SMU ECONOMICS & STATISTICS
WORKING PAPER SERIES

Effects of Technological Improvement in the ICT-Producing Sector on Business Activity

Hian Teck Hoon, Edmund S. Phelps

February 2006

Paper No. 07-2006

Effects of Technological Improvement in the ICT-Producing Sector on Business Activity *

Hian Teck Hoon†
Singapore Management University
Edmund S. Phelps
Columbia University

February 2006

Abstract

It seems to be taken for granted by many commentators that the sharp decline in prices of computers, telecommunications equipment and software resulting from the technological improvements in the information and communications technology (ICT)-producing sector is good for jobs and is a major driving force behind the non-inflationary employment miracle and booming stock market in the latter half of the nineties in the U.S. and their recurrence since 2004. We show that, in our model, a technical improvement in the ICT-producing sector by itself cannot explain a simultaneous increase in employment and a rise

*Research support from the Office of Research at the Singapore Management University is gratefully acknowledged.

†School of Economics and Social Sciences, Singapore Management University, 90 Stamford Road, Singapore 178903, Republic of Singapore; e-mail: hthoon@smu.edu.sg; tel: (65)-6828-0248; fax: (65)-6828-0833.

in firms' valuation (or Tobin's Q ratio). There are two cases. If the elasticity of equipment price (p^I) with respect to ICT-producing sector's productivity is less than one, labor's value marginal productivity increases thus pulling up the demand wage and expanding employment. However, the increased output by adding to the capital stock and thus driving down future capital rentals causes a decline in firms' valuation, q per unit, even though Tobin's Q ($= q/p^I$) is up. If the elasticity is greater than one, equipment prices fall so dramatically that labor's *value* marginal productivity declines, employment in the ICT-using sector expands proportionately more than the increase in capital stock, thus raising future capital rentals, so both firms' valuation and Tobin's Q rise; but then real demand wage falls and employment contracts. The key to generating a booming stock market alongside employment expansion is to hypothesize that when technical improvement in the ICT-producing sector occurs, the market forms an expectation of *future* productivity gains to be reaped in the ICT-using sector. Then we can explain not only the stock market boom and associated rise in investment spending and employment in the period 1995-2000 but also the subsequent decline in employment, in Tobin's Q and in investment spending in 2001, with consumption holding up well as productivity gains in the ICT-using sector were realized. An anticipation of a future TFP improvement in the ICT-using sector can once more play the role of raising the stock market.

JEL classification: E13, E22, E23, E24, O33

Keywords: Business asset valuation, Tobin's Q, investment spending, employment

1. Introduction

There are three inter-related facts of the U.S. economy starting from 1995 that this paper seeks to provide a coherent explanation of. Fact number one concerns the behavior of three measures of asset prices, namely, stock market valuation, the price-earnings ratio and Tobin's Q (defined as the total market valuation taken as a ratio to the total replacement cost of capital). All three measures underwent sharp increases from around 1995, reached a peak round about 2000 and thereafter headed south. Fact number two is that despite the increased business asset valuation in the second half of the nineties, which would act to increase the value of leisure, total hours worked zoomed and real wage increased until early 2001 before declining in the next few years despite higher realized productivity gains. Fact number three is the rise of investment spending over the 1995-2000 period followed by a sharp downturn in early 2001 while consumption held up.

It seems to be taken for granted by many commentators that the sharp decline in prices of computers, telecommunications equipment and software resulting from the technological improvements in the information and communications technology (ICT)-producing sector is good for jobs and is a major driving force behind the non-inflationary employment miracle and booming stock market in the latter half of the nineties in the U.S. and its recurrence since 2004. See, for example, Jorgensen (2001) who discussed the pick-up in hours worked in the U.S. economy during the 1995-99 period in tandem with the productivity pick-up brought about by information technology.[1] But is this presumption theoretically correct?

With a view to identifying the shocks and propagation mechanisms that can provide a coherent account of the late nineties boom and its end that is consistent with the three facts noted above, we first study the effects of a technical improvement in the ICT-producing sector. We show that if the elasticity of equipment price with respect to ICT-producing sector's productivity is less than one, technical improvement in the ICT-producing sector leads to a decline in both stock market valuation as well as price-earnings ratio even though Tobin's Q rises contrary to fact number one. When the elasticity is greater than one, we show that the stream of higher future capital rentals justifying the stock market increase implies that workers' real hourly compensation relative to their total wealth is reduced so the total hours worked is reduced contrary to fact number two. The nub of the problem is this. A technical improvement in the ICT-producing sector, in raising the physical

[1] Jorgensen (2001) argued that a shift in product cycle for semiconductors in 1995 from three years to two years explained why 1995 marked the much sharper acceleration in the decline of ICT equipment prices.

stock of ICT equipment, drives down the stream of future capital rentals and thus causes the valuation per unit of business asset to fall. This negative asset valuation effect of higher capital stocks in the future can, however, be more than offset by a precipitous decline in relative equipment prices. When equipment prices fall so dramatically that labor's *value* marginal productivity declines, employment in the ICT-using sector expands by proportionately more than the increase in capital stock thus raising future capital rentals so both firms' valuation and Tobin's Q rise but then real demand wage falls and employment contracts. The key to generating a booming stock market alongside employment expansion is to hypothesize that when technical improvement in the ICT-producing sector occurred, the market also formed an expectation of *future* productivity gains to be reaped in the ICT-using sector. We are then able to explain not only the stock market boom and associated rise in investment spending and employment in the period 1995-2000 but also the subsequent decline in employment, in Tobin's Q and in investment spending in 2001 with consumption holding up well as productivity gains in the ICT-using sector were realized (fact number three).[2]

According to our theory, it was the anticipation of the productivity improvement that the ICT-using sector could achieve in the future through re-organization of work practices to take advantage of telecommunications and information technology that was the driving force behind the late 1990s boom. This anticipation provided the further boost to asset prices required to raise the real demand wage (relative to wealth) and to expand employment. When the reorganization needed to raise productivity by taking advantage of information technology in the ICT-using sector was actually completed, a cut in investment activity occurred, causing employment to decline. (The reason is that the realized productivity gain generally raises the cost of acquiring an additional unit of the business asset thus causing a reduction of Tobin's Q.) The arrival of technical improvement in the ICT-using sector therefore spelt the end of the boom as anticipatory investment and total hours worked both suffered a dip in 2001. Such *long-anticipated* gains are why booms *end*, not

[2]A natural question is why the market formed expectations of productivity gains to be reaped in the ICT-using sector in 1995 and not some other time. An answer suggested by Shiller (2005, pp. 37-40) is that the introduction of the internet and World Wide Web around that time brought into public consciousness the economic importance of advances in information technology.

how they are created. However, an anticipation of a future TFP improvement in the ICT-using sector can once more play the role of raising the stock market.

Our analysis suggests that in a collection of countries such as the G7 where Jorgensen (2005) has documented that productivity improvements in ICT-producing industries have all taken place, different anticipations about the extent of future productivity gains in the ICT-using industries in each of these countries will translate into different stock market and employment performances. Different anticipations about how much productivity gains can be achieved in the ICT-using industries, in turn, depend on prevailing institutions that best enable firms to bring about organizational and work practice changes that will take advantage of information technology. Feldstein (2003) argues that while Europe and America both experienced productivity improvements in the ICT-producing sector, there was less reason to anticipate productivity improvements in the ICT-using sector in most of the European economies compared to America due to severe organizational and institutional constraints in the former. Accordingly, the late nineties boom experienced in the U.S. was missed out by several of the Continental European economies such as Belgium, Germany and Italy.

The rest of the paper is organized as follows. In section 2, we set up the basic model where the rate of interest is parametrically given. Then, in section 3, we use the basic model to analyze the effects of a sudden increase in productivity of the ICT-producing sector as well as the effects of this shock occurring along with a simultaneous anticipation of a future step-increase in the productivity measure of the ICT-using sector. In section 4, we show how the basic model can be extended to allow trend growth and a finite sequence of step-improvements in the technological parameter in the ICT-producing sector. Section 5 shows how the natural rate of interest can be made endogenous. We discuss some related literature and conclude in section 6.

2. The basic model

Agents derive utility from consumption and leisure, have finite lives and face an instantaneous probability of death θ that is constant throughout life. Let $c(s,t)$ denote consumption at time t of an agent born at time s, $l(s,t)$ the number of hours worked, $w(s,t)$ non-human wealth, and $h(s,t)$ human wealth. We make the assumption that workers of all age cohorts have the same productivity and receive the same hourly compensation, $v(t)$. We let r denote the parametrically given real interest rate, $\rho(>0)$ the pure rate of time preference, and $\bar{L}$ the total time available per worker.

The agent maximizes

$$\int_t^{\infty} [\log c(s,\kappa) + B \log(\bar{L} - l(s,\kappa))] \exp^{-(\theta+\rho)(\kappa-t)} d\kappa, \quad B \equiv \text{parameter} > 0$$

subject to

$$\frac{dw(s,t)}{dt} = [r+\theta]w(s,t) + v(t)l(s,t) - c(s,t)$$

and a transversality condition that prevents agents from going indefinitely into debt. The solution to the agent's problem is given by

$$\begin{aligned} c(s,t) &= (\theta+\rho)[h(s,t)+w(s,t)], \\ \frac{\bar{L}-l(s,t)}{c(s,t)} &= \frac{B}{v(t)}, \end{aligned}$$

where human wealth is given by

$$h(s,t) = \int_t^{\infty} [l(s,\kappa)v(\kappa)] \exp^{-\int_t^{\kappa}[r+\theta]d\nu} d\kappa.$$

Aggregating across all individuals and denoting per capita aggregate variables by capital letters, we obtain

$$C_t = (\theta+\rho)[H_t + W_t], \tag{1}$$

$$L_t = \bar{L} - \frac{BC_t}{v_t}, \tag{2}$$

$$\dot{H}_t = (r+\theta)H_t - L_t v_t, \tag{3}$$

$$\dot{W}_t = rW_t + L_t v_t - C_t, \tag{4}$$

where a dot over a variable denotes its time derivative. We note that although every worker faces the same hourly pay, the fact that the members of the labor force are of different ages means that their wealth levels are different, and consequently, the number of hours worked will be different across the different age cohorts.

The neoclassical labor supply decision

We see from (2) that aggregate hours worked is positively related to the real hourly compensation relative to consumption. Alternatively, substituting (1) in (2), we obtain

$$L_t = \bar{L} - B(\theta + \rho)\left[\frac{H_t + W_t}{v_t}\right], \tag{5}$$

which says that aggregate hours worked is positively related to real hourly compensation relative to total wealth, the sum of human and non-human wealth.

Production-side conditions

The output of the ICT-producing sector is given by $Z_t^I = \Lambda L_t^I$, where L_t^I is allocation of labor to the ICT-producing sector and Λ is an index of technical efficiency in the ICT-producing sector. The output of the ICT-using sector is given by $Z_t^C = \Pi F(K_t, L_t^C)$, where K_t is the stock of ICT equipment, L_t^C is the allocation of labor to the ICT-using sector and Π is a measure of TFP in the ICT-using sector. The profit-maximizing problem solved by the typical competitive price-taking firm in the ICT-producing sector is simply:

$$\text{Max } p_t^I \Lambda L_t^I - v_t L_t^I$$

by choosing L_t^I. The first-order condition is given by

$$v_t = p_t^I \Lambda. \tag{6}$$

A typical competitive firm in the ICT-using sector purchases ICT equipment and must pay a cost for installing the equipment. This installation cost is paid to competitive firms in the installation sector in the form of labor cost. To instal I_t units of ICT equipment requires $I_t T(I_t/K_t)$ units of labor time; $T(0) = 0$, $T'(\cdot) > 0$, $2T'(\cdot) + (I_t/K_t)T''(\cdot) > 0$, where $T(\cdot)$ is the number of hours required to instal one additional piece of equipment. The total cost required to instal I_t units of equipment is therefore equal to $v_t I_t T(\cdot)$. With free entry into the installation sector, the total cost of purchasing and installing I_t units of equipment is given by $p_t^I I_t[1 + \Lambda T(I_t/K_t)]$ taking note of (6). Accordingly, the optimization problem solved by a typical firm in the ICT-using sector is:

$$\text{Max } \int_t^{\infty} \{\Pi F(K_s, L_s^C) - v_s L_s^C - p_s^I I_s[1 + \Lambda T(\frac{I_s}{K_s})]\} \exp^{-r(s-t)}$$

subject to

$$\dot{K}_s = I_s - \delta K_s,$$

where δ is the exogenously given rate of equipment depreciation, by choosing L_s^C and I_s. Solving this problem yields the following first-order conditions:

$$\begin{aligned}
v_t &= \Pi[f(k_t^C) - k_t^C f'(k_t^C)], && (7)\\
\frac{q_t}{p_t^I} &= 1 + \Lambda[T(\frac{I_t}{K_t}) + \left(\frac{I_t}{K_t}\right) T'(\frac{I_t}{K_t})], && (8)\\
\dot{q}_t &= (r+\delta)q_t - [\Pi f'(k_t^C) + p_t^I \Lambda \left(\frac{I_t}{K_t}\right)^2 T'(\frac{I_t}{K_t})], && (9)\\
\lim_{s\to\infty} \exp^{-rs} q_s K_s &= 0, && (10)
\end{aligned}$$

where $k_t^C \equiv K_t/L_t^C$ and $f(k_t^C) \equiv F(k_t^C, 1)$; $f'(\cdot) > 0, f''(\cdot) < 0$. We note that with the production function being homogeneous of degree one in capital and labor and the installation cost function being constant returns to scale in investment and capital stock, the marginal q_t here is equal to the average $q_t \equiv V_t/K_t$.[3]

Some key reduced-form relationships

From (8), we obtain

$$\frac{I_t}{K_t} = \Psi(\frac{q_t}{p_t^I}; \Lambda), \ \Psi_1 > 0, \Psi_2 < 0, \qquad (11)$$

which makes investment demand a positive function of Tobin's Q (defined as q_t/p_t^I). Given Tobin's Q, an increase in Λ leads to a fall in investment demand as marginal installation cost rises.

Equating (6) to (7), we note that $k_t^C = \phi(p_t^I \Lambda/\Pi)$; $\phi'(\cdot) > 0$. Writing $Z_t^C = \Pi K_t[f(k_t^C)/k_t^C]$, equating consumption demand to supply, and using (7), we re-express (2) as

$$L_t = \bar{L} - \frac{BK_t[f(k_t^C)/k_t^C]}{f(k_t^C) - k_t^C f'(k_t^C)}. \qquad (12)$$

[3]The proof is as follows: $d(q_s K_s)/ds = \dot{q}_s K_s + q_s \dot{K}_s = r q_s K_s - \{\Pi F(K_s, L_s^C) - v_s L_s^C - p_s^I I_s[1 + \Lambda T(\frac{I_s}{K_s})]\}$, after using (8) and (9). Integrating and using (10), we obtain $q_t K_t = V_t \equiv \int_t^\infty \{\Pi F(K_s, L_s^C) - v_s L_s^C - p_s^I I_s[1 + \Lambda T(\frac{I_s}{K_s})]\} \exp^{-r(s-t)}$.

Since $k_t^C = \phi(p_t^I\Lambda/\Pi)$; $\phi'(\cdot) > 0$ and $d[f(k_t^C)/k_t^C]/dk_t^C < 0$, we find that total hours worked is negatively related to K_t (the "capital stock" effect) and positively related to $p_t^I\Lambda/\Pi$ (the "relative price" effect). We summarize this reduced-form relationship as

$$\text{Hours worked function: } L_t = \mathrm{L}(K_t, \frac{p_t^I\Lambda}{\Pi});\ \mathrm{L}_1 < 0, \mathrm{L}_2 > 0. \tag{13}$$

Noting that total number of hours worked is divided among production in the ICT-producing and ICT-using sectors as well as the installing activity, we can write investment supply as $Z_t^I = \Lambda[L_t - L_t^C - I_t T(I_t/K_t)] = \Lambda[L_t - (K_t/k_t^C) - I_t T(\Psi(q_t/p_t^I;\Lambda))$. Equating investment demand to supply, $Z_t^I/K_t = \Psi(q_t/p_t^I;\Lambda)$, we obtain Tobin's Q as a function of $p_t^I\Lambda/\Pi$, K_t and Λ:

$$\text{Tobin's Q function: } \frac{q_t}{p_t^I} = \Upsilon(\frac{p_t^I\Lambda}{\Pi}, K_t;\Lambda);\ \Upsilon_1 > 0, \Upsilon_2 < 0, \Upsilon_3 > 0. \tag{14}$$

With a view later to summarize the general-equilibrium system in terms of two endogenous variables, q_t/Π and K_t, we can also use the condition equating investment demand to supply to write

$$\text{Relative price function: } \frac{p_t^I}{\Pi} = \Omega(\frac{q_t}{\Pi}, K_t;\Lambda);\ \Omega_1 > 0, \Omega_2 > 0, \Omega_3 < 0. \tag{15}$$

Figure 1 depicts in the (investment, relative price) plane an upward-sloping investment supply curve that shifts left with an increase in K_t and shifts right with an increase in Λ and a downward-sloping investment demand curve that shifts right with an increase in q_t/Π.

Substituting out for Tobin's Q in (11) using (14), we obtain

$$\frac{I_t}{K_t} = \Psi(\Upsilon(\frac{p_t^I\Lambda}{\Pi}, K_t;\Lambda);\Lambda). \tag{16}$$

An increase in Λ stimulates investment spending through raising Tobin's Q but discourages it by raising the marginal installation cost. We make the assumption that the first channel dominates. This can be expressed in two different ways.[4]

$$\text{Assumption 1: } \Psi_1\Upsilon_3 + \Psi_2 > 0, \tag{17}$$

[4]Assumption 1' is obtained by taking the derivative through $I_t/K_t = \Psi((q_t/\Pi)/\Omega(q_t/\Pi, K_t;\Lambda);\Lambda)$.

$$\text{Assumption 1': } -\Psi_1\left(\frac{q_t}{\Pi}\right)\left(\frac{1}{\Omega}\right)^2\Omega_3+\Psi_2>0. \quad (18)$$

Moreover, maintaining a constant stock of capital requires $\Psi(q_t/p_t^I;\Lambda)=\delta$. Given q_t, a unit increase in capital stock K_t shifts investment supply to the left and raises p_t^I consequently reducing Tobin's Q. We assume that Tobin's Q can be restored to its original level by raising q_t, that is, the elasticity of p_t^I with respect to q_t is less than unity.

$$\text{Assumption 2: } 0<\frac{\left(\frac{q_t}{\Pi}\right)\Omega_1}{\Omega}<1. \quad (19)$$

Further integrating (9) subject to (10), and using $k_t^C=\phi(p_t^I\Lambda/\Pi)$,

$$\frac{q_t}{\Pi}=\int_t^\infty\{f'(\phi(p_s^I\Lambda/\Pi))+\left(\frac{p_s^I\Lambda}{\Pi}\right)\Psi(\frac{p_s^I\Lambda}{\Pi};\Lambda)^2T'(\Psi(\frac{p_s^I\Lambda}{\Pi};\Lambda))\}\exp^{-r(s-t)}\,ds. \quad (20)$$

Marginal q_t, which is also equal to average q_t, is the present discounted value of future total value marginal products of capital or future real rentals. Total value marginal product of capital is, in turn, the sum of two terms: the first is the value marginal product of capital in production while the second is the reduction in the marginal cost of installing a given flow of equipment investment due to the increase in capital stock. (The installation cost depends negatively on the amount of capital already in place.[5]) Defining $R_t\equiv\Pi[f'(\phi(p_t^I\Lambda/\Pi))+(p_t^I\Lambda/\Pi)\Psi(\Upsilon(p_t^I\Lambda/\Pi,K_t;\Lambda);\Lambda)^2T'(\Psi(\Upsilon(p_t^I\Lambda/\Pi,K_t;\Lambda);\Lambda))]$, we note that an increase in $p_t^I\Lambda/\Pi$ leads to a rise in the capital intensity (k_t^C) in the ICT-using sector and reduces the value marginal product of capital used in production hence reducing capital rentals. However, an increase in $p_t^I\Lambda/\Pi$ also raises the value of the cost saving from reducing the marginal installation cost as a result of expanding the capital stock hence increasing capital rentals. We make the assumption that the first channel dominates:

$$\text{Assumption 3: } f''\phi'+\Psi^2T'+\left(\frac{p_t^I\Lambda}{\Pi}\right)\Psi\Psi_1\Upsilon_1[2T'+\Psi T'']<0. \quad (21)$$

Hence, $\partial(R_t/\Pi)/\partial(p_t^I\Lambda/\Pi)<0$. We also note that in view of Assumption 1, $\partial(R_t/\Pi)/\partial\Lambda>0$. Ceteris paribus, a technical improvement in the ICT-producing sector raises Tobin's Q, which raises the rate of investment and

[5]Notice that the second term in the expression for the total value marginal product of capital is increasing in the rate of investment I_t/K_t.

increases the rate at which marginal installation cost is reduced by having more capital. Finally, we can readily check that $\partial(R_t/\Pi)/\partial K_t < 0$. Ceteris paribus, a unit increase in capital stock lowers Tobin's Q, which lowers the rate of investment and decreases the rate at which marginal installation cost is reduced by having more capital. We summarize this reduced-form capital rental relationship as:

$$\text{Rental price function } \frac{R_t}{\Pi} = \Phi(\frac{p_t^I \Lambda}{\Pi}, K_t; \Lambda); \ \Phi_1 < 0, \Phi_2 < 0, \Phi_3 > 0. \quad (22)$$

Dynamic system of two equations

We summarize the general-equilibrium system in two dynamic equations in q_t/Π and K_t:

$$\frac{\dot{q}_t}{\Pi} = (r+\delta)\frac{q_t}{\Pi} - \Phi(\frac{p_t^I \Lambda}{\Pi}, K_t; \Lambda), \quad (23)$$

$$\frac{\dot{K}_t}{K_t} = \Psi(\Upsilon(\frac{p_t^I \Lambda}{\Pi}, K_t; \Lambda); \Lambda) - \delta, \quad (24)$$

recalling (15). The slope of the stationary K locus is given by

$$\left.\frac{d(q_t/\Pi)}{dK_t}\right|_{KK} = \frac{-[\Upsilon_2 + \Upsilon_1 \Omega_2 \Lambda]}{\Upsilon_1 \Omega_1 \Lambda} > 0,$$

while the slope of the stationary q locus is given by

$$\left.\frac{d(q_t/\Pi)}{dK_t}\right|_{qq} = \frac{\Phi_1 \Omega_2 \Lambda + \Phi_2}{(r+\delta) - \Phi_1 \Omega_1 \Lambda} < 0.$$

We obtain saddle-path stability as depicted in Figure 2. We use this model for analysis in section 3.

Before proceeding with our analysis, it is useful to point out a neutrality result.

Neutrality result: Starting from an initial steady state obtained by setting $\dot{q}_t = 0$ and $\dot{K}_t = 0$ in (23) and (24), respectively, and taking note of (15), an unanticipated permanent increase in Π leaves q_t/Π, p_t^I/Π, K_t, R_t/Π, v_t/Π and L_t unchanged.

3. Analysis

A pure technological improvement in the ICT-producing sector

To study the effects of a sudden permanent increase in Λ, it is useful to classify two cases depending on how far the relative price of ICT equipment falls in response to the permanent increase in Λ. Case one is where a one percent increase in Λ leads to a less than one percent decline in p_t^I (elasticity less than one) so that $\partial(p_t^I\Lambda)/\partial\Lambda > 0$ (or alternatively that $-1 < \Omega_3\Lambda/\Omega < 0$). Case two is where a one percent increase in Λ leads to a more than one percent decline in p_t^I (elasticity greater than one) so that $\partial(p_t^I\Lambda)/\partial\Lambda < 0$ (or alternatively that $\Omega_3\Lambda/\Omega < -1$). Under Assumption 1' in (18) and Assumption 2 in (19), the increase in Λ leads, in both cases, to a downward shift of the stationary K locus:[6]

$$\left.\frac{d(q_t/\Pi)}{d\Lambda}\right|_{\text{At given } K_t}^{KK} = \frac{\Psi_1(q_t/\Pi)\Omega_3/\Omega^2 - \Psi_2}{(\Psi_1/\Omega)[1-(q_t/\Pi)\Omega_1/\Omega]} < 0.$$

In case one where elasticity is less than one ($\partial(p_t^I\Lambda)/\partial\Lambda > 0$), the stationary q/Π locus could remain invariant or shift downward or upward depending on the size of the two terms in the numerator of the following equation

$$\left.\frac{d(q_t/\Pi)}{d\Lambda}\right|_{\text{At given } K}^{qq} = \frac{\{\Phi_1\Omega[1+(\Omega_3\Lambda/\Omega)]\} + \Phi_3}{r+\delta-\Phi_1\Omega_1},$$

where

$$\left.\frac{d(q_t/\Pi)}{d\Lambda}\right|_{\text{At given } K_t}^{qq} < 0 \text{ if } \{\Phi_1\Omega[1+(\Omega_3\Lambda/\Omega)]\} + \Phi_3 < 0,$$

and

$$\left.\frac{d(q_t/\Pi)}{d\Lambda}\right|_{\text{At given } K_t}^{qq} \geq 0 \text{ if } \{\Phi_1\Omega[1+(\Omega_3\Lambda/\Omega)]\} + \Phi_3 \geq 0.$$

[6] Here, we use this form of the $\dot{K}_t = 0$ equation: $\dot{K}_t/K_t = \Psi((q_t/\Pi)/\Omega(q_t/\Pi, K_t;\Lambda);\Lambda) - \delta$.

To understand the influences at work, we need to understand how the capital rental is affected by an increase in Λ. Recall that the capital rental is the sum of two terms: the first term measures the marginal value contribution of an additional unit of capital used in production while the second term measures the decline in cost of installing a new piece of ICT equipment due to a larger capital stock, a sort of scale economy in installation. When the (absolute value of the) elasticity of equipment price in response to a one-percent increase in Λ is less than one, labor is drawn out of the ICT-using sector into the ICT-producing sector given the stock of capital. Consequently, the value marginal product of capital in production (the first term) declines when Λ increases. On the other hand, an increase in Λ, in reducing equipment prices, raises Tobin's Q and stimulates the pace of investment. Since the marginal contribution of an additional unit of capital in reducing the installation cost is increasing in the rate of investment (I_t/K_t), the second term in total capital rental increases. Unless the cost saving from economies of scale in installing ICT equipment overwhelms the decline in value marginal product of capital in production, the stationary q/Π locus shifts downward as total capital rental drops.[7]

A useful benchmark is when the the cost saving from economies of scale in installing ICT equipment exactly offsets the decline in value marginal product of capital in production when Λ increases so the stationary q/Π locus does not shift at all. In terms of Figure 2, the benchmark case would show a downward shift of the stationary K locus along an unshifted stationary q/Π locus (not shown). The economy's response would show an immediate drop of q_t/Π followed by an expectation of a further decline of q_t/Π. The logic here is that the market's anticipation of reduced future capital rentals caused by the stream of future higher capital stocks causes a drop of stock market capitalization despite a rise of Tobin's Q on account of cheaper ICT equipment.[8]

Figure 3 depicts an illustrative path taken to reach the new steady state when the stationary q/Π locus shifts downward. Market valuation per unit of business asset declines and is expected to continue to fall on its way down

[7]With $\dot{q}_t = 0$, $q_t = R_t/(r+\delta)$.

[8]Due to the rise of the value marginal product of labor in the ICT-producing sector in the elasticity less than one case, capital intensity in the ICT-using sector increases as the capital stock increases.

to a lower steady-state q_t. This implies that the price-earnings ratio must decline in order to offset the expected capital loss so that the yield on the business asset remains equal to the unchanged instantaneous real interest rate. The lower reproduction cost of capital arising from the technological improvement in the ICT-producing sector raises Tobin's Q despite the decline in market valuation of the business asset. These implications, however, do not fit the behavior of asset prices in the late nineties, which saw a rise in all three measures, namely, market valuation, price-earnings ratio and Tobin's Q. As for total employment, unless the decline in firms' valuation induces such a large decline in demand for the ICT good that the net effect is to reduce labor's value marginal productivity, employment at point A is up.

In case two where the elasticity is greater than one $(\partial(p_t^I\Lambda)/\partial\Lambda < 0)$ when the relative price of ICT equipment falls precipitously, the stationary q/Π locus unambiguously shifts upward.[9] In this scenario, the technical advance in the ICT-producing sector prompts such a huge fall in equipment prices that the value marginal product of labor in the ICT-producing sector declines causing a decrease in the capital intensity of the ICT-using sector as employment in the ICT-using sector expands proportionately more than the increase in capital stock. As a result, the value marginal product of capital in production increases so future capital rentals rise on balance. The market valuation of a unit of business asset then jumps up and begins to fall, which we illustrate in Figure 4. The expectation of capital loss together with a rise in the asset price means that the total value marginal product of capital, R_t, must have risen by more than q_t has risen in order to equate yield to the unchanged interest rate. The reduced value of $p_t^I\Lambda/\Pi$, which pulls up capital rentals so helping to justify the rise in business asset valuation, however, implies that the economy-wide real demand wage is reduced thus contracting the total number of hours worked (see (13)). The value of $p_t^I\Lambda/\Pi$ corresponding to point A in Figure 4 must be less than its original value corresponding to point E_0 since point A lies below the new stationary q/Π locus drawn to represent the case of elasticity greater than one $(\partial(p_t^I\Lambda)/\partial\Lambda < 0)$. Along the whole new saddle path AE_1, labor's value marginal productivity is reduced and correspondingly the whole path of employment is shifted down. This implication regarding employment does not match with fact number two.

[9]The stationary q/Π locus also unambiguously shifts upward when the elasticity of equipment price in response to a rise in Λ is unitary.

Do we have any guide as to which is the empirically relevant assumption about the elasticity of equipment price to productivity improvement in the ICT-producing sector? Nordhaus (2005) recently conducted a detailed analysis of the behavior of U.S. employment at detailed manufacturing industry level and found that the lower prices that result from higher productivity have increased demand growth and more than offset the employment-lowering effect of higher productivity. In our model, the shock to the supply price in driving the ICT-producing sector down a given demand curve may or may not increase employment in that sector. When account is taken of the induced upward shift in demand for the ICT good, Figure 4 (covering the case of elasticity greater than one) shows that a net contraction of employment in the ICT-producing sector occurs (the initial rise in firms' valuation which increases the demand for ICT goods in the ICT-using sector is not sufficient to boost the value marginal product of labor in the ICT-producing sector). On the other hand, Figure 3 (covering the case of elasticity less than one) shows that the decline in firms' valuation leads to a fall in the demand for ICT goods in the ICT-using sector. The next exercise combines the sudden permanent increase in Λ at time t_0 with an anticipated future increase in Π to occur at time t_1. Such an anticipation of future TFP improvement in the ICT-using sector, we show, is capable of raising the demand for ICT goods thus causing employment in the ICT-producing sector to expand up till the time when productivity gains in the ICT-using sector are actually realized.

A technological improvement in ICT-producing sector accompanied by an anticipated future technological improvement in ICT-using sector

In Figure 5, we show the trajectory taken by the economy in response to a sudden permanent increase in Λ at time t_0 along with an anticipated future increase in Π to occur at time t_1. At t_0, asset prices jump up and the market forms an expectation of capital gains. Consequently, all three measures of asset prices—market valuation of business assets, price-earnings ratio and Tobin's Q—all jump up. The price-earnings ratio must rise in order to offset the expected capital gain so that the yield on the business asset remains equal to the unchanged instantaneous real interest rate. In the case shown in Figure 5 where elasticity is less than one ($\partial(p_t^I\Lambda)/\partial\Lambda > 0$), the rise in q_t/Π, in stimulating investment spending, unambiguously raises $p_t^I\Lambda/\Pi$ and the economy-wide real demand wage so the total number of hours worked increases. As q_t/Π continues to rise from t_0 to t_1, real workers' compensation is further increased, which increases the incentive to supply labor despite the increase in wealth. Along the trajectory AB in Figure 5, rising asset prices act to lower capital share even while an increase in capital stock works in the opposite direction (Phelps and Zoega (2001) showed that the economies that caught the late nineties investment boom including Canada, Holland, Sweden, the U.K. and the U.S. saw their labor share all increased).[10]

At t_1, asset price q_t does not suffer any discrete drop (to avoid the possibility of windfall gains) but Π increases so q_t/Π suddenly drops.[11] As reproduction cost is increased with the realized productivity gain in the ICT-using sector, Tobin's Q suddenly drops and brings in its wake a drop in investment spending and a decline in employment. Consumption, however, does not experience a similar drop as the ICT-using sector experiences a productivity gain and draws labor out of the ICT-producing and installation sectors.

4. Allowing for trend growth and finite sequence of step-improvements in technology

Aggregate output of the ICT-producing sector is now given by $Z_t^I = \Lambda \exp^{\lambda t} L_t^I$, where we let $\lambda > 0$ represent the trend growth rate. The aggregate output of the ICT-using sector is given by $Z_t^C = \Pi F(K_t, \exp^{\lambda t} L_t^C)$. The total cost required to instal I_t units of equipment (measured in units of the output of the ICT-using sector) is now assumed to be equal to $v_t I_t T(\cdot)/\exp^{\lambda t}$ so that efficiency of installing grows at the exponential rate of λ.[12]

Equation (6) is now replaced by $v_t/\exp^{\lambda t} = p_t^I \Lambda$ and (7) by $v_t/\exp^{\lambda t} = \Pi[f(\tilde{k}_t^C) - \tilde{k}_t^C f'(\tilde{k}_t^C)]$, where $\tilde{k}_t^C \equiv K_t/(\exp^{\lambda t} L_t^C)$. It follows that $\tilde{k}_t^C = \phi(p_t^I \Lambda/\Pi)$; $\phi'(\cdot) > 0$. The term involving k_t^C in (9) is replaced by $\tilde{k}_t^C$. Equation (11) continues to hold and (12) is now replaced by $L_t = \bar{L} - \{B\tilde{K}_t[f(\tilde{k}_t^C)/\tilde{k}_t^C]/[f(\tilde{k}_t^C) -$

[10]The economy's capital share is given by: $[1 + (v/R)\{(\bar{L}/K) - B[f(k^C)/k^C]/[f(k^C) - k^C f'(k^C)]\}]^{-1}$.

[11]Observe from (15) that at t_1 when Π increases, the drop in q_t/Π given K_t and Λ means that p_t^I/Π falls. From (14), the lower p_t^I/Π given K_t and Λ means that q_t/p_t^I falls. Since q_t does not fall at t_1, p_t^I must have risen so the productivity surge in the ICT-using sector at t_1 raises the cost of investing.

[12]Making this assumption will mean that if the economy grows along its trend path, installing an additional piece of ICT equipment does not become steadily more costly.

$\tilde{k}_t^C f'(\tilde{k}_t^C)]\}$. Noting $\tilde{k}_t^C = \phi(p_t^I \Lambda/\Pi)$; $\phi'(\cdot) > 0$, we can readily check that (13) is now replaced by $L_t = \mathrm{L}(\tilde{K}_t, p_t^I \Lambda/\Pi)$; $\mathrm{L}_1 < 0, \mathrm{L}_2 > 0$, where $\tilde{K}_t \equiv K_t/\exp^{\lambda t}$. Equations (14), (15), (16) and (22) continue to hold with K_t replaced by $\tilde{K}_t$.

The general-equilibrium system in two dynamic equations in q_t/Π and $\tilde{K}_t$ is given by:

$$\frac{\dot{q}_t}{\Pi} = (r+\delta)\frac{q_t}{\Pi} - \Phi(\frac{p_t^I \Lambda}{\Pi}, \tilde{K}_t; \Lambda), \tag{25}$$

$$\frac{\dot{\tilde{K}}_t}{\tilde{K}_t} = \Psi(\Upsilon(\frac{p_t^I \Lambda}{\Pi}, \tilde{K}_t; \Lambda); \Lambda) - (\delta + \lambda), \tag{26}$$

where we note that $p_t^I/\Pi = \Omega(q_t/\Pi, \tilde{K}_t; \Lambda)$. It is readily checked that saddle-path stability exists and the phase diagram is similar to Figure 2 with K_t replaced by $\tilde{K}_t$. A steady state of the system, therefore, exists (absent any shock) with capital stock and real hourly wage growing at the trend growth rate λ but relative equipment price, Tobin's Q, capital rentals, shadow price of capital, and total hours worked remain unchanged.

We can use the dynamic system represented by (25) and (26) to study the following problem. Suppose that we let the parameter Λ undergo discrete jumps at lengths of regular time intervals given by Δ. Suppose that at time 0, the parameter that initially takes the value Λ_0 suddenly jumps to Λ_1, $\Lambda_1 > \Lambda_0$. Between time 0 and Δ, the new technology index in the ICT-producing sector is given (in natural logs) by $\log \Lambda_1 + \lambda t$, $0 \leq t < \Delta$.[13] Then, in period $\Delta \leq t < 2\Delta$, it becomes $\log \Lambda_2 + \lambda t$, where $\Lambda_1 < \Lambda_2$. In general, for $j\Delta \leq t < (j+1)\Delta$, $j = 0, 1, 2, \ldots, J$, we have the technology parameter taking on the value $\log \Lambda_{j+1} + \lambda t$, with $\Lambda_j < \Lambda_{j+1}$.

For concreteness, suppose that $J = 2$ so that after the sudden step-increase at time 0 from the initial Λ_0 to Λ_1, the market at time 0 anticipates two further consecutive step-improvements in Λ that will occur in the future. Let us take the benchmark case where the cost saving from economies of scale in installing ICT equipment exactly offsets the decline in marginal product of capital in production each time Λ experiences a step-improvement so the stationary q/Π locus in the $(\tilde{K}_t, q_t/\Pi)$ plane does not shift. Figure 6 shows that

[13] In a graph depicting $\log \Lambda_t \equiv \log \Lambda_i + \lambda t$, $i = 1, 2, \ldots, J$ against time, there is a vertical parallel displacement whenever a step-improvement in $\log \Lambda_i$ occurs.

q_t/Π immediately drops from E_0 to A before continuing a steady decline along $ABCE_1$. The economy is at point B when the second step-improvement in Λ takes place and at point C when the third step-improvement occurs after which it travels along the new saddle path to reach final point E_1. An anticipation of a future step increase in Π in the ICT-using sector can once again be shown to generate a rise in the stock market until its realization when q_t/Π suddenly drops (not shown).

5. Endogenizing the rate of interest

To endogenize the rate of interest in the basic model, we use (1), (3) and (4) and equate consumption demand to supply to obtain

$$r_t = \rho + \theta(\theta + \rho)\left(\frac{q_t}{\Pi f(k_t^C)/k_t^C}\right) + \frac{\dot{Z}_t^C}{Z_t^C}. \tag{27}$$

Further noting

$$\frac{Z_t^C}{\Pi} = \Gamma(K_t, \frac{p_t^I \Lambda}{\Pi});\ \Gamma_1^C > 0, \Gamma_2^C < 0,$$

(15), (23) and (24), we obtain a reduced-form interest rate function,

$$\text{Interest rate function: } r_t = \mathrm{r}(q_t/\Pi, K_t; \Lambda, \rho, \theta). \tag{28}$$

Substituting (26) into (23), we obtain

$$\frac{\dot{q}_t}{\Pi} = (\mathrm{r}(\frac{q_t}{\Pi}, K_t; \Lambda, \rho, \theta) + \delta)\frac{q_t}{\Pi} - \Phi(\frac{p_t^I \Lambda}{\Pi}, K_t; \Lambda). \tag{29}$$

In conjunction with (15), (29) and (24) give the pair of dynamic equations summarizing the general equilibrium system wherein the interest rate adjusts endogenously. A sufficient set of conditions for saddle-path stability is that $\mathrm{r}_1 > 0$ and $\mathrm{r}_2 > 0$. A diagram similar to Figure 2 is obtained. We leave it to the interested reader to pursue the analysis with this dynamic system.

6. Related literature and conclusion

One major idea in our paper is that the macroeconomic effects of technical improvement in the ICT-producing sector are very different from those arising from productivity gains achieved in the ICT-using sector. While technical improvements in the ICT-producing sector are well-documented, is there any evidence that industries that have made investments in ICT equipment have also achieved productivity gains (beyond what is expected from capital deepening) after a waiting period since it is a time-consuming process to re-organize work practices and business processes in order to enjoy the benefits of cheaper ICT equipment? Brynjolfsson and Hitt (2000) use several case studies to show that cheaper ICT equipment spurs managers to create new processes and organizational structures to take advantage of information technology. Bresnahan, Brynjolfsson and Hitt (2002) further point to the complementarity that exists between ICT equipment investment and workplace re-organization based on firm-level evidence. Beaudry and Portier (2004) find empirical evidence in the U.S. that news regarding shifts in future technological possibilities is important in explaining business fluctuations.

Caballero, Farhi and Hammour (forthcoming) also examine the extraordinary rise of the stock market in the U.S. in the 1990s but argue that this was due to low real interest rates in that decade compared to the 1980s. A reduced cost of borrowing in our basic model will shift the stationary q/Π locus upwards and juxtaposed against the downward shift of the stationary K locus can deliver the result that the stock market rises and employment expands along with cheaper ICT equipment prices. The problem with relying on a reduced cost of borrowing to explain the stock market boom, however, is that (in our model) the stock market jumps up to reach its peak initially (when the real interest rate suddenly falls) and gradually declines whereas in actual fact the U.S. stock market steadily rose until it reached its peak in 2000. The decline in the stock market from 2001 would require a sudden rise in the real rate of interest in 2001, which did not occur.

We see the 1990s boom and its unwinding and slide into an outright slump from 2000 to mid-2003 having some striking parallels to the boom of the roaring 1920s and the deep decline into the early 1930s.[14] Both experiences began with an investment boom, then a downturn in investment while consumption held up pretty well. Economic activity closely tracked investment: Employment and hours worked were elevated from 1925 to 1929 and were again elevated in the second half of the nineties. Each boom was

[14] For a more detailed causal account of the 1990s/2000s and the 1920s/1930s, see Phelps (2004).

caused by the advent of a new general-purpose technology—commercially available electric power in the 1920s, the information and communication technologies in the 1990s. The basic mechanisms are simple, though not widely understood: New visions of future profits raise the values (per unit) that entrepreneurs and CEOs put on new investments in business assets without raising the cost (not soon at any rate) the cost of acquiring them; this prompts stepped-up investing in such assets. In addition, increases in these asset values eventually lead to a sympathetic rise in share prices, despite errors and distortions. These developments in turn have labor-demand effects pulling up wages, hours, and employment. The realization of cost-savings and productivity gains by the end of the decade made possible by the 1920s investments in the new general-purpose technology was what led to the slump in the 1930s. (Field (2003) found empirical evidence to support his hypothesis that the Depression years were, in the aggregate, the most technologically progressive of any comparable period in U.S. economic history.) The surge of productivity reduced the incentive to invest since what ultimately determines the rate at which firms invest is the value (per unit) put on its business assets taken as a *ratio* to the *cost* of acquiring the asset (per unit). This led to a cut in investment activity, causing employment to decline. In our model, the cost of acquiring a unit of the business asset was increased by the realization of productivity gains in the ICT-using sector. The general message of our paper is this: It is a mistake to see productivity increases as creating jobs. Distinctions are required. *New expectations* of *future* productivity increases are a strong job creator. *Actual* increases are different.

References

Beaudry, Paul and Franck Portier, 2004, "Stock Prices, News and Economic Fluctuations," *NBER Working Paper*, No. 10548, June.

Bresnahan, Timothy, Erik Brynjolfsson and Lorin Hitt, 2002, "Information Technology, Workplace Organization, and the Demand for Skilled labor: Firm-Level Evidence," *Quarterly Journal of Economics*, Vol. 117, No. 10, February, 339-76.

Brynjolfsson, Erik and Lorin Hitt, 2000, "Beyond Computation:

Information Technology, Organizational Transformation and Business Practices," *Journal of Economic Perspectives,* Vol 14, No. 4, Fall, 23-48.

Ricardo Caballero, Emmanuel Farhi and Mohamad L. Hammour, forthcoming, "Speculative Growth: Hints from the U.S. Economy," *American Economic Review.*

Feldstein, Martin, 2003, "Why is Productivity Growing Faster?" NBER Working Paper No. 9530.

Field, Alexander J., 2003, "The Most Technologically Progressive Decade of the Century," *American Economic Review,* Vol. 93, No. 4, September, 1399-413.

Jorgensen, Dale, 2001, "Information Technology and the U.S. Economy," *American Economic Review*, Vol. 90, No. 1, March, 1-32.

Jorgensen, Dale, 2005, "Accounting for Growth in the Information Age," in Philippe Aghion and Steven Durlauf, eds., *Handbook of Growth Economics*, Amsterdam, North-Holland.

Nordhaus, William, 2005, "The Sources of the Productivity Rebound and the Manufacturing Employment Puzzle," *NBER Working Paper*, No. 11354, May.

Phelps, Edmund S., 2004, "The Boom and the Slump: a Causal Account of the 199s/2000s and the 1920s/1930s," *Policy Reform,* Vol. 7, No. 1, March, 3-19.

Shiller, Robert J., 2005, *Irrational Exuberance,* second edition, Princeton and Oxford: Princeton University Press.

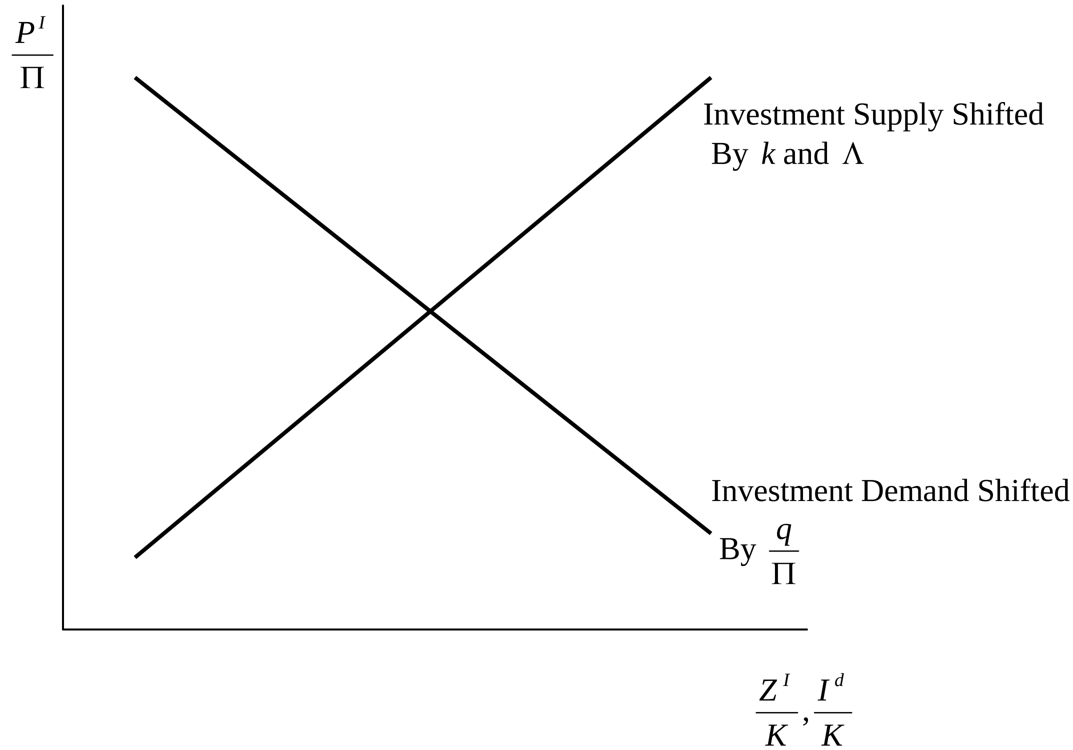

Figure 1: Investment Demand and Supply

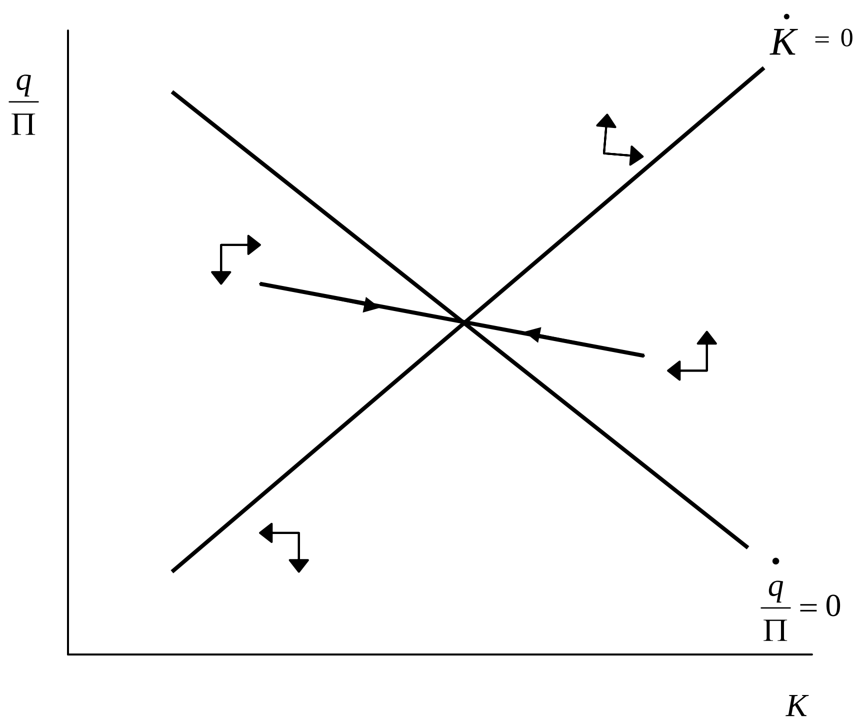

Figure 2: Saddle-Path Stability

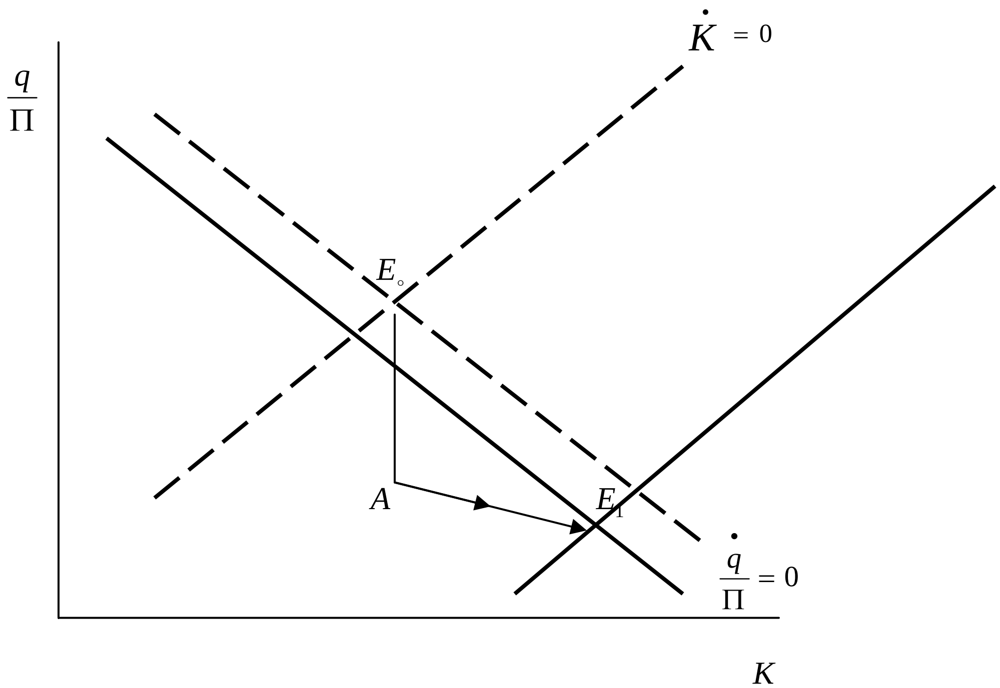

Figure 3: Pure Increase in Λ with $\frac{q}{\Pi}$ Initially Dropping

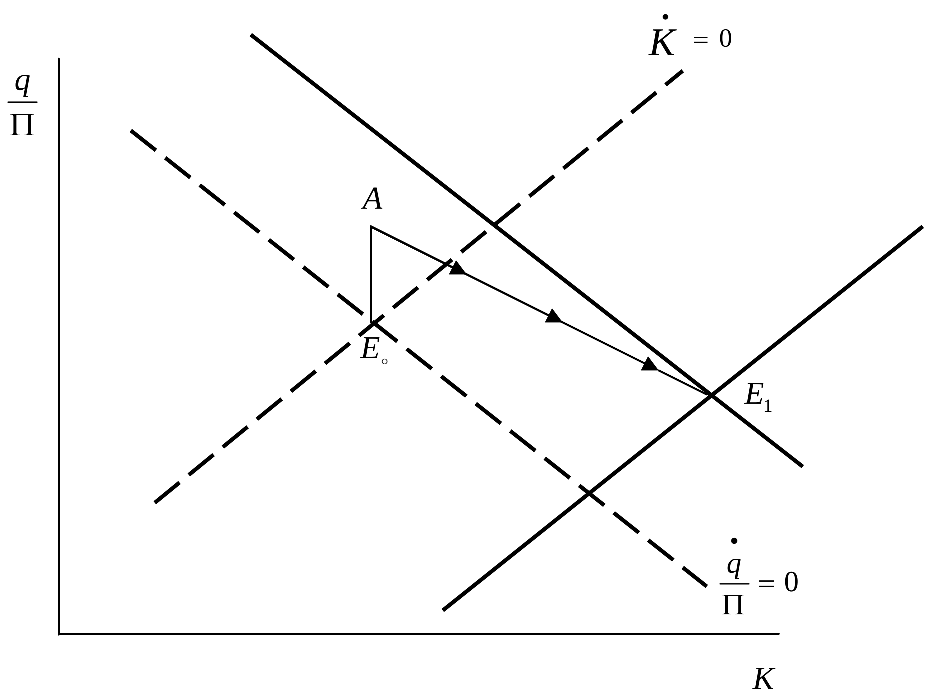

Figure 4: Pure Increase in Λ with $\frac{q}{\Pi}$ Initially Jumping Up

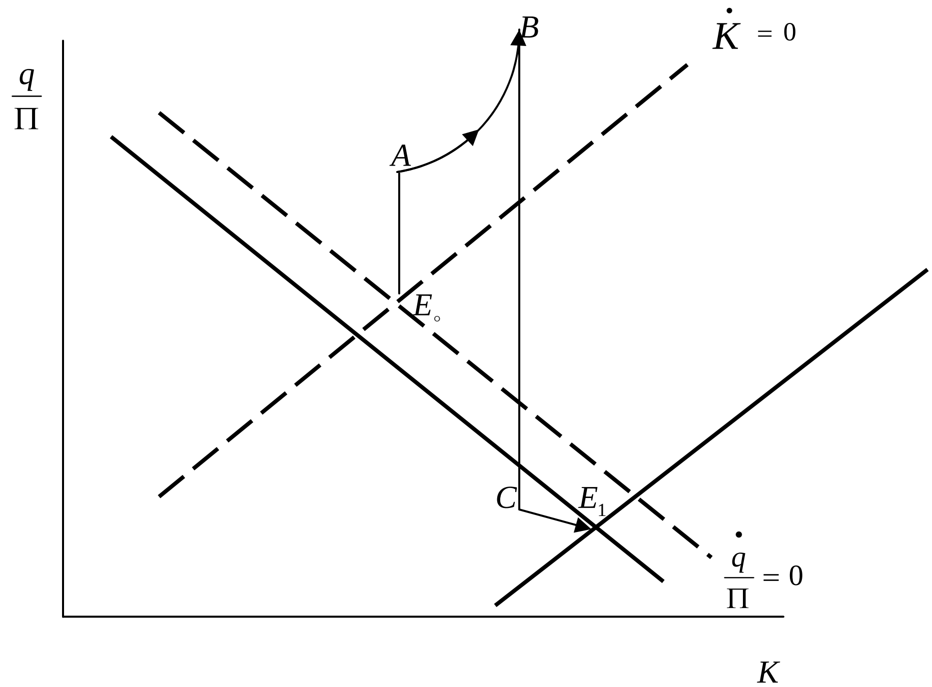

Figure 5: Sudden Increase in Λ Accompanied by
Anticipated Increase in Π

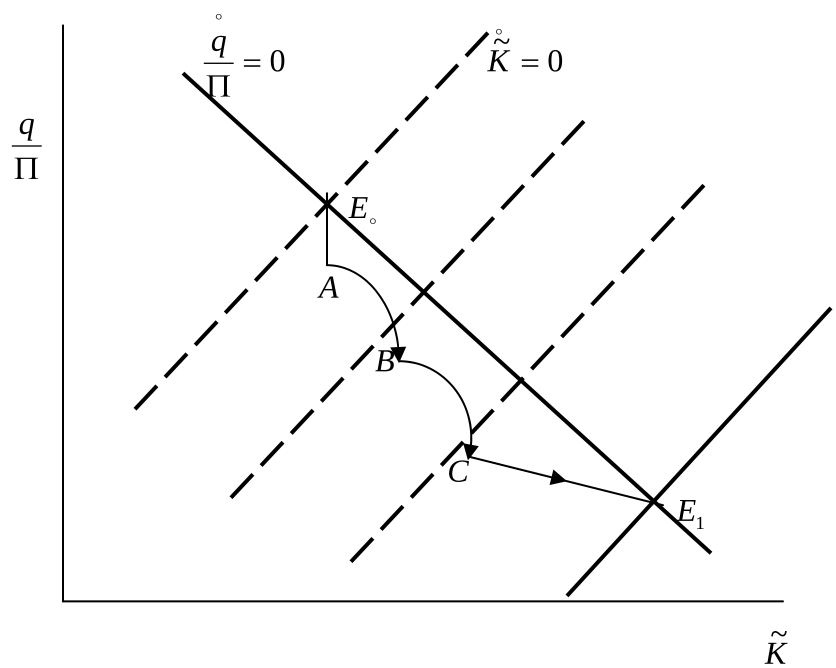

Figure 6: Sequence of Step-Improvements in Λ