capitalization is k_1. Right after the shock, it falls to qk_1. With $k_1 = 1$,the stock market thus exhibits an immediate drop at $t = 0$, from 1 to q.[10] Figure 9 shows that the stock market declined in 1973-74. No such sudden drop is

[10] The drop is in this model due entirely to the jump in r. Hobijn and Jovanovic (2001) get a bigger stock-market drop by assuming that the output produced by the old capital falls in price when new capital is introduced – i.e., through the obsolescence of old capital.

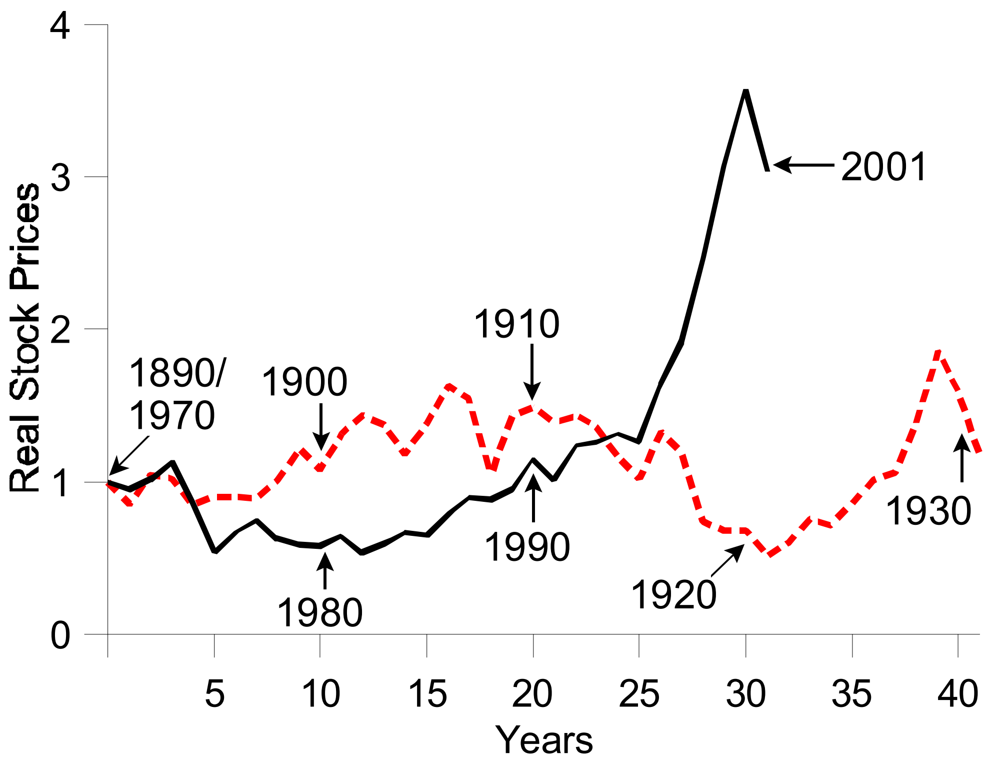


Figure 9: The real Cowles/S&P stock price index across the the transition periods, 1890-1931 and 1970-2001.

visible for stock prices in the early 1890's. Why not? Maybe because the market was thin and unrepresentative in those days, with railway stocks absorbing a large chunk of market capitalization. More likely, the realization that the new technology would work well was more gradual and was not prompted by any single event like the completion of the Niagara Falls dam in 1894.[11]

4.0.7 The productivity slowdown and multiple waves

The productivity slowdown (about 7 years) that the model seems to predict in the last panels of Figures 3 and 4 is shorter than observed during the second transition, at least. This may be related to the bigger puzzle for this paper, namely that each technological transition as we have defined it had two merger waves, and not just one, as the simulations imply.

[11] We obtain the composite stock price index from Wilson and Jones (2002), and deflate using the CPI.

4.0.8 Micro-estimates of ϕ and ψ

The two sets values for (μ, ν) of $(2.7, 2.7)$ and $(0.6, 0.06)$ used in the simulations are higher than the micro data would suggest. In other words, the estimates that we are about to report from the micro data suggest much higher costs of adjustment (at least for acquisitions) than are needed to explain the aggregate data on exits and mergers.

In another paper we use Q-theory to derive an investment equation for acquisitions from which one can uncover the adjustment-cost parameter. If $\phi(m) = \frac{m^2}{2\mu}$, (6) reads $m = \mu(Q - q)$. Table 1 of Jovanovic and Rousseau (2002) reports an estimate of $\mu = 0.022$ from the Compustat data. The estimate was divided by 100 in order to get it into the present units.

For the costs of exit we now look at evidence on the salvage value of capital from Ramey and Shapiro (2001). Consider the resources lost when a z_1-firm retires some of its capital. Let p_i be the sales price divided by the purchase price of machine i. Table 3 of Ramey and Shapiro reports the data. Per dollar spent on the machine, the firm's cost of retiring machine i is $C_i \equiv 1 - p_i$. We imagine that if the firm were to retire some of its capital, it would first sell off those machines for which p_i was closest to unity, and so on in order of descending p_i. Suppose the firm has k_1 machines on hand, $i = 1, 2, ...k_1$. Let $G\left(\frac{i}{k_1}\right)$ be the cumulative distribution of C_i among the stock of machines:

$$C_i = G\left(\frac{i}{k_1}\right).$$

The total cost to the firm of retiring εk_1 machines is

$$\begin{aligned} \psi(\varepsilon) k_1 &= k_1 \int_0^{\varepsilon k_1} G\left(\frac{s}{k_1}\right) ds \\ &= k_1 \int_0^{\varepsilon} G(s') ds' \end{aligned}$$

after the change of variables $s' = s/k_1$, so that

$$\psi(\varepsilon) = \int_0^{\varepsilon} G(s) ds.$$

Now suppose that the C_i are distributed uniformly on the interval $[0, \nu]$, so that $G(s) = \frac{1}{\nu}s$. Then $\psi(\varepsilon) = \varepsilon^2/2\nu$. The age-aggregated data underlying Figure 3 of Ramey and Shapiro's paper were kindly supplied us by Valerie Ramey, and we plot them in Figure 10. Indeed, there are more C_i values close to unity than to zero. Ignoring this asymmetry, however, we would conclude that $\nu = 1.0$, which actually gives relatively low costs of adjustment, roughly half-way between the values of 0.06 and 2.7 used in the simulations.

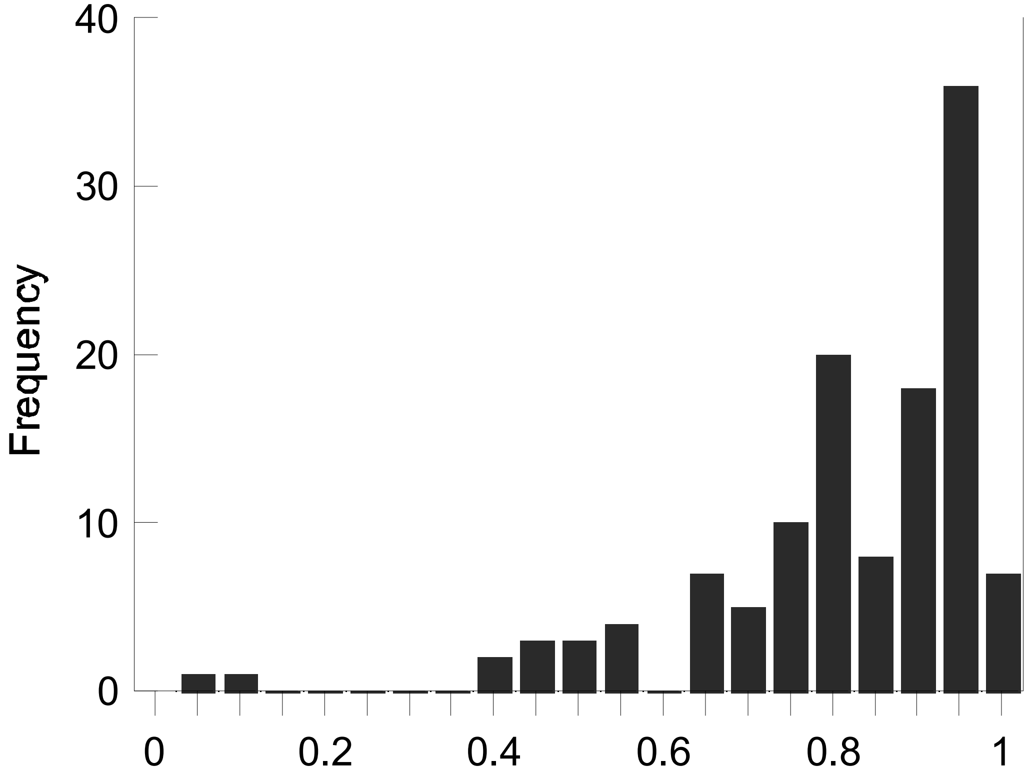


Figure 10: Frequency distribution of 1-p_i from the Ramey and Shapiro (2001) data.

Finally, we have assumed that ϕ and ψ are both convex in spite of evidence to the contrary. The micro data on acquisitions suggest a fixed-cost component to ϕ, as we have argued in Jovanovic and Rousseau (2002). Similarly, exit is also likely to involve fixed costs – e.g., the auction in Ramey and Shapiro (2001) was costly to set up. Such realism was sacrificed in return for simpler algebra.

5 Related work

We mentioned David (1991) earlier. Boldrin and Levine (2001) also have a technology for converting old capital to new. Since they do not allow goods to be converted into new capital one for one, their results are different. In related theoretical work, Mortensen and Pissarides (1998) look at constant growth, not at transitions, and they focus on the labor market, but their work is similar in that they have two modes of job-improvement that are similar to the two that we have modeled. Caballero and Hammour (1994) study transitions at business-cycle frequencies. Finally, Atkeson and Kehoe (2001), Greenwood and Yorukoglu (1997) and Hornstein and Krusell (1996) study transitions, but they do not focus on adjustment costs like we do.

The argument that mergers reallocate resources in much the same way as E&E implies that they raise the values of the capital involved in mergers. Why, then, do merger announcements lead to declines in the prices of acquirer shares? Jovanovic and Braguinsky (2002) show that when firms have private information about the quality of the capital that they own, the bidder discount is consistent with takeovers being constrained efficient.

6 Conclusion

This paper has studied the role of acquisitions and E&E in two economy-wide technological transformations. It reinforces the evidence in Jovanovic and Rousseau (2002) for the view that mergers reallocate capital to more productive purposes and to more efficient managers. The adjustment costs associated with E&E seem to have risen substantially relative to the adjustment costs associated with takeovers reflecting, probably, the rising importance of organization capital.

References

[1] Atkeson, Andrew, and Patrick Kehoe. "The Transition to a New Economy After the Second Industrial Revolution." National Bureau of Economic Research (Cambridge, MA) Working Paper No. 8676, 2001.

[2] Bartel, Ann, and Nachum Sicherman. "Technological Change and the Skill Acquisition of Young Workers." *Journal of Labor Economics* 16, no. 4 (October 1998): 718-755.

[3] Boldrin, Michele, and David K. Levine. "Growth Cycles and market Crashes." *Journal of Economic Theory* 96 (2001): 13-39.

[4] Boyd, John, and Edward C. Prescott. "Dynamic Coalitions: Engines of Growth." *American Economic Review* 77, no. 2 (May 1987), Papers and Proceedings.

[5] Caballero, Ricardo J., and Mohamad L. Hammour. "The Cleansing Effect of Recessions." *American Economic Review* 84, no. 5 (December 1994): 1350-1368.

[6] David, Paul. "Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror." In *Technology and Productivity: The Challenge for Economic Policy.* Paris: OECD, 1991.

[7] Dow Jones Inc. *The Wall Street Journal.* 1997-2001, various issues.

[8] Hobijn, Bart, and Boyan Jovanovic. "The IT Revolution and the Stock Market: Evidence." *American Economic Review* 91, no. 5 (December 2001): 1203-1220.

[9] Greenwood, Jeremy, and Mehmet Yorukoglu. "1974." *Carnegie-Rochester Conference Series* 46 (June 1997): 49-95..

[10] Hornstein, Andreas, and Per Krusell. "Can Technology Improvements Cause Productivity Slowdowns?" *NBER Macroeconomic Annual* (1976): 209-259.

[11] Jovanovic, Boyan, and Peter L. Rousseau. "The Q-Theory of Mergers" *American Economic Review* 92, no. 2 (May 2002), Papers and Proceedings: 198-204.

[12] Jovanovic, Boyan, and Peter L. Rousseau. "Vintage Organization Capital." National Bureau of Economic Research (Cambridge, MA) Working Paper No. 8166, March 2001.

[13] Jovanovic, Boyan, and Serguey Braguinsky. "Bidder Discounts and Target Premia in Takeovers." National Bureau of Economic Research (Cambridge, MA) Working Paper No. 9009, June 2002.

[14] Kendrick, John. *Productivity Trends in the United States.* Princeton: Princeton University Press, 1961.

[15] Kuznets, Simon S. Technical tables underlying *Capital in the American Economy: Its Formation and Financing.* Princeton, NJ: Princeton University Press, 1961.

[16] Lichtenberg, Frank, and Donald Siegel. "Productivity and Changes in Ownership of Manufacturing Plants." *Brookings Papers on Economic Activity* 1987, no. 3, Special Issue On Microeconomics: 643-673.

[17] McGuckin, Robert, and Sang Ngyen. "On Productivity and Plant Ownership Change: New Evidence from the Longitudinal Research Database." *Rand Journal of Economics* 26 (1995): 257-276.

[18] Nelson, Ralph L. *Merger movements in American industry*, 1895-1956. Princeton, NJ: Princeton University Press, 1959.

[19] Mortensen, Dale T., and Christopher A. Pissarides. "Technological Progress, Job Creation and Job Destruction" *Review of Economic Dynamics* 1, no. 4 (October 1998): 733-753.

[20] Ramey, Valerie A., and Matthew D. Shapiro. "Displaced Capital: A Study of Aerospace Plant Closings." *Journal of Political Economy* 109, no. 5 (October 2001): 958-992.

[21] Schoar, Antoinette. "Effects of Corporate Diversification on Productivity." Working paper, MIT Sloan School, 2000.

[22] Schwert, G. William. "Hostility in Takeovers: In the Eyes of the Beholder?" *Journal of Finance* 55 (December 2000): 2599-2640.

[23] U.S. Department of Commerce. *Survey of Current Business*. Washington, DC: Government Printing Office, August 2002.

[24] Wilson, Jack W., and Charles P. Jones. "An Analysis of the S&P 500 Index and Cowles' Extensions: Price Indexes and Stock Returns," *Journal of Business* 75, no. 3 (July 2002): 505-534.

7 Appendix: The planner's solution

The economy is convex, competitive and there are no external effects. We derive the optimal solution for the planner here, whereas in the text we reinterpret the optimum in terms of prices. We use optimal control. The Hamiltonian is

$$H = e^{-\rho t} \left\{ \begin{array}{c} U\left[\left(z_1 - \psi\left[\varepsilon\right] \right) k_1 + \left(z_2 - \phi\left[m\right] \right) k_2 - x_2 \right] + q^* \left(-\left[\delta + \varepsilon\right] k_1 - m k_2 \right) \\ +Q^* \left(\left[m - \delta\right] k_2 + \varepsilon k_1 + x_2 \right) + \lambda^* k_1 \end{array} \right\}$$

where $e^{-\rho t} q^*$ is the multiplier on the $\dot{k}_1$ constraint, $e^{-\rho t} Q^*$ is the multiplier on the $\dot{k}_2$ constraint, and $e^{-\rho t}\lambda^*$ is the multiplier on the non-negativity of k_1. To save on notation, we have assumed that $x_1 = 0$. This is valid if $Q^* > q^*$ so that the planner values k_2 more than k_1. We also ignore the nonnegativity constraint on x_2. The FOCs are

$$\frac{\partial H}{\partial m} = 0 = -U'(c)\,\phi'(m) - q^* + Q^* \tag{15}$$

$$\frac{\partial H}{\partial \varepsilon} = 0 = -U'(c)\,\psi'(\varepsilon) - q^* + Q^* \tag{16}$$

$$\frac{\partial H}{\partial x_2} = 0 = -U'(c) + Q^*$$

$$-\rho q^* + \dot{q}^* = -\frac{\partial H}{\partial k_1} = -U'(c)\left(z_1 - \psi\left[\varepsilon\right]\right) + \left(\delta + \varepsilon\right) q^* - \varepsilon Q^* + \lambda^*$$

$$-\rho Q^* + \dot{Q}^* = -\frac{\partial H}{\partial k_2} = -U'(c)\left(z_2 - \phi\left[m\right]\right) + m q^* - \left(m - \delta\right) Q^*.$$

Now define

$$Q = \frac{Q^*}{U'(c)} \quad \text{and} \quad q = \frac{q^*}{U'(c)} \text{ and } \lambda = \frac{\lambda^*}{U'(c)}.$$

Then the equations become

$$\phi'(m) = Q - q$$

$$\psi'(\varepsilon) = Q - q$$

$$Q = 1$$

$$\frac{-\rho q U' + \dot{q} U' + q \dot{U}'}{U'} = -\left(z_1 - \psi\left[\varepsilon\right]\right) + \left(\delta + \varepsilon\right) q - \varepsilon Q + \lambda$$
$$\frac{-\rho Q U' + \dot{Q} U' + Q \dot{U}'}{U'} = -\left(z_2 - \phi\left[m\right]\right) + mq - \left(m - \delta\right) Q,$$

because

$$-\rho q^* + \dot{q}^* = -\rho q U' + \dot{q} U' + q \dot{U}'$$

and

$$-\rho Q^* + \dot{Q}^* = -\rho Q U' + \dot{Q} U' + Q \dot{U}'.$$

Since $Q = 1$, and since $k_1 > 0$ on $[0, T]$, these conditions simplify to

$$\phi'\left(m\right) = 1 - q$$
$$\psi'\left(\varepsilon\right) = 1 - q$$
$$\frac{\dot{q} U' + q \dot{U}'}{U'} = -\left(z_1 - \psi\left[\varepsilon\right]\right) - \varepsilon\left(1 - q\right) + \left(\rho + \delta\right) q$$

and

$$\frac{\dot{U}'}{U'} = -\left(z_2 - \phi\left[m\right]\right) + m\left(1 - q\right) + \rho + \delta,$$

or,

$$\frac{\dot{q}}{q} + \frac{\dot{U}'}{U'} = -\frac{\left(z_1 + \pi^{\varepsilon}\left[q\right]\right)}{q} + \rho + \delta$$
$$\frac{\dot{U}'}{U'} = -\left(z_2 + \pi^{m}\left[q\right]\right) + \rho + \delta.$$

This reduces to a single differential equation for q:

$$\frac{\dot{q}}{q} = \left(z_2 + \pi^{m}\left[q\right]\right) - \frac{\left(z_1 + \pi^{\varepsilon}\left[q\right]\right)}{q}. \tag{17}$$

The only stationary solution would be a value q^* at which

$$\left(z_2 - \pi^{m}\left[q\right]\right) = \frac{\left(z_1 + \pi^{\varepsilon}\left[q\right]\right)}{q}$$

for all $t \in [0, T]$. Under mild conditions (e.g., if ϕ and ψ are the same function),

$$0 < q^* < 1,$$

and the steady state is unstable. That is,

$$q \gtrless q^* \quad \Longrightarrow \quad \frac{\dot{q}}{q} \gtrless 0.$$

Therefore we must have

$$q_0 > q^*,$$

or else q_t could not converge to unity. Now, if this were so, (17) would imply that

$$\lim_{t \to T} \frac{\dot{q}_t}{q_t} = z_2 - z_1$$

because $\lim_{q \to 1} \pi^i(q) = 0$.

One caveat to the above is that it ignores the constraint $x_2 > 0$. If the upgrading technology is efficient enough, the planner may prefer to set not just x_1 (which we have set equal to zero) but also x_2 equal to zero for a while. We have ignored this constraint, and the solution we derived would not be valid if ψ and especially ϕ were low for relatively large values of ε or m.