

The Information Technology Revolution and the Puzzling Trends in Tobin's average q

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Abstract

The market value of US corporations declined by 50% during the period 1973-74 and stagnated for the following 15 years. This abrupt decline in market valuations coincided with a good news shock - the start of the Information Technology Revolution - and a bad news shock - a slowdown in productivity growth -. I use general equilibrium theory to quantify the equity price and macroeconomic implications of these two shocks. The Information Technology Revolution and the observed productivity slowdown make the theory consistent with the secular trends of US corporate capital, output, and productivity from the mid 1970s to the 1990s. Most of the observed drop in market values can also be accounted for. Theories based exclusively on good news are shown to conflict with one or more of the main features of US aggregate data (*JEL* E44, O33, O41)

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1 Introduction

It has been argued that a good news shock hit the US economy during the mid 1970s. This positive shock was comprised of the start of a new industrial revolution based on Information Technologies (cf. Greenwood and Yorukoglu [12], Greenwood and Jovanovic [13], Hobijn and Jovanovic [17]). A bad news shock, consisting of a three-fold decline in the growth rate of total factor productivity, also hit during the mid 1970s. These major changes in the production possibilities of the US economy coincided with one of the largest and more persistent declines in market capitalization ever experienced by the US stock market. During 1973-1974, the market value of existing corporations, shown in Figure 1 as a ratio of the replacement value of their capital stock¹ (i.e., Tobin's average q), went down by 50% and did not recover until the 1990s.

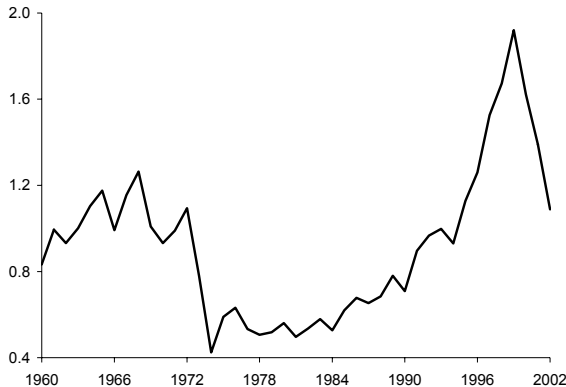


Figure 1: Market value of US corporations as ratio to the replacement cost of their tangible assets

I employ an inter-temporal general equilibrium model of capital asset pricing to quantify the equity price and macroeconomic implications of the joint arrival of good news and bad news. A key element of my analysis is the growth accounting decomposition of Jorgenson [18] who studied the US economy from 1948 to 2002, splitting it into Information Technology (IT) producing sectors and non-IT producing sectors. One of Jorgenson's main findings was that the productivity slowdown of the mid 1970s was localized in non-IT producing sectors and that almost all productivity growth between 1973 and 1989 could be attributed to large productivity gains in the IT producing sectors. Motivated by these data, I take a stylized view of 1974, modeling good news as the unexpected arrival of a better technology and bad news as an unexpected slowdown in the productivity of old production methods. I find that the good news and the bad news shock taken together make the equilibrium time series of the model consistent with the secular trends of consumption, corporate

¹Figure 1 is based on data from the flow of funds (market value) and the wealth tables (capital stock) reported by the BEA (see the data appendix for the details). The timing and magnitude of the major movements observed in this figure are robust to the use of the improved investment and capital stock data in Gordon [11].

capital, output, and productivity. Moreover, more than half of the observed drop in equity prices is also accounted for.

I also find that theories of the stock market crash of 1974 based exclusively on good news, which have received increased attention in recent years, conflict with one or more of the main features of the US data. To accomplish this, I evaluate two different types of good news shocks. In the first one, agents learn of the future arrival of a new, better, technology (as in Greenwood and Jovanovic [13] or Hobijn and Jovanovic [17]) and realize that existing production methods and all of the capital therein installed are about to become obsolete. My analysis shows that learning about the future arrival of a better technology cannot deliver a consistent explanation for the observed patterns in equity prices and those in corporate output, capital stock, and consumption. The second type of good news shock that I consider consists of the actual arrival of a new better technology (as in Laitner and Stolyarov [21] or Jovanovic and Rousseau [19]). Numerical experiments show that even in an extreme setup where investment is completely irreversible and capital is immobile across existing technologies, equity prices can fall substantially but the model must imply a strong expansion of corporate GDP and total factor productivity. The latter two predictions of the model are the opposite to what one observes in the data.

My paper focuses on the 1974-1990 period, and it does not try to account for the boom and subsequent collapse in equity prices of 1990-2002. I give a particular emphasis to the study of what Hall [15] calls the “single hardest episode to understand” about the behavior of US equity markets: the market value of US corporations was much lower than the replacement cost of their tangible assets, i.e. Tobin’s average q was lower than one, from 1974 to 1990.

2 Related literature

Jovanovic and Rousseau [19] show that the unexpected arrival of a better technology causes a sudden drop in Tobin’s average q . The authors are, however, interested in explaining the merger waves of the US economy. Mergers are, in their view, a way for the economy to reallocate resources from low q firms to high q firms. For the purpose of studying resource reallocation, the authors develop a model in which capital can be transferred across different technologies. As a result, the decline in market value predicted by their theory is much smaller than what my model achieves. Finally, and because of the nature of the questions that Jovanovic and Rousseau [19] address, their paper does not contrast the macroeconomic implications of the IT revolution against the data. The latter is one of the main objectives of my study.

The closest paper in spirit and basic intuition is Laitner and Stolyarov [21]. The authors analyze the negative impact of a technology revolution on the stock market using a general equilibrium framework. Three things distinguish their study from mine. First, they only consider the impact of

a good news shock on the US stock market. Second, the authors assume a fixed saving rate, which makes their model not suitable for studying the implications of the IT-revolution on aggregate saving and investment. As I show later, fixing the saving rate hides one of the main counterfactual implications of the good news hypothesis. In my theoretical analysis the saving rate is endogenous. Finally, Laitner and Stolyarov [21] see the IT-revolution as a once-and-for-all increase in an otherwise constant level of total factor productivity. According to their model, the growth of per capita GDP should have declined monotonically after the arrival of the IT-revolution. That is not what we see in the US data. I instead capture the IT-revolution as a temporary change in an exogenously growing level of total factor productivity so that GDP per capita has a constant long-run growth rate.

My analysis abstracts from intangible capital. As Hall [16] points out, a theory of equity price movements based on fluctuations in intangible assets would have to explain why intangibles suddenly disappeared during 1974-90, and why firms chose to accumulate assets of zero or negative returns for more than a decade. McGrattan and Prescott [24] and Li [22] have computed some indirect measures of intangible capital and conclude that movements in intangibles cannot account for the observed fluctuations in Tobin's average q .

A related study of asset price movements based on technological change is Wei [34], who evaluates the impact of the energy crisis on the stock market. She focuses on a putty-clay model where higher energy prices affect market values via higher total costs and lower dividend flows. As the share of energy in total costs is small the energy crisis translates into a 2% drop in market values. Alpanda and Peralta-Alva [1] consider a framework where energy saving technological change is a choice rather than an exogenous event. However, the development and adoption of energy saving capital involves a one-shot fixed cost. Energy saving technologies are also subject to learning by doing. The authors conclude that the energy price hike of the mid 1970s, together with the energy-saving innovation it triggered, can account for a substantial drop in market valuations.

3 The model

This section presents a general equilibrium asset-pricing model with capital accumulation and production, based on Brock [5], which will be the basis of my quantitative analysis. The saving rate is endogenously determined so as to quantify the effects of good news and bad news on aggregate investment. Once capital accumulation and endogenous savings are taken into account good news have a dramatically different effect on equity prices than what Greenwood and Jovanovic [13], Hobbijn and Jovanovic [17] and Laitner and Stolyarov[21] obtain. I also assume capital to be technology-specific and irreversible, as is standard in the literature (e.g. Dixit and Pindyck [8], and

Sargent [32])².

I now describe the model in detail, define a competitive equilibrium, and obtain a characterization for Tobin's average q .

3.1 Households and equity markets

Preferences of the representative household can be represented by

$$\sum_{t=0}^{\infty} \beta^t u(c_t),$$

where t indexes time, c is per-capita consumption, and $0 < \beta < 1$ is the discount factor. Each household has n_t units of time, and supplies them inelastically to the labor market. The household's problem consists of choosing the sequences of consumption and asset holdings that maximize utility subject to its budget constraint

$$\sum_{t=0}^{\infty} p_t \{c_t + V_t(s_{t+1} - s_t)\} \leq \sum_{t=0}^{\infty} p_t \{d_t s_t + w_t n_t\}$$

$$s_t \geq 0, \quad s_0 \text{ given.}$$

The Arrow-Debreu price, denoted by p_t , is the date-0 value of one unit of consumption in period t . I denote by s_t the number of shares held at the beginning of period t , and by V_t the price per share. The wage is w_t , and dividends per-share d_t . Household's income equals labor earnings, $w_t n_t$, plus total dividend income, $d_t s_t$. Expenditures are consumption, c_t , and net purchases of shares of stocks, $V_t(s_{t+1} - s_t)$. Thus, the present value of the household expenditures must be less than or equal to the present value of its income.

At every given period there is one perfectly divisible equity share outstanding. Hence, market clearing in the market for shares requires $s_t = 1$ for all t (per person).

3.2 Firms and aggregate resource constraints

Firms have potential access to two different technologies (and types of capital, k_1 and k_2) and hire labor to produce an identical output good. The productivity sequences for each of the two production functions, A_1 and A_2 , respectively, follow a deterministic exogenous process. Corporate output is taxed over time at a constant rate τ_y . Tax revenues are wasted by the government (thrown into the ocean). The problem of the representative firm is to find the sequences of investment and

²For an optimal growth model to generate values of q below one, a positive cost of transforming capital into consumption, and of moving capital across different technologies, must exist.

labor that maximize the present value of dividends

$$\max_{\{x_1, x_2, n_1, n_2\}} \sum_{t=0}^{\infty} p_t \left[\sum_{i=1}^2 \{(1 - \tau_y) F_i(k_{i,t}, A_{i,t} n_{i,t}) - w_t n_{i,t} - x_{i,t}\} \right]$$

s.t.

$$\begin{aligned} k_{i,t+1} &= x_{i,t} + (1 - \delta)k_{i,t} \\ A_{i,t+1} &= \gamma_i A_{i,t} \\ x_{i,t} &\geq 0 \text{ for } i = 1, 2 \\ 0 &< \delta \leq 1, \gamma \geq 1 \\ &\text{given } A_{1,0}, A_{2,0}, k_{1,0} \text{ and } k_{2,0}. \end{aligned} \tag{1}$$

The constraints in (1) imply that investment is irreversible. Newly produced goods can be either consumed or used to augment the stock of capital. But once designated as a given type of capital, they cannot be physically converted into consumption or the other type of capital. Finally, the economy's aggregate resource constraints are

$$\begin{aligned} \text{(AR)} \quad x_{1,t} + x_{2,t} + c_t &= (1 - \tau_y) \sum_{i=1}^2 F_i(k_{i,t}, A_{i,t} n_{i,t}) \\ n_{1,t} + n_{2,t} &= n_t \text{ for all } t. \end{aligned}$$

3.3 Competitive equilibrium

A competitive equilibrium is a sequence of prices $\{p_t, V_t\}_{t=0}^{\infty}$ and allocations of consumption, asset holdings, investment, capital, and labor $\{c_t, s_{t+1}, x_{1,t}, x_{2,t}, k_{1,t+1}, k_{2,t+1}, n_{1,t}, n_{2,t}\}_{t=0}^{\infty}$ such that

1. Given s_0 and prices, $\{c_t, s_{t+1}\}$ are a solution to the household's problem
2. Given prices, $\{x_{1,t}, x_{2,t}, k_{1,t+1}, k_{2,t+1}, n_{1,t}, n_{2,t}\}$ solve the problem of the firm, and
3. The allocations $\{c_t, s_{t+1}, x_{1,t}, x_{2,t}, k_{1,t+1}, k_{2,t+1}, n_{1,t}, n_{2,t}\}$ are such that all markets clear and the aggregate resource constraints (AR) are satisfied at all $t \geq 0$.

As a consequence of the aggregate resource constraints (AR), and of the laws of motion of capital, one has

Remark 3.1 *In terms of period t consumption, the replacement cost of each unit of capital is constant and equal to one*

It is now possible to relate the theory to the data³ in Figure 1. Market capitalization in the model, as of the end of period t , equals V_t , and that is the numerator of q . The model's total replacement cost of existing capital at the beginning of period $t + 1$ is $k_1 + k_2$. The latter is the denominator of q , and thus

Remark 3.2 *The model's measure of Tobin's average q is*

$$q_t = \frac{V_t}{k_{1,t+1} + k_{2,t+1}}.$$

My analysis is based on a one-sector neoclassical growth model. Two facts suggest that a one-sector model is appropriate for evaluating the effects of the IT-revolution on US equity prices. First, the total market value of each and every one of the two-digit SIC industries reported by CRSP went down by at least 30% from 1972 to 1974. Hence, the stock market crash of 1973-74 was present in all sectors of the economy and can be studied within an aggregate model. Second, the main theoretical implications tested here extend without change to a more general multi-sector environment. In particular, for Tobin's average q to fall below one in a multi-sector model (where capital is sector and technology specific) it is necessary for at least one of the irreversibility constraints to bind along the equilibrium path (compare this to Propositions 4.1 and 5.1 below).

I have also restricted my analysis to a perfectly competitive environment, which seems to be a good starting point for my study. In particular, the data suggests that the stock market crash was not caused by the potential loss of monopoly rents associated to the entry of new firms - which are the ones that have the comparative advantage in adopting the new technologies -. If the stock market crash of 1973-74 was caused by a decrease in the monopoly power of incumbent firms then the level of industrial concentration (one of the standard measures for the level of monopoly power) should have decreased as a result of the IT-revolution. The empirical papers by Attaran and Saghafi [3] and O'Neill [26] do not validate the previous implication. If anything, the level of concentration increased during 1974-84. Secondly, the market value to output ratio of the 1972 incumbents⁴ started recovering from its 1973-74 fall around 1986. If incumbents were to lose their monopoly rents as a result of increased competition then their market value to output ratio should not have recovered. Finally, if this hypothesis was true then one should find a strong negative correlation between the cashflow of incumbents and that of the new firms entering the market. In contrast to this one finds that the actual correlation between cashflows is either positive or statistically

³A complete model of the US economy would have a corporate and a non-corporate sector. The results I obtained when simulating such a model were essentially the same as the ones presented here. However, the analysis was much more convoluted and harder to relate to the existing literature. For the sake of simplicity, and knowing the aforementioned incompleteness is irrelevant for the results, I use a one sector model in all of what follows.

⁴The market value to output ratio of incumbents I talk about consists of the aggregate market value to sales ratio of the firms that were listed in the Standard and Poor's compustat data base in any year previous to 1972.

insignificant⁵.

The rest of the paper is structured as follows. Section 4 studies the impact of learning about the future arrival of a better technology. Section 5 considers, first, a good news shock consisting of the actual arrival of a better technology. Then, it examines the quantitative implications of the arrival of a better technology paired with a slowdown in the productivity of old production methods. Section 6 concludes.

4 News about the future arrival of a better technology

4.1 The economic environment before the shock

I depart from a situation where, both, technology and capital of type 2 are not available. Thus, k_2 and x_2 are constrained to be zero. I assume F_1 and F_2 to be homogeneous of degree one, and that the share of total income going to labor is constant and equal to $1 - \alpha$. Any change in this state of affairs is assumed impossible.

To simplify the analysis, I also assume that the production and the utility functions satisfy the following Inada-type conditions: F_1, F_2 and u are strictly increasing, strictly concave, $\lim_{k_i \rightarrow 0} \frac{\partial}{\partial k_i} F_i(k_i, A_i n_i) = \infty$, and $\lim_{k_i \rightarrow \infty} \frac{\partial}{\partial k_i} F_i(k_i, A_i n_i) = 0$ for $i = 1, 2$. Finally, $\lim_{c \rightarrow 0} u'(c) = \infty$ and $\lim_{c \rightarrow \infty} u'(c) = 0$.

The following result characterizes the equilibrium behavior of Tobin's average q .

Proposition 4.1 *Whenever the irreversibility constraint binds $q < 1$; otherwise $q = 1$*

All proofs are given in Appendix 7.2. Proposition 4.1 explains how the market value of a firm can go lower than the replacement cost of its assets. In a world where investment decisions are *reversible*, if agents have too much capital they can then consume a portion of it and bring it back to its optimal level. In a world where capital is *irreversible*, it is impossible to resort to this mechanism. When agents have a stock of capital larger than the optimal one irreversibility binds and the price of capital falls below one.

In the present optimal growth model, agents would never over-accumulate capital and irreversibility would never bind. Learning about the future arrival of a better technology - the good news shock - can make q go down because it alters optimal investment allocations. Sub-sections 4.2 and 4.3 below evaluate the quantitative implications of this mechanism.

⁵In particular, the correlation between the time series behavior of the operating income (item13) to sales (item12) ratio of US firms listed in compustat before 1972 (the incumbents) and those listed in any future date (the new firms) is positive but statistically insignificant.

4.2 The future arrival of a better technology is announced

In period zero, agents learn about the future arrival of a better technology (and its associated type of capital). Technology of type 2 will become available starting at period $T > 0$. Technology 2 is better because it has a higher productivity level (i.e. $A_2 \geq A_1$). However, investment in the new type of capital is not permitted before period T . No further shocks are expected.

If the two types of capital are substitutes in the production of the final good then good news can make the market value of old capital fall. The new type of capital may displace old capital as an input and this will show up as a lower price for old capital. That is the transmission channel emphasized by Hobijn and Jovanovic [17]. In my model F_1 and F_2 are perfect substitutes in the production of the final consumption good, which maximizes the negative impact of good news on equity prices.

4.3 Testing the theory

The equilibrium behavior of Tobin's average q after the announcement of the future arrival of a better technology can be characterized as follows [cf. Lemma 4.1 in the appendix]

$$(2) \quad q_t = \left(1 - \frac{\mu_{1,t}}{p_t}\right) \text{ for all } 0 \leq t < T,$$

where $\mu_{1,t}$ is the multiplier associated to the irreversibility constraint of k_1 .

What are the implications of assuming that the announcement of a new technology caused the stock market collapse and stagnation of the mid 1970s? First, for q to fall below one irreversibility must bind from the time of the shock, $t = 0$, up to period T . Then, regardless of the specific functional forms that F_1 , F_2 and u may take, the law of motion of aggregate capital becomes

$$(3) \quad k_{1,t+1} = (1 - \delta)^t k_{1,0} \text{ for } t = 0, \dots, T.$$

If good news caused any drop in the stock market on 1974 and also the subsequent stagnation of q then one should see the capital stock of the US economy decreasing at a 6% (δ) annual rate during the 1974-1984 period. This prediction is the opposite of the 27% increase in the net stock of capital reported by the BEA.

In a world without capital accumulation, Hobijn and Jovanovic [17] show that the announcement of a new technology can explain the observed patterns in the market value to corporate output ratio illustrated by the bold line in Figure 2 below.

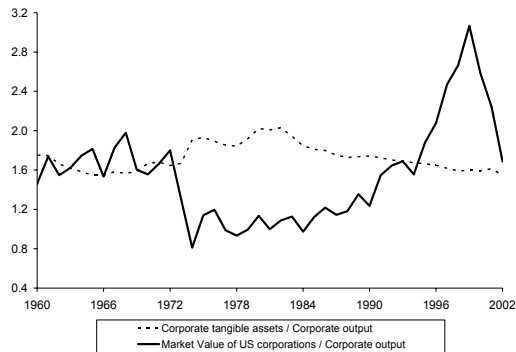


Figure 2: Market and replacement value of corporate assets as ratios to corporate output

However, in a one-sector Neoclassical growth model, good news cannot explain the trends in the market value to corporate output ratio. As discussed above, a continuously binding irreversibility constraint is not consistent with the US capital stock data. On the other hand, a non-binding irreversibility constraint forces the market value of capital to equal its replacement cost. If good news caused the 50% drop in the market value to corporate output ratio one should see the corporate capital to corporate output ratio decreasing by 50% around 1974 and staying at that level for the following decade. Such predictions are orthogonal to the data plotted in Figure 2.

In conclusion, once capital accumulation is introduced into the analysis, learning about the future arrival of a better technology could neither have caused the stock market collapse of 1974 nor the stagnation that followed.

5 Arrival of information technologies and productivity slowdown

In this section I model the information technology revolution as the sudden arrival of a new, better, technology. It is straightforward to show this shock causes irreversibility to bind for investment on capital of type 1. When a better technology becomes available it is pointless to continue investing in the old type of capital (which can only be used in the technology with a lower total factor productivity). As a result, the market value of old capital declines and Tobin's average q falls below one.

The present theory implies a positive correlation between the productivity level of the new technology, relative to that of the old one, and the resulting drop in Tobin's q . I will start by assuming that the IT-revolution was the main force causing the stock market crash of 1973-74. In particular, I will set the level of productivity of the new technology so that the model accounts for most (two thirds) of the observed drop in Tobin's average q . As I discuss later on, the qualitative properties of the model are the same regardless of the magnitude of the drop one requests from the theory. I compare the implied equilibrium time series from the model to their US data counterparts. The congruence between the theory and the data tests the consistency of the IT-hypothesis.

5.1 The economic environment before the shock

To perform quantitative analysis one has to determine the functional forms of the production and utility functions of the model. As is standard in the literature, I choose a Cobb-Douglas specification for F_1 and F_2 , so that

$$\begin{aligned} \text{corporate } GDP &= k_1^\alpha (A_1 n_1)^{1-\alpha} + k_2^\alpha (A_2 n_2)^{1-\alpha} \\ &\text{with } 0 < \alpha < 1. \end{aligned}$$

I also assume $u(c_t) = \frac{c_t^{1-\sigma}}{1-\sigma}$ when $\sigma \neq 1$, and $u(c_t) = \ln(c_t)$ when $\sigma = 1$.

Before the shock, the technology using capital of type 2 is not available, and investment in this type of capital must equal zero. The economy is assumed to start at its balanced growth equilibrium. Agents expect these conditions to prevail forever.

5.2 Arrival of Information Technologies

In period zero a new, better, technology arrives. It is better because its TFP level is higher than that of the old technology⁶. In particular,

$$\begin{aligned} A_{2,0} &> A_{1,0} \\ \frac{A_{2,t+1}}{A_{2,t}} &= \frac{A_{1,t+1}}{A_{1,t}} = \gamma. \end{aligned}$$

When taking the model to the data, period zero will be assumed to be 1974. The equilibrium behavior of q is characterized by the following result.

Proposition 5.1 *For q to be lower than 1 at least one of the irreversibility constraints must bind.*

Observe that good news would not have any impact on asset prices if capital were not assumed to be technology-specific. Otherwise, agents would transfer capital from the old technology to the new one, irreversibility would not bind, and Tobin's average q would not change as a result of the shock.

In the baseline experiment presented below parameter $\sigma = 1.5$ but I discuss later on how the results change when different values of σ are considered. I calibrate the model so that the labor share of corporate output and the ratios corporate investment to output, corporate capital to output, and consumption to output match the corresponding 1959-1972 averages of the US data.

⁶For q to fall at the time of the shock it is necessary for the new technology to be more productive than the old one.

The data appendix describes in greater detail the data sources employed in this procedure. The resulting parameter values are in the range of those found in other studies

$$\beta = 0.94, \alpha = 0.34, \delta = 0.06, \tau_y = 0.22.$$

The initial productivity level of the old technology is normalized at $A_{1,0} = 1$. The corresponding productivity parameter for the new technology, $A_{2,0} = 1.2A_{1,0}$, is chosen so that the model generates a 35% drop in market value. To give this version of the good news hypothesis its best chance, the growth rate of A_2 is set equal to that of the old technology⁷.

This model cannot be solved analytically. To obtain an approximate solution I follow Santos [31] and set up an associated numerical model with spline interpolation. The numerical model is solved using the value function iteration algorithm⁸. The results are summarized in Figures 3 and 4 (corporate GDP is in per capita real units, detrended by a 2% growth rate, and its 1962-73 average has been normalized to 100). Note that in a balanced growth equilibrium all aggregate (detrended) quantities become constant over time. Appendix 7.1 describes the data sources and procedures used in the construction of each of the following figures.

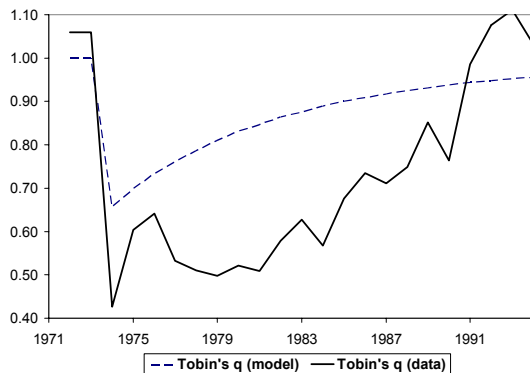


Figure 3: Asset price implications of the IT-revolution: Model vs. data.

⁷If the new technology grew faster than the old one the theory would imply an even stronger economic expansion.

⁸The source code (in Fortran 77) can be downloaded from the author's web site at: <http://moya.bus.miami.edu/~aperalta>.

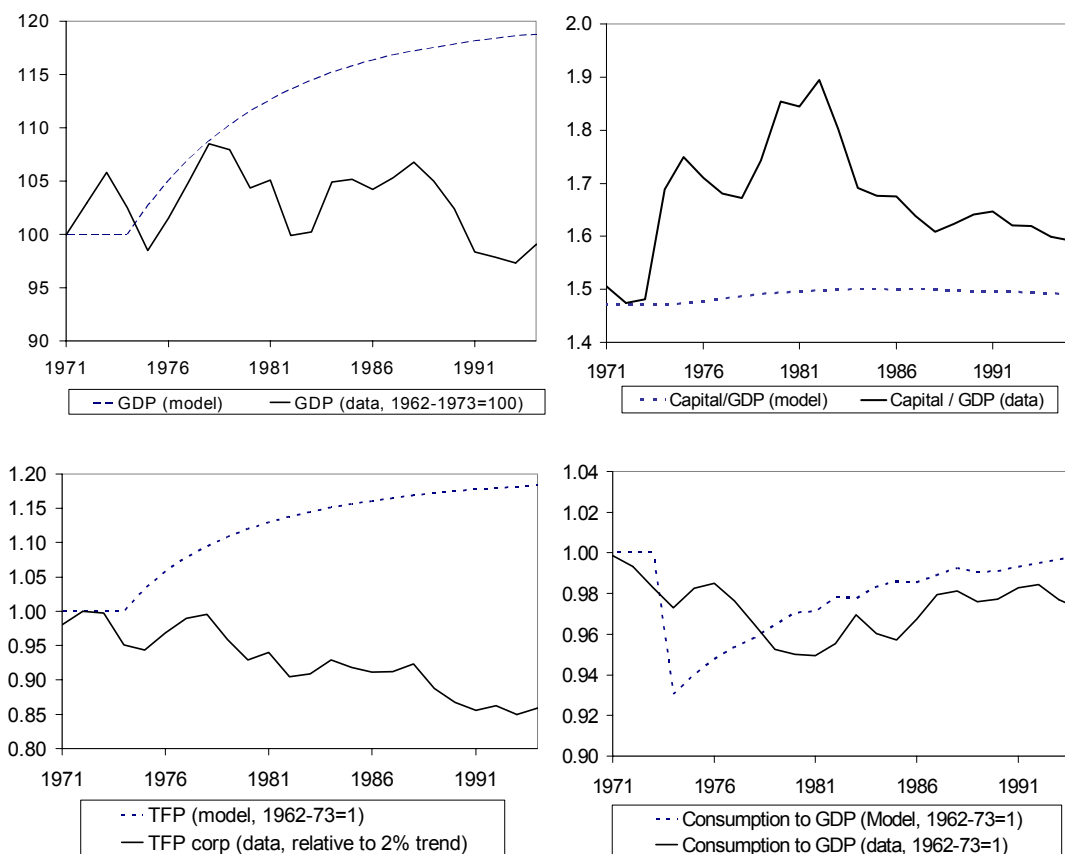


Figure 4: Macroeconomic implications of the IT-revolution: Model vs. data.

By construction, the initial drop in equity prices equals 35%. The technology shock does not affect the productivity of the old technology but a new, better, technology becomes available. Not surprisingly, corporate output and total factor productivity grow faster than trend (that is, at a rate higher than 2%) from the time of the shock up to 1994, when all aggregate quantities become indistinguishable from their new balanced growth levels. The model's predictions for corporate GDP and TFP are not consistent with the data. As is well known, the mid 1970s were a period of slow economic growth. As a matter of fact, any drop in market value generated by the arrival of a better technology will cause a counterfactual expansion in corporate output and productivity.

When the shock hits there is no capital invested in the new technology. Because the new technology is better than the existing one agents have an incentive to save more and enjoy higher future consumption. These are the patterns that one observes in the above figures. Yet, given the increase in corporate output, the corporate capital output ratio remains basically constant throughout the sample period. In the data, the capital output ratio increased much more than what is predicted by the model during the mid 1970s.

It is well known that the capital stock and investment data from the BEA is subject to different types of measurement errors. Gordon [11] has conducted an extensive study to derive improved capital stock and investment data. However, I have found that none of the conclusions discussed here would be substantially changed as a result of the use of Gordon’s data. Moreover, his data ends at year 1983 and it does not allow one to compare the complete transition of the model to that of the US economy. Hence, I have decided to confine my analysis to the data provided by the BEA.

Laitner and Stolyarov [21] and Hall [14] suggest that the IT-revolution brought a technology relatively intensive in intangible capital (such as knowledge). Intangible investments are not captured by the US NIPA. Thus, one can conjecture that the explosion in corporate output and productivity observed in the above graphs may be consistent with corrected macroeconomic measures that take into account intangible investments. However, some recent empirical studies on the behavior of intangible capital do not validate this conjecture. Hall [16] and Wright [35] find that intangible capital collapsed during the mid 1970s. Li [22] measures intangible investments from the perspective of three different general equilibrium models and she finds that intangible capital either did not change much or decreased during the mid 1970s.

According to the model the consumption to output ratio should have fallen during the mid 1970s, which is consistent with the data. However, the model’s consumption falls two percentage points of GDP more than the largest fall observed in the data during the relevant period. The largest drop in consumption implied by the model is immediate, while in the data the minimum value for the consumption to output ratio is reached in a smooth fashion and occurs around 1981.

Simulations using higher values for the inter-temporal substitution parameter σ result in smoother graphs for corporate capital, output, and consumption. For values of σ higher than 2 consumption does not fall as much as in the baseline case. Relative to the baseline experiment, values of σ higher than 2 make the model’s predictions for aggregate quantities more similar to their US counterparts at the time of the shock. In the long-run, however, the model’s predictions for aggregate quantities under different values of σ are basically the same. Thus, if one wants the model to match any substantial drop in Tobin’s average q a counterfactual expansion in output, and total factor productivity will necessarily follow.

Introducing adjustment costs or time-to-build would avoid the sudden collapse in consumption observed in the baseline experiment. Unfortunately, both situations make it more difficult for the theory to match the observed drop in q . The decline in the value of old capital depends on how much better the new technology is. If installing capital is costly then the new technology is not as attractive, and q does not fall as much ⁹. Moreover, a large drop in q can be obtained but it will be necessarily accompanied by a too strong long-run expansion in corporate output and productivity.

⁹These simulations, and the ones for the case $\sigma \neq 1.5$, are available from the author upon request.

In conclusion, if one interprets the IT-revolution as the sudden arrival of a better technology, then a large and persistent decline in Tobin’s average q can be obtained. However, in a neoclassical competitive framework, it must imply a strong economic expansion precisely at the time that the US economy slowed down. Moreover, the better one wants the model to match the observed trends in corporate GDP, TFP, and consumption, the smaller the drop in Tobin’s average q it will predict.

5.3 Arrival of Information Technologies and productivity slowdown of old production methods

Many of the inconsistencies of a theory purely based on the arrival of a better technology can be resolved by bringing into the analysis the productivity slowdown of the mid 1970s. Relative to its 1948-73 average, total factor productivity growth in the United States declined by a factor of three during 1974-1994. More importantly, the productivity slowdown took place in sectors that did not produce, nor use intensively, Information Technologies (cf. Jorgenson [18]).

I now take a stylized view of 1974 as a year where two unexpected shocks occurred. The first, was a sudden slowdown in the productivity of existing production methods. This productivity slowdown makes the model consistent with the economic slowdown of the mid 1970s. The second shock was the arrival of Information Technologies. The information technology revolution renders old capital obsolete causing its market value to go down.

For ease of comparison with the results of the previous section, I calibrate the initial productivity of the new technology so as to match a 35% drop in Tobin’s q , which implies $A_{2,0} = 1.02A_{1,0}$. As in the previous quantitative example, the growth rate of productivity for the new technology equals 2% throughout the sample period. In contrast to the experiments of the previous section, where only good news are considered, the growth rate of the productivity of old production methods for 1974-1994 is set to one third of its 1960-73 average, which is what Jorgenson reports for the non-IT producing sectors (see Jorgenson [18], Figure 2.7). Finally, I set the 1974 level of old production methods, $A_{1,0} = 0.945$, to match the productivity level of US corporations during 1974, relative to trend and to its 1960-73 average level. The latter is a consistent measure for productivity given that, in the model, all corporate output is produced using the old technology at the time of the shock. The resulting sequences of total factor productivities for each of the two technologies are illustrated in Figure 5.

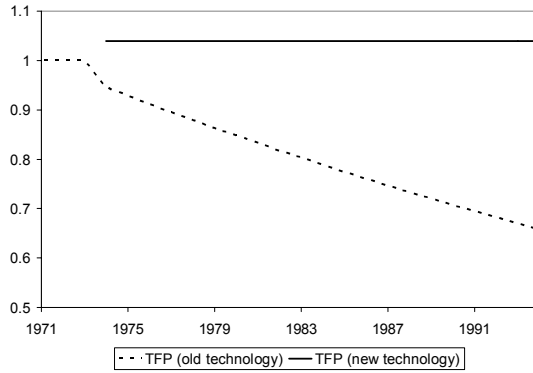


Figure 5: Calibrated model productivities (relative to a 2% trend).

The equilibrium time series that emerge when the model is hit with the aforementioned productivity shocks, together with their US data counterparts, are illustrated in Figures 6 and 7.

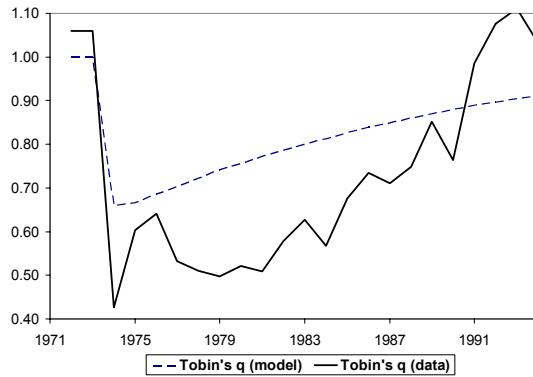
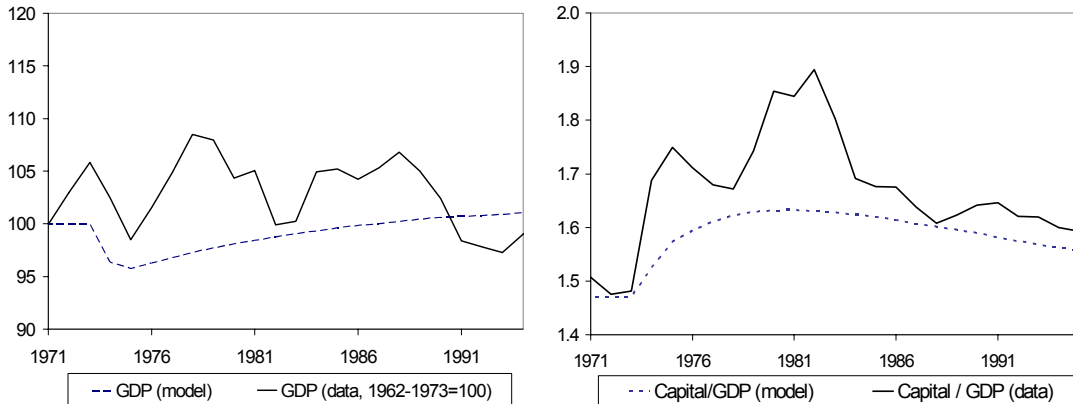


Figure 6: Asset price implications of the two shocks of 1974: Model vs data.

The unexpected arrival of information technologies paired with the productivity slowdown generate a 35% drop in Tobin's average q . Old capital is left to depreciate and it is gradually replaced by a new one. After the shocks, market values recover in a smooth fashion. This recovery takes longer than in the US data.



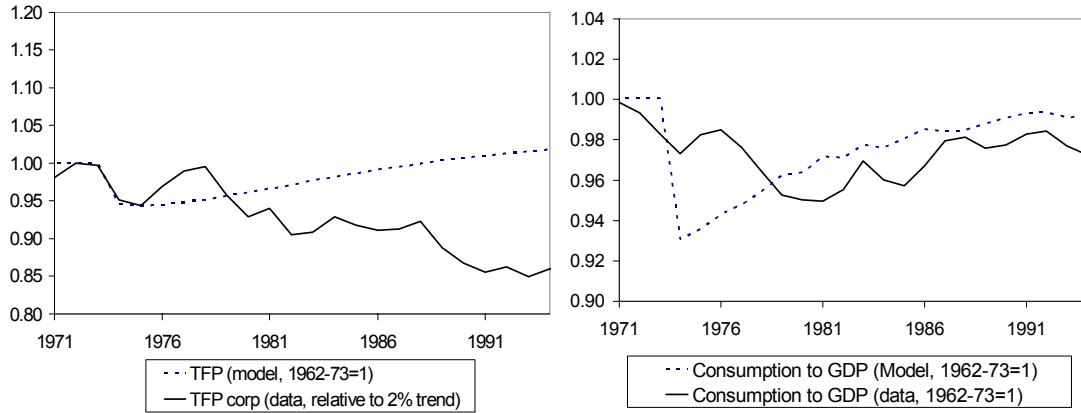


Figure 7: Macroeconomic implications of the two shocks of 1974: Model vs data.

In sharp contrast to a theory based exclusively on good news, the crash and stagnation in the productivity of old production methods generates a slowdown for corporate output and productivity comparable to the observed ones. As the new aggregate production method replaces the old one, the economy recovers in a smooth fashion towards its new balanced growth equilibrium. The information technology revolution brings a better technology and people are willing to sacrifice consumption at the time of the shock in order to build the necessary capital. As a result, investment increases and so does the capital output ratio of the model. The increase in the capital output ratio predicted by the model accounts for one half of what is observed in the data. However, it is important to note that I have abstracted the analysis from the impact of investment subsidies, which peaked in the mid 1970s. Investment subsidies would make capital move up even further and, as argued by McGrattan and Prescott [24], investment subsidies would also generate a larger drop in asset prices.

Just as in the good-news-only experiment of the previous section, the consumption to output ratio from the theory at the time of the shock is slightly lower than the minimum value reached by its US counterpart during the sample period. The predicted consumption to output ratio drops immediately after the shock while it drops smoothly in the data.

6 Conclusions

This study employs general equilibrium theory to determine whether the Information Technology Revolution and the Productivity slowdown can account for the stock market collapse of the mid 1970s, its subsequent stagnation, and recovery. The tool of analysis was a dynamic general equilibrium model with technology-specific capital and irreversible investment.

Theory showed that good news about the *future availability* of a better technology cannot deliver a consistent explanation for the observed patterns in equity prices and those in corporate

output, capital stock, and consumption. I assessed another type of good news shock consisting of the *actual arrival* of a new, better technology. The model can make q fall substantially, or even as much as in the data, but it must also imply a strong economic expansion precisely at the time that the US economy slowed down. I found, however, that once the observed productivity slowdown in old production methods is incorporated into the theory it becomes possible to reconcile the equilibrium behavior of the model to the secular trends of the data. Moreover, two thirds of the observed drop in the market value of US corporations can be accounted for.

My results reinforce Sargent’s view that any general equilibrium theory of stock market fluctuations must “necessarily stem from a model in which ‘frictions’ are present that prevent the price of existing capital from being driven equal at all times to the price of newly produced capital.”¹⁰ Theory shows that for such frictions to have any *equilibrium* effect on asset prices, it is necessary that agents find, suddenly, a better place to allocate investment resources. Good news seem then essential for the construction of a successful model.

Finally, the quantitative analysis of this paper suggests that a big challenge for any general equilibrium theory of equity price movements resides in accounting for the long stagnation of Tobin’s average q . The economic model I evaluated generates a smooth recovery of market values right after the shock hits while the data shows a decade long stagnation. Reconciling the magnitude of the drop in market values with the observed trends of consumption seems also challenging. The lower the values of q that one demands from the model, the better the new technology has to be, and the larger the drop in consumption that the model may deliver. Constructing credible ways for overcoming these problems demands further research.

7 Appendix

7.1 Data

Figure 1. Ratio of Market Value to Replacement Cost of Tangible Assets for Corporations

Market value of corporations was constructed using data from the *Flow of Funds Accounts of the United States* (FOF) issued by the Board of Governors of the Federal Reserve System (FRB).¹¹ In FFA, domestic corporations are divided into nonfinancial and financial corporate business. Financial corporations are further divided to the following categories as listed in Table F.213: Commercial banking, life insurance companies, other insurance companies, closed-end funds, exchange-traded funds, real estate investment trusts (REITs) and brokers and dealers.

My measure of market value reflects both equity value and debt of all domestic corporations. All direct or indirect (through mutual funds) intercorporate holdings of corporate equity and debt has

¹⁰Sargent [32], page 1.

¹¹This data can be downloaded from the FRB website at <http://www.federalreserve.gov/releases/z1/current/data.htm>.

been netted out. To that effect market value of domestic corporations (MV) has been constructed as follows:

$$\begin{aligned}
MV = & \text{Corporate equity issued by nonfinancial corp. business (Table L.213 Line 2)} \\
& + \text{Corporate equity issued by financial corp. (Table L.213 Line 4)} \\
& + \text{Total liabilities of nonfarm nonfinancial corp. business (Table L.102 Line 20)} \\
& - \text{Total financial assets of security brokers and dealers (Table L.130 Line 1)} \\
\\
& - \text{Total financial assets of nonfarm nonfinancial corp. business (Table L.102 Line 1)} \\
& + \text{Total liabilities of commercial banking (Table L.109 Line 21)} \\
& - \text{Total financial assets of commercial banking (Table L.109 Line 1)} \\
& + \text{Total liabilities of life insurance companies (Table L.117 Line 16)} \\
& - \text{Total financial assets of life insurance companies (Table L.117 Line 1)} \\
& + \text{Total liabilities of other insurance companies (Table L.118 Line 14)} \\
\\
& - \text{Total financial assets of other insurance companies (Table L.118 Line 1)} \\
& + \text{Total liabilities of closed-end funds (Table L.123 Line 7)} \\
& - \text{Total financial assets of closed-end funds (Table L.123 Line 1)} \\
& + \text{Total liabilities of exchange-traded funds (Table L.123 Line 13)} \\
& - \text{Total financial assets of exchange-traded funds (Table L.123 Line 8)} \\
& + \text{Total liabilities of REITs (Table L.129 Line 11)} \\
& - \text{Total financial assets of REITs (Table L.129 Line 1)} \\
& + \text{Total liabilities of security brokers and dealers (Table L.130 Line 13)}
\end{aligned}$$

Replacement cost of tangible assets of corporations was constructed using data from the *Fixed Assets Tables* (FA) reported by the Bureau of Economic Analysis (BEA)¹² and also from the FOF. My measure of tangible assets includes all nonresidential and residential fixed assets, plus inventories. Corporate fixed assets are the sum of corporate nonresidential fixed assets (FA Table 4.1 Line 13) and corporate residential fixed assets (FA Table 5.1 Line 3). Stock of inventories held by nonfarm nonfinancial corporations is from FOF Table B.102 Line 5. I assumed financial corporations hold no inventories as their inventory investment is zero in the product account, and I ignored the inventories held by farm corporations, since they are negligibly small.

¹²This data can be downloaded from the BEA website at <http://www.bea.doc.gov/bea/dn/faweb/AllFATables.asp>.

Macroeconomic data for the figures in section 5

The data on corporate GDP is taken from NIPA's Table 1.14. Corporate Investment is the sum of non-residential and residential corporate investment from BEA's Fixed Asset Tables 4.7 and 5.7. To compute total factor productivity I solve for TFP from the aggregate production function

$$\text{corporate output}_t = k_t^\alpha (TFP_t n_t)^{1-\alpha}.$$

Corporate capital, k_t , is the sum of non-residential and residential corporate capital, as reported in the BEA's Fixed Asset Tables 4.2 and 5.2 (chained quantity indexes).

There is no data on hours worked in the corporate sector. I approximate them as follows:

$$\frac{n_{t+1}}{n_t} = \text{Factor of change in hours worked in private industries} \times \text{change in the fraction of private employment accounted for US corporations}$$

Given that the output of the corporate sector accounts for more than 70% of the output of private industries, this approximation seems a reasonable one. The data on hours worked is taken from the BLS series ID CES0500000040. The data on employment by form of organization is taken from the US Census bureau.

Finally, to make the US NIPA data compatible with the measures of our model, consumption data is obtained from the aggregate feasibility condition

$$c = (1 - \tau_y) \text{corporate output} - \text{investment}$$

7.2 Proofs

Proof of proposition 4.1

The consumer's first order conditions with respect to s_{t+1} and c_t imply

$$(4) \quad p_t V_t = p_{t+1} (d_{t+1} + V_{t+1}).$$

On the other hand, the firm's first order conditions with respect to $k_{1,t+1}$ and $x_{1,t}$ can be combined to deliver

$$(5) \quad p_t - \mu_{1,t} = p_{t+1} \left[(1 - \delta) + (1 - \tau_y) \frac{\partial F_1(k_{1,t+1}, A_{1,t+1} n_{t+1})}{\partial k_{1,t+1}} \right] - \mu_{1,t+1} (1 - \delta),$$

where $\mu_{1,t}$ is the multiplier of the irreversibility constraint (1). Notice that the share of total after tax output going to labor is $1 - \alpha$. Thus, dividends equal

$$d_{t+1} = \alpha(1 - \tau_y) F_1(k_{1,t+2}, A_{1,t+2} n_{t+2}) - x_{1,t+1}.$$

One can multiply both sides of (5) by $k_{1,t+1}$ and use the homogeneity of F , the law of motion of capital, and the above expression for dividends to get

$$(6) \quad (p_t - \mu_{1,t})k_{1,t+1} = (p_{t+1} - \mu_{1,t+1})k_{1,t+2} + p_{t+1}d_{t+1}.$$

Without loss of generality set $p_0 = 1$, equations (4) and (6) imply

$$(7) \quad V_0 = \lim_{\tau \rightarrow \infty} \left\{ \sum_{t=1}^{\tau} p_t d_t + p_{\tau} V_{\tau} \right\}$$

$$(8) \quad (1 - \mu_{1,0})k_1 = \lim_{\tau \rightarrow \infty} \left\{ \sum_{t=1}^{\tau} p_t d_t + (p_{\tau} - \mu_{1,\tau})k_{1,\tau+1} \right\}$$

$$(9) \quad p_t V_t - p_{t+1} V_{t+1} = (p_t - \mu_{1,t})k_{1,t+1} - (p_{t+1} - \mu_{1,t+1})k_{1,t+2}.$$

It is well known that, in equilibrium, all variables converge to a balanced growth path, which is independent of the given initial conditions (cf. Arrow and Kurz [2], or Olson [25]). In a balanced growth path investment is strictly positive and thus, by continuity, there is a τ , large enough, such that for all $t \geq \tau$ investment is strictly positive, and $\mu_{1,t} = 0$. Hence, equations (7), (8), the transversality condition for the problem of the firm [$\lim_{T \rightarrow \infty} p_T k_{1,T+1} = 0$], the one for the consumer [$\lim_{T \rightarrow \infty} p_T V_T s_{T+1} = 0$], and the market clearing condition ($s_t = 1$ for all t) imply $V_0 = (1 - \mu_{1,0})k_1$. Using this as an initial condition for the difference equation in (9) delivers the following relationship between the market value of a firm and its capital stock

$$(10) \quad V_t = \left(1 - \frac{\mu_{1,t}}{p_t}\right)k_{1,t+1} \text{ for all } t.$$

To prove the first statement of the proposition note that $\mu_{1,t}$ is strictly positive only when the irreversibility constraint binds; in that case, equation (10) says $V_t < k_{t+1}$. The definition of q_t delivers $q_t < 1$. To prove the second statement assume the irreversibility constraint does not bind, then $\mu_{1,t} = 0$, $V_t = k_{t+1}$ and $q_t = 1$. QED

Lemma 4.1: *Under the assumptions outlined in section 4.1, if news about the period T arrival of a better technology arrives at date 0 then*

$$q_t = \left(1 - \frac{\mu_{1,t}}{p_t}\right), \text{ for all } t < T.$$

Proof: Notice that equation (5) can still be derived from the first order conditions of the problem of the firm for all periods $0 \leq t < T$. Hence,

$$(11) \quad (p_{t-1} - \mu_{1,t-1})k_{1,t} = (p_t - \mu_{1,t})k_{1,t+1} + p_t d_t$$

also holds for all $t < T$.

In period T all existing capital is of type 1. However, the firm must take into account that a positive stock of capital of type 2 may be available from the next period onwards. A method symmetric to the one employed to derive (6) delivers the corresponding optimality condition

$$(12) \quad (p_{T-1} - \mu_{1,T-1})k_{1,T} = (p_T - \mu_{1,T})k_{1,T+1} + (p_T - \mu_{2,T})k_{2,T+1} + p_T d_T,$$

where $\mu_{2,T}$ is the multiplier associated to the irreversibility constraint for capital of type 2.

Consider now all periods $t > T$ in which both types of capital are available. The first order conditions of the firm's problem with respect to $k_{1,t+1}, k_{2,t+1}, x_{1,t}, x_{2,t}$, the homogeneity of each of the two production functions, and the definition of dividends can be used to get

$$(13) \quad (p_t - \mu_{1,t})k_{1,t+1} + (p_t - \mu_{2,t})k_{2,t+1} = (p_{t+1} - \mu_{1,t+1})k_{1,t+2} + (p_{t+1} - \mu_{2,t+1})k_{2,t+2} + p_{t+1}d_{t+1},$$

Finally, note that the recursive application of (11, 12, and 13) together with the transversality conditions for the problem of the firm imply that for all $t < T$

$$(p_t - \mu_{1,t})k_{1,t+1} = \lim_{\tau \rightarrow \infty} \left\{ \sum_{i=t+2}^{\tau} p_i d_i + (p_{\tau} - \mu_{1,\tau})k_{1,\tau+1} + (p_{\tau} - \mu_{2,\tau})k_{2,\tau+1} \right\} = \sum_{i=t+1}^{\infty} p_i d_i.$$

Using the fact that the first order conditions of the consumer are unchanged, and in particular that (4) still holds, it is possible to write

$$p_t V_t = \sum_{i=t+1}^{\infty} p_i d_i = (p_t - \mu_{1,t})k_{1,t+1},$$

for all $t < T$. The above expression and the definition of Tobin's q yield the desired result

$$q_t = \frac{V_t}{k_{1,t+1}} = \left(1 - \frac{\mu_{1,t}}{p_t}\right), \quad t < T$$

QED

Proof of proposition 5.1

Applying the method of proof of proposition 4.1 to this economy one can arrive at

$$V_t = k_{1,t+1} \left(1 - \frac{\mu_{1,t}}{p_t}\right) + k_{2,t+1} \left(1 - \frac{\mu_{2,t}}{p_t}\right),$$

where $\mu_{1,t}$ and $\mu_{2,t}$ are the multipliers of the irreversibility constraints for each type of capital. Now consider the definition of Tobin's average q

$$q_t = \frac{k_{1,t+1} \left(1 - \frac{\mu_{1,t}}{p_t}\right) + k_{2,t+1} \left(1 - \frac{\mu_{2,t}}{p_t}\right)}{k_{1,t+1} + k_{2,t+1}},$$

and note that if none of the irreversibility constraints bind both multipliers will equal zero. Hence, $q_t = 1$. QED

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