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

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Abstract

A growing literature argues that the Information Technology revolution caused the stock market crash of 1973-1974, its subsequent stagnation and eventual recovery. This paper employs general equilibrium theory to test whether this good news hypothesis is consistent with the behavior of US equity prices and with the trends in corporate output, investment and consumption. I find it is not. A model based exclusively on good news can make equity prices fall as much as in the data but it must also imply a strong economic expansion right when the US economy stagnated. However, when the observed productivity slowdown in old production methods is incorporated into the model consistency with major macroeconomic aggregates can be achieved and a 20% drop in equity values can be accounted for. (*JEL* E44, O33, O41)

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1 Introduction

It has been argued that the mid 1970s marked the beginning of a new industrial revolution, associated with the introduction of information technologies (cf. Greenwood and Yorukoglu [13], Greenwood and Jovanovic [14], Hobijn and Jovanovic [18]). The start of this Information Technology (IT) revolution coincides 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 ratio of their net capital stock[1] (i.e., Tobin's average q), went down by 50% and did not recover until the 1990s.

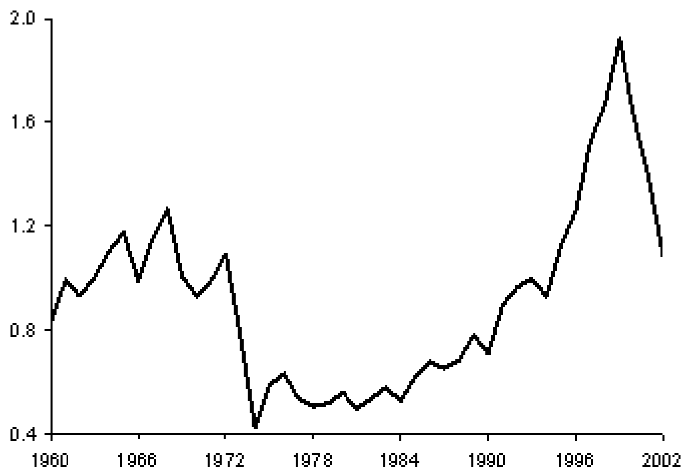


Figure 1: Market value of US corporations as ratio to the replacement cost of their tangible assets

A growing literature suggests there is a causal link between these two events, and that the arrival and diffusion of information technologies have been an important force driving fluctuations in equity prices. Roughly speaking,

[1] Figure 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 [12].

this good news hypothesis states that the IT-revolution rendered old capital obsolete, causing its market value to collapse. New technologies gradually replaced the old ones, and the stock market smoothly recovered (e.g. Greenwood and Jovanovic [14], Hobijn and Jovanovic [18] and Laitner and Stolyarov [22]).

In this paper I measure the extent to which the good news hypothesis can provide a consistent explanation of the stock market collapse of 1974, its subsequent stagnation and recovery. My analysis 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 [16] 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.

The framework of this study is an inter-temporal general equilibrium model of capital asset pricing. The rules of the exercise are simple. A model is considered successful if it accounts for the observed movements in Tobin's average q and if it is also consistent with the behavior of the US corporate output, investment and consumption.

To evaluate the quantitative aspects of the good news hypothesis I use a one-sector neoclassical growth model with perfect competition. Investment decisions are irreversible and capital is technology specific. The latter two assumptions are standard in the literature and allow the price of installed capital to fall below its replacement cost[2]. Following existing theories, I analyze the effects of two different types of shocks. In the first one agents learn of the future arrival of a new, better, technology (as in Greenwood and Jovanovic [14] or Hobijn and Jovanovic [18]) and realize that existing production methods, and all of the capital therein installed, are about to become

[2] Certain taxes also break the equality between market value and replacement cost (e.g. McGrattan and Prescott [25]).

obsolete. A calibrated version of the model shows that learning about the future arrival of a better technology has no effect on Tobin's average q. The second type of shock I consider consists of the actual arrival of a new better technology (as in Laitner and Stolyarov [22] or Jovanovic and Rousseau [20]). Numerical experiments show that even in an extreme setup where investment is completely irreversible, and capital immobile across existing technologies, for equity prices to fall as much as in the data the model must imply a two-fold increase in investment and a strong expansion of corporate GDP and consumption. These predictions are orthogonal to what one observes in the data.

A theory for asset pricing fluctuations based exclusively on good news cannot be reconciled with certain features of the US data. However, a very important factor has been left out of the analysis. The 1974 collapse of the US stock market also coincides with a dramatic decline in the growth rate of total factor productivity. The average growth rate of total factor productivity during 1973-89 was three times lower than the corresponding average for 1948-73. Productivity growth recovered in the late 1990s and the stock market boomed. Jorgenson [19] performs a growth accounting decomposition of the US economy from 1948 to 2002 splitting the economy in IT producing sectors and non-IT producing sectors (computed as a residual). His main finding is 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 can be attributed to large productivity gains in IT producing sectors. During the mid 1990s information technologies spread out to other sectors of the economy and total factor productivity recovered.

Motivated by Jorgenson's findings, I evaluate the quantitative implications for market values and other major macroeconomic aggregates of the good news hypothesis, but this time paired with a bad news shock. Bad news correspond to an unexpected slowdown of old production technologies comparable to the one in the data. Consistency with major macroeconomic aggregates is achieved. Moreover, I find that the unexpected arrival of information technologies and the productivity slowdown can account for a 20% drop in equity values.

2 Related literature

Jovanovic and Rousseau [20] 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 [20] 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 [22]. The authors analyze the negative impact of a technology revolution on the stock market using a general equilibrium framework. Two things distinguish their study from mine. First, they 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 on, 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. Second, Laitner and Stolyarov [22] 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 theory ignores intangible capital so as to give the good news hypothesis its best chance at accounting for the low market valuations of the mid 1970s. As Hall [17] points out, if one includes intangible capital into the analysis one would also 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 [25] and Li [23] 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 complementary explanation for the stock market collapse of 1974, which is also based on technological change, is given by Alpanda and Peralta-Alva [1]. According to the authors, the energy crisis of the mid 1970s gave agents the incentives to develop a new energy-saving technology. The introduction of an energy-saving technology rendered existing capital obsolete. Old capital was left to depreciate, the expected flow of dividends it paid suddenly decreased, and its market value collapsed. In that model the energy crisis also generates an economic slowdown consistent with the data. The paper concludes that the energy price hike of the mid 1970s, together with the energy-saving innovation it triggered, can account for more than half of the observed drop in market valuations. Wei [35] also evaluates the impact of the energy crisis on the stock market. However, 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, in her framework the energy crisis translates into a 2% drop in market values.

The trends in the US stock market have also been studied by McGrattan and Prescott [25]. These authors compute the impact of changes in taxes and the regulatory system across different long-run equilibria of a neoclassical growth model. Their findings suggest taxes and regulations have the potential for explaining one half of the 1974 collapse in equity prices and most of the expansion of the 1990s. Bian [4] has computed the full dynamic transition for McGrattan and Prescott's model. McGrattan and Prescott's model implies that the market value of the firm at any given year must be proportional to the replacement value of its capital stock, where the constant of proportion depends (only) on current tax laws. In their balanced growth analysis, McGrattan and Prescott assume the capital stock of US corporations to be constant during the mid 1970s, which is not consistent with available data on US corporate capital. According to Bian (op. cit.), the observed increase in corporate capital together with the full dynamic behavior of the different taxes and regulations emphasized by McGrattan and Prescott, result in an almost imperceptible drop in the US stock market during the 1974-1980 period.

3 The model

This section describes a general equilibrium asset-pricing model with capital accumulation and production, based on Brock [5], to evaluate the quantitative implications of the good news hypothesis. The saving rate is endogenously determined so as to quantify the effects of the IT-revolution on aggregate investment. Once capital accumulation and endogenous savings are included in the analysis good news have a dramatically different effect on equity prices than what Greenwood and Jovanovic [14], Hobijn and Jovanovic [18] and Laitner and Stolyarov[22] obtain. I also assume capital to be technology-specific and irreversible, as is standard in the literature (e.g. Dixit and Pindyck [9], and Sargent [33])[3].

I now describe the model in detail, define a competitive equilibrium, and

[3] For 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. The present model takes this assumption to the extreme giving the IT-hypothesis its best shot at explaining the stock market collapse of the mid 1970s.

obtain a characterization for Tobin's average q.

3.1 Households and equity markets

Preferences of the representative household are described by

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

where t indexes time and c is per-capita consumption. 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

$$\sum_{t=0}^{\infty} p_t \left\{ c_t + V_t(s_{t+1} - s_t) \right\} \leq \sum_{t=0}^{\infty} p_t \left\{ d_t s_t + w_t n_t \right\}$$
$$0 < \beta < 1, \; s_t \geq 0, \; s_0 \text{ given.}$$

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 rate is denoted by w_t, and dividends per-share by 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, $V_t(s_{t+1} - s_t)$.

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 labor that maximize the present value of dividends

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

$s.t.$

$$k_{i,t+1} = x_{i,t} + (1-\delta)k_{i,t}$$

$$A_{i,t+1} = \gamma_i A_{i,t}$$

(1) $$x_{i,t} \geq 0 \text{ for } i = 1, 2$$

$$0 < \delta \leq 1, \gamma \geq 1$$

(2) $$\text{given } A_{1,0},\ A_{2,0},\ k_{1,0} \text{ and } k_{2,0}.$$

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. Finally, the economy's aggregate resource constraints are

(AR) $$x_{1,t} + x_{2,t} + c_t = (1-\tau_y) \sum_{i=1}^{2} F_i(k_{i,t}, A_{i,t}n_{i,t})$$

$$n_{1,t} + n_{2,t} = n_t \text{ for all } t.$$

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 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. Markets clear, so that $\{c_t, s_t, x_{1,t}, x_{2,t}, k_{1,t+1}, k_{2,t+1}, n_{1,t}, n_{2,t}\}$ satisfy the aggregate resource constraints (AR), and $s_t = 1$ for all t.

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 data[4] 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 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*

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

[4] A complete model of the US economy would have a corporate and a non-corporate sector. That can be done a more precise mapping to the data would be achieved. 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 inconsistency is irrelevant for the results, I use a one sector model in all of what follows.

The next two sections of the paper derive the quantitative implications of different types of good news shocks. 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 good news paired with a productivity slowdown in old technologies. Section 6 concludes.

The framework of analysis considered in this study is that of a perfectly competitive, 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). My analysis is also constrained to a perfectly competitive economy, which seems to be a good starting point for this study. In particular, the data suggests that the stock market crash was not caused by the potential loss of monopolic 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 [27] do not validate to the previous implication. If anything, the level of concentration increased during 1974-84.

Secondly, the market value to output ratio of the 1972 incumbents[5] 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 insignificant[6].

4 News about the future arrival of a better technology

4.1 The economic environment before the shock

Before the arrival of good news, 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 thought to be 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, $\lim_{k_i \to 0} \frac{\partial}{\partial k_i} F_i(k_i, A_i n_i) = \infty$, and $\lim_{k_i \to \infty} \frac{\partial}{\partial k_i} F_i(k_i, A_i n_i) = 0$ for $i = 1, 2$. Finally, $\lim_{c \to 0} u'(c) = \infty$ and $\lim_{c \to \infty} u'(c) = 0$.

[5] The 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.

[6] In 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.

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 the optimal investment allocation. Sub-sections 4.2 and 4.3 below evaluate the quantitative implications of this mechanism.

4.2 Agents learn about the future arrival of a better technology

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 [18]. 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 good news shock can be characterized as follows [cf. Lemma 4.1 in the appendix]

$$q_t = \left(1 - \frac{\mu_t}{p_t}\right) \text{ for all } 0 \leq t < T, \tag{3}$$

where μ_t is the multiplier associated to the irreversibility constraint of k_1.

What are the implications of assuming that good news caused[7] the stock market collapse and stagnation of the mid 1970s? First, 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 capital becomes

$$k_{1,t+1} = (1 - \delta)^t k_{1,0} \text{ for } t = 0, ..., T. \tag{4}$$

If good news caused the 1974 drop and subsequent stagnation of q, then one should see the capital stock of the US economy decreasing at a 5% 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 [18] show that good news can explain the observed patterns in the market value to corporate output ratio illustrated by the bold line in Figure 2 below.

[7] I have also studied the effects of "good news" under standard functional forms for F_1, F_2 and u. Numerical simulations show that such a shock does not have any effects on Tobin's average q. Consumption for periods 0 through T can only come from the old technology. Investment decreases as a result of the good news shock, but not all the way to zero. Then, the irreversibility constraint does not bind and Tobin's q is unaffected by the shock. These results are available upon request from the author.

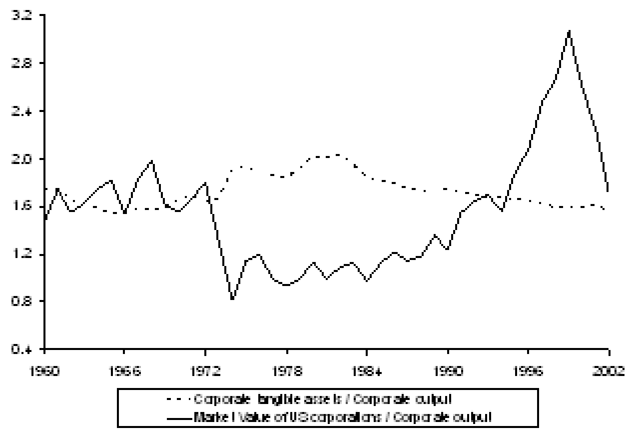


Figure 2: Market and replacement value of corporate assets as ratios to corporate output

In a one-sector Neoclassical growth model, good news cannot explain the trends in the market 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 Information technology revolution 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 is 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 matches the observed drop in Tobin's average q. The implied equilibrium time series from the model can then be compared 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

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

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 Unexpected 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 technology[8]. In particular,

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

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.

I calibrate the model so that the share of corporate output captured by labor 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. 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

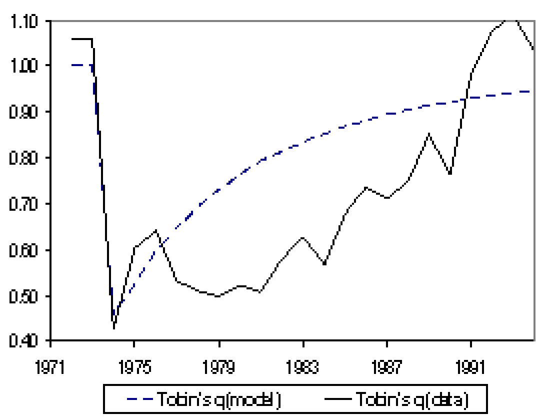
$$\beta = 0.94, \alpha = 0.34, \delta = 0.06,\ \tau_y = 0.22.$$

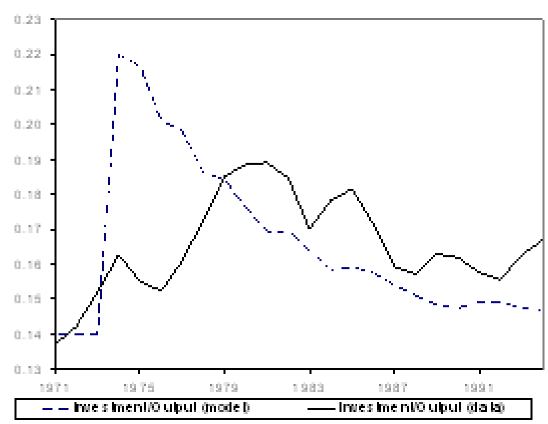
The initial level of productivity of the new technology, $A_{2,0}$, is chosen so that the drop in market values predicted by the model is equal to the observed

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

one. In the baseline experiment $A_{2,0} = 1.5A_{1,0}$. 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 technology[9]. In the baseline experiment presented below $\sigma = 1.5$ but I discuss later on how the results change when different values of σ are considered.

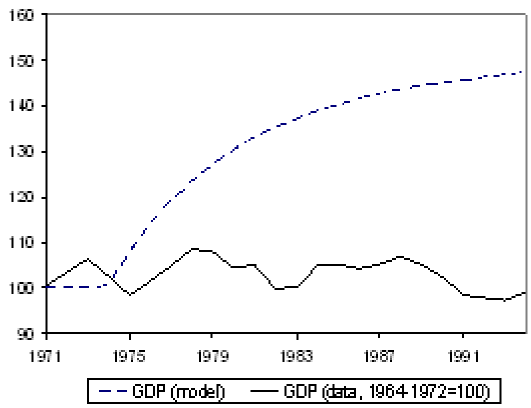
This model cannot be solved analytically. To obtain an approximate solution I follow Santos [32] and set up an associated numerical model with spline interpolation. The numerical model is solved using the value function iteration algorithm[10]. The results are summarized in the figures below (corporate GDP is in per capita real units, detrended by a 2% growth rate, and normalized to 100 in 1972). Note that in a balanced growth equilibrium all aggregate (detrended) quantities become constant over time. Appendix 7.1 describes the data sources used in the construction of each of the following figures.

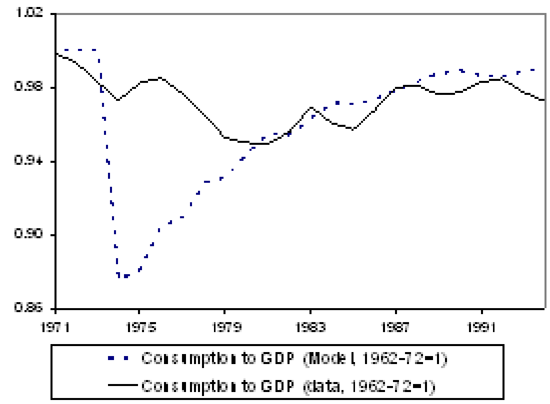




[9] If the new technology grew faster than the old one the theory would imply an even stronger economic expansion.

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





By construction, the initial drop in equity prices is equal to that in the data. The technology shock does not affect the productivity of the old technology but a new, better technology becomes available. Not surprisingly, corporate output grows faster than trend (that is, at a rate higher than 2%) from the time of the shock up to 1990, when all aggregate quantities become indistinguishable from their new balanced growth levels. The model's predictions for corporate GDP are not consistent with the data. As is well known, the mid 1970s were a period of slow economic growth.

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, the corporate investment to output ratio increases by 57% at the time of the shock and stays high for the next 15 years. In the data, investment did not change as much as what is predicted by the model during 1973-1974, nor in the years that followed. It is well known that the capital stock and investment data from the BEA is subject to different types of measurement errors. Gordon [12] 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 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 [22] and Hall [15] 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 GDP and investment observed in the above graphs may be consistent with a correct measure of GDP and investment that takes into account intangible investments. However, some recent empirical studies on the behavior of intangible capital do not validate this conjecture. Hall [17] and Wright [36] find that intangible capital collapsed during the mid 1970s. Li [23] 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.

The quantitative implications of the model with respect to consumption are also inconsistent with the US experience. The consumption to output ratio did not fall as much as the previous simulations indicate (minus 12% in 1974). The theory predicts a strong expansion in consumption, starting two periods after the shock, that cannot be found in the data.

Simulations using higher values for the inter-temporal substitution parameter σ result in smoother graphs for corporate output, investment, and consumption. For values of σ higher than 2 consumption does not fall as much as in the baseline case, and investment does not immediately explode. Relative to the baseline experiment, values of σ higher than 2 make the model's predictions for aggregate quantities more similar to the data 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 too strong expansion in output, consumption and investment will necessarily follow.

Introducing adjustment costs or time-to-build would avoid the sudden explosion in investment 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 [11]. Moreover, a large drop in q can be obtained but it will be necessarily accompanied by a too strong long-run expansion in investment, consumption and corporate output.

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, consumption and investment, the smaller the drop in Tobin's average q it will predict.

5.3 Unexpected slowdown of existing production methods

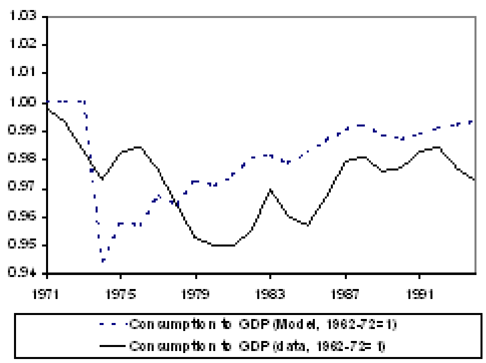
The main inconsistencies of a good news based model can be resolved by bringing into the analysis the productivity slowdown of the mid 1970s. Relative to its 1948-73 average total factor productivity growth in the United States declined by a factor of three during 1973-1989. More importantly, the productivity slowdown took place in sectors that did not produced, nor used intensively, Information Technologies (cf. Jorgenson [19]).

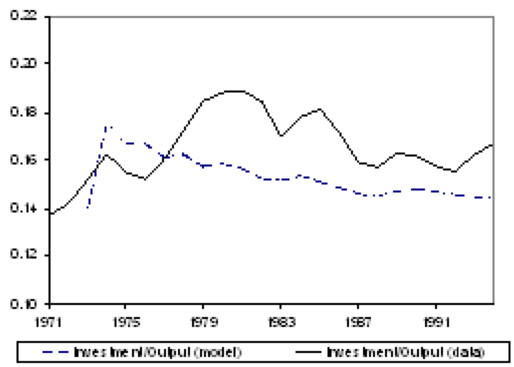
I now take a stylized view of 1974 as a year where two unexpected shocks occurred. The first, was a productivity slowdown in existing production methods. This productivity slowdown makes the model consistent with the

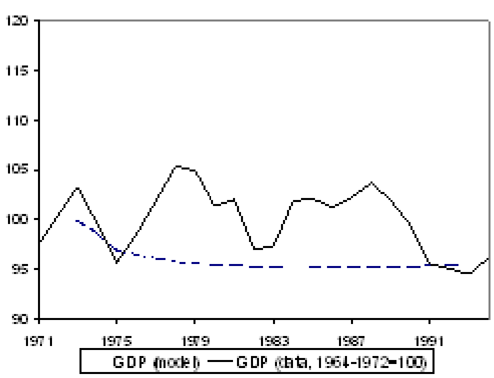
[11] These simulations, and the ones for the case $\sigma \neq 1.5$, are available from the author upon request.

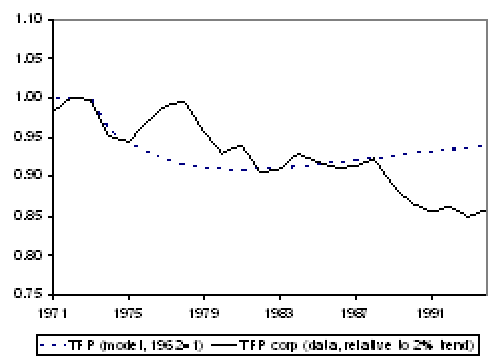
economic slowdown of the mid 1970s. The second shock was the arrival of Information Technologies. The information technology revolution renders old capital obsolete causing its market value to go down.

I calibrate the sequence of productivity parameters of old production methods, $\{A_{1,t}\}$, to match the productivity slowdown observed in non-IT producing sectors reported in Jorgenson's data. The sequence of productivity parameters for the technology that depends on IT capital, $\{A_{2,t}\}$, is assumed to grow at a 2% rate, the same rate of growth for old technologies before the slowdown. The initial value for $A_{2,1974}$ is calibrated so as to minimize the sum of square deviations between the model's predictions for corporate output, investment, consumption, total factor productivity and their corresponding US data counterparts for 1974-1989. The equilibrium time series of the model and the US data are summarized in the figures below.









The qualitative properties of the investment and consumption to output ratios from the theory are similar to what we observed in the good news only case. The information technology revolution brings a better technology and people are willing to sacrifice some consumption at the time of the shock in order to build the necessary capital. As opposed to the good news only case, the magnitude of the fluctuations in corporate investment and consumption from the model are within the range of movements observed in the US data. Similarly, the behavior of total factor productivity and corporate output of the theory is qualitatively and quantitatively consistent with the US data. The unexpected productivity slowdown of old production methods generates an economic slowdown comparable to the observed one. As the new aggregate production method replaces the old one, the economy recovers in a smooth fashion towards its new balanced growth equilibrium.

The quantitative implications for asset prices of the two shocks of 1974 are illustrated by Figure 3. The unexpected arrival of information technologies paired with the productivity slowdown generate a 20% 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. The recovery takes longer than 15 years, which is also compatible with the US data. The model's Tobin's q, however, recovers faster than its US counterpart.

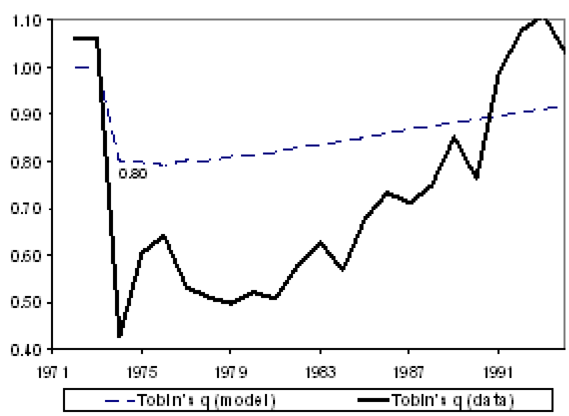


Figure 3: Quantitative Implications of the two shocks of 1974 for Tobin's q.

6 Conclusions

This study employs general equilibrium theory to quantitatively test the idea that the Information Technology revolution caused the stock market collapse of the mid 1970s, its subsequent stagnation, and recovery. The tool of analysis was a calibrated dynamic general equilibrium model with technology-specific capital and irreversible investment. Theory showed that 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, 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 as much as in the data, but it must also imply a two-fold increase in investment, and a strong economic expansion precisely at the time that the US economy slowed down.

The good news hypothesis can deliver a large and persistent drop in Tobin's average q, which is one of the most striking features of the data. Yet, within a neoclassical framework, this hypothesis always predicts a counterfactual expansion in aggregate quantities. I found, however, that when one takes into account the observed productivity slowdown in old production methods then the trends in the equilibrium time series of the model are compatible with the data. Moreover, almost one half 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."[12] 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

[12] Sargent [33], page 1.

model.

Finally, from the quantitative analysis in this paper, one can see that one of the main challenges for any general equilibrium theory of equity price movements resides in accounting for the long stagnation of Tobin's average q. In my model, market values start recovering 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 key macroeconomic aggregates, in particular investment and 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 jump in investment and 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).[13] 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) inter-

[13] This data can be downloaded from the FRB website at http://www.federalreserve.gov/releases/z1/current/data.htm.

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

MV = Corporate equity issued by nonfinancial corp. business (Table L.213 Line 2)
+ Corporate equity issued by financial corp. (Table L.213 Line 4)
+ Total liabilities of nonfarm nonfinancial corp. business (Table L.102 Line 20)
− Total financial assets of security brokers and dealers (Table L.130 Line 1)

− Total financial assets of nonfarm nonfinancial corp. business (Table L.102 Line 1)
+ Total liabilities of commercial banking (Table L.109 Line 21)
− Total financial assets of commercial banking (Table L.109 Line 1)
+ Total liabilities of life insurance companies (Table L.117 Line 16)
− Total financial assets of life insurance companies (Table L.117 Line 1)
+ Total liabilities of other insurance companies (Table L.118 Line 14)
− Total financial assets of other insurance companies (Table L.118 Line 1)
+ Total liabilities of closed-end funds (Table L.123 Line 7)
− Total financial assets of closed-end funds (Table L.123 Line 1)
+ Total liabilities of exchange-traded funds (Table L.123 Line 13)
− Total financial assets of exchange-traded funds (Table L.123 Line 8)
+ Total liabilities of REITs (Table L.129 Line 11)
− Total financial assets of REITs (Table L.129 Line 1)
+ Total liabilities of security brokers and dealers (Table L.130 Line 13)

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)[14] 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.

Macroeconomic data for the figures in section 5

The data on corporate GDP is taken from NIPA's Table 1.14. (Gross Value Added of Domestic Corporate Business in Current Dollars and Gross Value Added of Nonfinancial Domestic Corporate Business in Current and Chained Dollars). Corporate Investment is the sum of non-residential and residential corporate investment from BEA's Fixed Asset Tables, tables 4.7 and 5.7. To compute total factor productivity I apply the aggregate production function from the model and obtain TFP solving from the equation

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

Corporate capital, k_t, is the sum of non-residential and residential corporate capital, as reported in the BEA's Fixed Asset Tables, tables 4.2 and 5.2(chained quantity indexes). The behavior of hours worked int he corporate sector is computed as follows:

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

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

[14] This data can be downloaded from the BEA website at http://www.bea.doc.gov/bea/dn/faweb/AllFATables.asp.

bureau.

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

$$c = (1 - \tau_y)\, GDP - \text{investment}$$

7.2 Proofs

Proof of proposition 4.1

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

$$p_t V_t = p_{t+1} \left(d_{t+1} + V_{t+1} \right). \tag{5}$$

On the other hand, the firm's first order condition with respect to $k_{1,t+1}$ delivers

$$p_t - \mu_t = p_{t+1} \left[(1 - \delta) + (1 - \tau_y) F_1(k_{1,t+1}, 0, A_t n_t) \right] - \mu_{t+1}(1 - \delta), \tag{6}$$

where μ_t is the multiplier of the irreversibility constraint (1). The share of total after tax output going to labor is $1 - \alpha$, and dividends equal

$$d_{t+1} = \alpha(1 - \tau_y) F(k_{1,t+2}, 0, A_{t+2} n_{t+2}) - x_{1,t+1}.$$

One can multiply both sides of (6) 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

$$(p_t - \mu_t) k_{1,t+1} = \left(p_{t+1} - \mu_{t+1} \right) k_{1,t+2} + p_{t+1} d_{t+1}. \tag{7}$$

Without loss of generality set $p_0 = 1$, equations (5) and (7) imply

$$V_0 = \lim_{T\to\infty} \left\{ \sum_{t=1}^{T} p_t d_t + p_T V_T \right\} \tag{8}$$

$$(1-\mu_0)k_1 = \lim_{T\to\infty} \left\{ \sum_{t=1}^{T} p_t d_t + (p_T - \mu_T)\, k_{1,T+1} \right\} \tag{9}$$

$$p_t V_t - p_{t+1} V_{t+1} = (p_t - \mu_t)\, k_{1,t+1} - (p_{t+1} - \mu_{t+1})\, k_{1,t+2}. \tag{10}$$

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 [26]). 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 $\mu_t = 0$. Hence, equations (8), (9), the transversality condition for the problem of the firm $[\lim_{T\to\infty} p_T k_{1,T+1} = 0]$, the one for the consumer $[\lim_{T\to\infty} p_T V_T s_{T+1} = 0]$, and the market clearing condition ($s_t = 1$ for all t) imply $V_0 = (1-\mu_0)k_1$. Using this as an initial condition for the difference equation in (10) delivers the following relationship between the market value of a firm and its capital stock

$$V_t = (1 - \frac{\mu_t}{p_t})k_{1,t+1} \text{ for all } t. \tag{11}$$

To prove the first statement of the proposition note that μ_t is strictly positive only when the irreversibility constraint binds; in that case, equation (11) says $V_t < k_{t+1}$. The definition of q delivers $q_t < 1$. To prove the second one assume the irreversibility constraint does not bind, then $\mu_t = 0$, $V_t = k_{t+1}$ and $q_t = 1$. QED

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

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

Proof: Notice that equations (3), (4) and (5) are still first order conditions of the problem of the firm, and of the consumer, for all periods $0 \leq t < T$. Hence, for all $t < T$ one can still derive

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

The transversality condition of the consumer does not depend on the particular time period one is considering so that

$$p_t V_t = \lim_{\tau \to \infty} \left\{ \sum_{i=t+1}^{\tau} p_i d_i + p_\tau V_\tau \right\} = \sum_{i=t+1}^{\infty} p_i d_i. \tag{12}$$

Relative to the situation considered by proposition 4.1, equations (8) and (11) have to be changed to take into account the future availability of capital of type 2. Consider now all periods in which both types of capital are available. The first order conditions of the firm's problem with respect to $k_{1t+1}, k_{2t+1}, x_{1t}, x_{2t}$ can be used to derive

$$\begin{aligned}(p_t - \mu_t)\, k_{1,t+1} + (p_t - \mu_{2t}) k_{2,t+1} = {} & (p_{t+1} - \mu_{t+1}) k_{1,t+2} + \\ & (p_{t+1} - \mu_{2t+1}) k_{2,t+2} + p_{t+1} d_{t+1},\end{aligned} \tag{13}$$

where μ_{2t} denotes the multiplier associated to the irreversibility constraint for capital of type 2. Using this, and the first order condition of the consumer (6), yields

$$\begin{aligned}p_t V_t - p_{t+1} V_{t+1} = {} & (p_t - \mu_t) k_{1,t+1} + (p_t - \mu_{2t}) k_{2,t+1} \\ & - (p_{t+1} - \mu_{t+1}) k_{1,t+2} - (p_{t+1} - \mu_{2t+1}) k_{2,t+2}.\end{aligned}$$

Finally, using (12) one gets

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

which, by the transversality condition of the problem of the firm, renders

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

and thus

$$V_t = (1 - \frac{\mu_t}{p_t})k_{1,t+1}$$

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

$$q_t = \frac{V_t}{k_{1,t+1}} = (1 - \frac{\mu_t}{p_t}).$$

QED

Proof of proposition 5.1

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

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

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

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

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

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