EQUITY PRICES, PRODUCTIVITY GROWTH, AND 'THE NEW ECONOMY'[1]

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Abstract. The increase in equity prices over the 1990s has to a large degree been attributed to permanently higher productivity growth that is derived from the 'new economy' and related research and development (*R&D*) expenditures. This paper establishes a rational expectations model of technology innovations and equity prices, which shows that under plausible assumptions, productivity advances can only have temporary effects on fundamentals of equity prices. Using data on *R&D* capital and fixed capital productivity for 11 OECD countries, the evidence give strong support for the model by suggesting that technology innovations indeed have only temporary effects on equity returns.

JEL Classification: G120, G3, O4

Key words: New economy, productivity, economic growth, and equity prices.

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Introduction

The worldwide increase in equity prices in the 1990s has to a large extent been linked to permanent productivity growth effects of the IT revolution (Economist, 2001, Greenwood and Jovanovic, 1999, Hall, 2001, Keon, 1998, IMF, 2000).[3] It has been argued that the acceleration in productivity in the 1990s increased firms' current and expected real cash flow and therefore contributed to an increase in the value of firms. For example, analysing potential factors that are responsible for the recent boom in share prices Hall (2001) concludes that the high share prices could be justified by the recent growth in cash flow, thus implicitly accepting the thesis that cash flow growth rates are random walks. Greenwood and Jovanovic (1999) argue that the rise in the stock market from the 1980s onwards was linked to the rise of IT based firms, but did not make any predictions of the sustainability of the increased cash flow. Campbell and Shiller (2001) also highlight this issue, although they do not find a strong link from productivity to share prices. However, whether the increase in equity returns in the 1990s can be attributed to increasing growth in capital productivity and whether a sustainable higher capital productivity growth rate can be expected in the future, has gone almost unexplored.

This paper establishes a Tobin's q model of the interaction between capital productivity shocks and equity prices to gauge the short and long term effects of the IT revolution on equity prices. Section 3 considers an economy with only a tangible capital stock. The model is extended to allow for intangibles (*R&D* capital) in Section 4. Two important implications of the model are derived under plausible assumptions. First, capital productivity shocks are only temporary and, therefore, have only temporary effects on equity prices. In fact equity prices will precede the impact of the shock itself on the economy because equity markets react in a forward looking way to news of innovations. Second, productivity shocks lead to higher tangible and intangible capital stock in the long run, but that equity prices will revert back to a long-run equilibrium, which has been observed since the bull market peaked in 1999/2000. It is suggested that the analysis is of considerable relevance given the growing prevalence of intangible as opposed to tangible capital in the modern economy. Using data for real equity returns, GDP, the CPI, *R&D* capital stock, share price volatility and real bond yields over the period since 1965 for 11 OECD countries, the predictions of the model is tested in Section 5, with considerable support being offered to its predictions.

[3] Other factors such as a decrease in the risk premium, higher international liquidity, baby boomers, the disinflation, irrational exuberance have also been suggested as important factors behind the increase in stock prices in the 1990s (IMF, 2000, Shiller, 2000).

2 Equity returns and capital productivity

Before turning to a more formal model presentation in the next two sections this section discusses whether there has been a factor-productivity-induced increase in earnings in the 1990s and whether the share market has focussed on the correct productivity measure.

Consider Gordon's growth model, which is often used to calculate the fundamental value of equities (see Barsky and De Long, 1993, and IMF, 2000):

$$q = \frac{D}{r - \mu} \tag{1}$$

where q is the equity price, D is dividends per share, r is the real required returns to equity (the real long rate plus the risk premium), and μ is the permanent expected growth rate in real dividends. The model assumes that the firm is unlevered. This equation says that the fundamental value of equity is the discounted value of dividends. Since real dividends in this model are expected to grow at a constant rate to infinity it follows that the fundamental value of equity reflects the current dividends per share and the expected real growth rate therein.[4]

Assuming perfect competition in the goods market and the absence of depreciation of fixed capital stock and taxes, then Gordon's model can be rewritten as:

$$q = \frac{MP_K}{r - \mu} \tag{2}$$

where $\mu = \Delta \ln MP_K^e$ and MP_K is the marginal productivity of tangible and intangible capital, which equals earnings per unit of capital, and $\Delta \ln MP_K^e$ is expected growth in the marginal productivity of capital. This equation is formally derived in the next section.

Table 1 shows the trend in capital productivity for different countries since 1960, where capital productivity is computed as GDP divided by the non-residential fixed capital stock following the Cobb-Douglas technology assumption. The table shows no apparent uptrend in capital productivity, except in Australia and Denmark. In all other countries, capital productivity either fell or was stable

[4] A more realistic valuation model allows for taxes, leverage and that g is time-varying (see Copeland and Weston, 1992, and Barsky and De Long, 1993). However, the Gordon model simplifies the analysis substantially without affecting the principal results.

in the 1990s, and in all countries except Italy and Australia is well below the level attained in 1960. Japan stands out as an example of a dramatic decline in the marginal productivity of capital. The data sources and the construction of the capital stock are discussed in the data appendix.

Table 1: Estimated tangible capital productivity, index 1960=100

(GDP/non residential fixed capital stock)

	1960	1970	1980	1990	1999
Australia	100	100	100	103	121
Canada	100	97	99	95	93
Germany	100	82	74	74	76
Denmark	100	87	74	78	89
France	100	110	101	98	93
Italy	100	105	105	104	104
Japan	100	90	69	55	43
Neths	100	91	83	80	81
Sweden	100	101	91	90	88
UK	100	82	74	74	69
US	100	97	94	92	86

The absence of a pronounced increase in the marginal productivity of capital in the 1990s may appear surprising in the light of the recent emphasis on positive productivity effects of the IT revolution. Rather than focusing on capital productivity, the main international organisations and researchers have attributed a large part of the increase in equity prices in the 1990s to the accelerations in labour productivity and potential output. For example, in the IMF's *World Economic Outlook* (2000) and Kennedy *et al* (1998) of the OECD, the growth in potential output is used as a proxy for expected dividend growth in Gordon's growth model. Elsewhere IMF (ibid) suggests that labour productivity growth is the relevant measure of dividend growth. Similarly, the *Economist* in a series of articles has argued that labour productivity is the relevant productivity measure for share prices (see for instance, *Economist*, 2001). Finally, Campbell and Shiller (2001) suggest, without endorsement, that many analysts attribute the equity price boom in the 1990s partly to the accelerating labour productivity in the same period.

The problem with this line of reasoning is that labour productivity and potential output are severely biased proxies for firm's cash flow. To see the consequences of using labour productivity and potential output as measures of earnings per unit of capital, consider the Cobb-Douglas production function, $Y = BL^{\alpha}K^{1-\alpha}$, where B represents total factor productivity (TFP), Y is aggregate value-added output, K is capital services and L is labour services. The marginal productivities of labour and capital are given by:

$$\Delta \ln(Y / L) = (1 - \alpha)\Delta \ln(K / L) + \Delta \ln B \quad (3)$$

$$\Delta \ln(Y / K) = -\alpha \Delta \ln(K / L) + \Delta \ln B . \quad (4)$$

Comparing these equations, it is transparent that TFP growth enhances both capital and labour productivities. Capital deepening, however, increases the marginal productivity of labour but lowers the marginal productivity of capital. Underlying the data in Table 1 is the fact that historically, growth in capital deepening has dominated total factor productivity growth to such an extent that capital productivity has remained almost unaltered. The K/L ratio has increased by 3.7% annually in the OECD countries over the period from 1960 to 1999, whereas TFP has increased by 0.2% only on average, when α is set to 2/3. This explains why real wages are increasing over time whereas expected returns to bonds and shares (dividend yield plus expected dividend growth) tended to be constant in the long run.

The bias from using the growth in potential output as a proxy for the growth in capital productivity is even larger than using labour productivity. The bias is given by $\Delta \ln Y - \Delta \ln(Y / K) = \Delta \ln(K)$. The bias was 34% over the period from 1980 to 1992 and 18% from 1993 to 1999 for the countries used in this study; thus substantially biasing estimates of the fundamental value of shares.

What is the influence of the productivity bias on the fundamental value of equity? From Equation (1) it follows that the fundamental value of equity increases by $(r - \mu)^{-1}$ for each percentage point permanent increase in the expected growth in the marginal productivity of capital:

$$\frac{\partial \ln q}{\partial \Delta \ln MP_K} \approx \frac{1}{r - \mu} . \quad (5)$$

Suppose that r is 6%, that μ is expected to be 2%. If the 'new economy' is expected to permanently enhance the growth in labour productivity and potential output by 1%, this will add 25% to the fundamental value of equity. This suggests that substantial misvaluations appear when wrong proxies of expected growth in earnings are used.

3 A model of equity prices and productivity innovations

This section establishes a rational expectations dynamic model, which is used to show that under plausible assumptions, technology innovations will have only temporary effects on real dividends and equity prices. The model allows for a two-way relationship between equity returns and the capital stock. The capital stock influences the returns to capital and therefore equity prices, whereas the real equity price determines the desired capital stock. The model is based on the analytical framework of Abel (1982), Cochrane (1991), Hayashi (1982), Romer (1996), and Summers (1981) and allows for productivity-enhancing technological innovations in the investment-good producing sector.

We suggest that innovations in the investment-good producing sector, such as the IT revolution, have two effects on real corporate cash flow. First, it lowers the price of investment relative to economy-wide output prices and hence enhances profits for any positive level of investment. Relative prices of computers, for instance, have fallen substantially over the past two decades. Second, it increases the marginal productivity of the existing capital stock due to positive externalities of the technological innovations, θ. These two effects are incorporated into the profit function of the representative firm as follows:

$$\Pi_t = MP_K(K_t, \theta_t)\kappa_t - I_t \cdot (P_t^I / P_t^O) - C(I)_t \qquad (6)$$

where K is the industry-wide capital stock, I is investment, P^I is prices of investment, P^O is output prices, κ is the own capital stock, C is adjustment cost, MP_K is the marginal product of capital, and θ is the spill-over effect from innovations in the investment producing sector to the rest of the economy. Profit per unit of capital is assumed to be a negative function of the industry-wide capital stock, K, which follows from the assumption of a downward-sloping industry-wide demand curve; $\partial MP_K / \partial K < 0$.

Spillover effects are assumed to enhance profits per unit of capital, $\partial MP_K / \partial \theta > 0$. The firm's adjustment costs, $C(I)$, are assumed to be a convex function of the change in the firm's capital stock. The revenue function is assumed to be independent of labour cost because the labour force is assumed constant and fully employed. Finally, taxes are assumed absent.

The firm's optimisation problem is given by:

$$\max \ \Pi = \int_{t=0}^{\infty} e^{-rt}[MP_K(K_t,\theta_t)\kappa_t - \phi_t I_t - C(I_t)]dt \tag{7}$$

s.t.

$$\kappa_{t+1} = \phi_t^{-1} I_t + (1-\delta)\kappa_t \tag{8}$$

where $\phi_t = P_t^I / P_t^O$, δ is the rate of depreciation, and r is the discount rate facing the firm and equals the real required return to equity.

Investment is multiplied by relative prices in the resource constraint to allow for embodied technological progress. Hulten (1992) suggests measuring embodiment effects as the ratio of consumer prices to the equipment investment deflator, because technological advances make new equipment less expensive and more efficient than old equipment. Since corresponding technological advances do not occur in the consumer goods producing sector, reductions in I^I/P^O will reflect embodied technological progress, assuming that costs have changed by the same proportion in the consumer and the investment producing sectors.

The current-value Hamiltonian is given by:

$$H = MP_K(K_t,\theta_t)\kappa_t - \phi_t I_t - C(I_t) + \tilde{q}_t(\phi_t^{-1} I_t - \dot{\kappa}_t + \delta\kappa_t) \tag{9}$$

where $\tilde{q}$ is the shadow price for the constraint given by Equation (8). This equation yields the first order conditions for optimality as follows:

$$\phi_t^2 + C'(I_t)\phi_t = \tilde{q}_t \tag{10}$$

$$MP_K(K_t,\theta_t) = (r+\delta)\tilde{q}_t - \dot{\tilde{q}}_t, \tag{11}$$

where a dot over a variable signifies the change in the variable. Equation (10) is the investment function which links investment to the real shadow price of new capital goods. In equilibrium, the shadow price of additions to the capital stock, $\tilde{q}$, equals the marginal cost on the left hand side. Since $C'(I_t) > 0$ (positive marginal adjustment costs) there is a positive relationship between investment and real share prices modified by relative prices of investment goods. Shadow prices of new capital goods and the real value of equity only differ to the extent that relative prices of investment goods differ from the numeraire of one. From the assumption that $C'(0) = 0$, it follows that investment is zero when $\tilde{q}_t = \phi_t^2$.

From this derivation, it follows that investment can be positive even if the shadow price of capital is below one, if a lower real price of new capital lowers the effective acquisition costs of an additional unit of capital. If relative prices are normalised to one, then the shadow price of capital is identical to Tobin's q, and net investment is zero when Tobin's q is one. The shadow price of capital will be referred to as Tobin's q for simplicity so that $\widetilde{q} = q$.

In this context, the recent IT revolution has had the important effect of lowering the shadow price of capital because of the reduction in the real price of computers and other investment goods. Suppose that investment is initially zero at $q = 1$, and that the IT revolution lowers the relative price of computers. This brings Tobin's q below one and renders investment profitable.

Equation (11) says that the firm invests up to the point at which the marginal product of employing one unit extra of capital stock equals the opportunity cost of a unit of capital, which equals the rental cost of capital, $(r+\delta)\widetilde{q}_t$, minus the capital gain from owning the capital. Setting $\widetilde{q} = q$, Equation (11) can be rewritten to obtain the following well-known expression for real return to equity:

$$r + \delta = \frac{MP_K}{q_t} + \frac{\Delta q_t}{q_t}. \tag{12}$$

The final condition for optimality is that the terminal value of capital stock is zero:

$$\lim_{t \to \infty} e^{rt} q_t \kappa_t = 0, \tag{13}$$

which is the well-known transversality condition, which has to be satisfied to prevent explosive bubbles.

Equation (12) can be used to derive a standard equity valuation model. It can be rewritten as:

$$q_t = \int_{v=t}^{T} e^{-(r+\delta)(v-t)} MP_{Kt} dv + e^{-r(T-t)} q_t. \tag{14}$$

From the transversality condition it follows that the second right-hand-side term in this equation disappears. Assuming that the marginal productivity of capital is growing at a constant rate of μ this equation reduces to:

$$q_t = \int_{t=0}^{T} e^{-(\rho+\delta)t} MP_{Kt} dt = \frac{MP_K}{\rho+\delta-\mu}, \qquad (15)$$

where the time-subscripts are omitted for simplicity. Suppose that all earnings are paid out as dividends, then we arrive at the well-known Gordon growth model as outlined above.

$$q = \frac{D}{\rho+\delta-\mu}. \qquad (16)$$

The framework above can be used to analyse the effects of a technological innovation on share prices in the short run and in the long run. Equations (10) and (11) form the simultaneous first-order differential equation system as follows:

$$\dot{K} = f(q, \phi) \qquad (17)$$

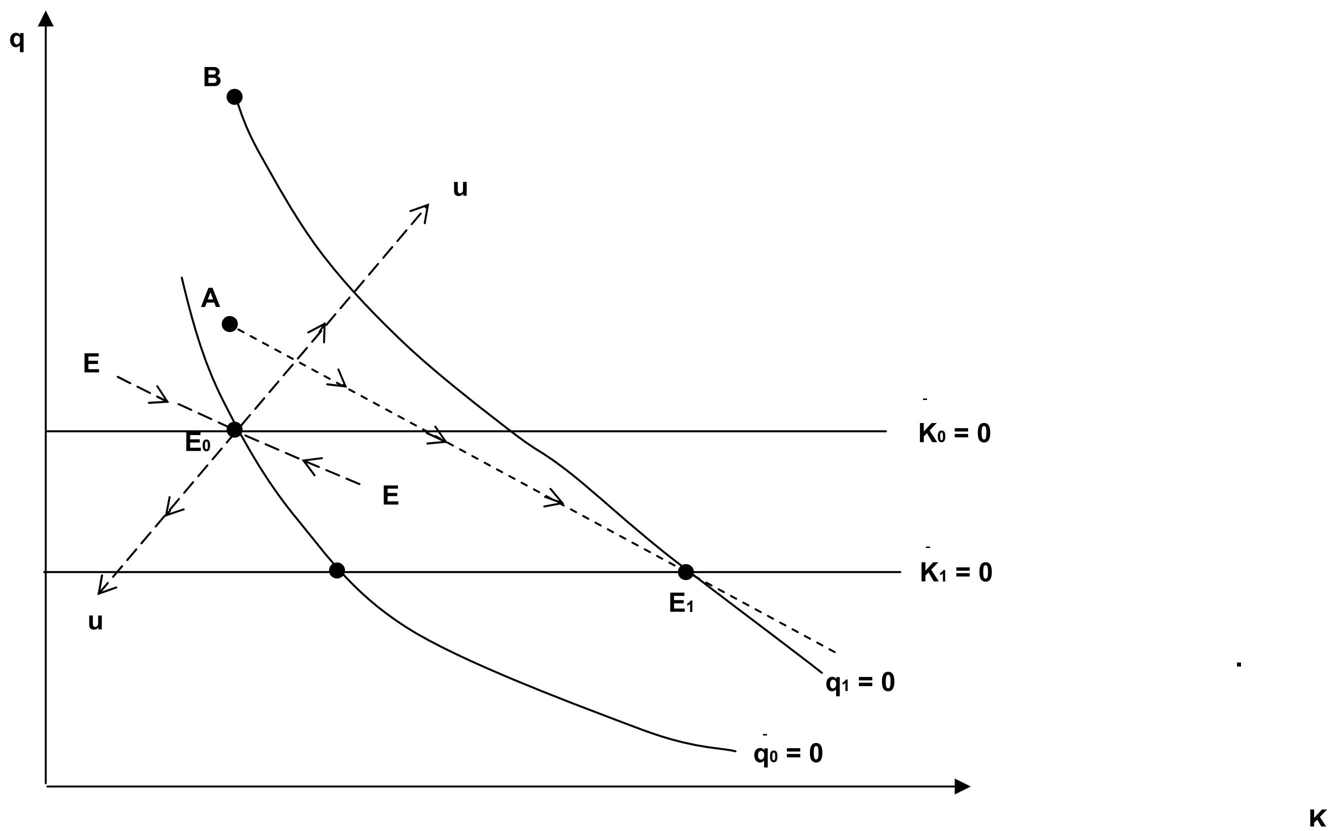
$$\dot{q} = qr - MP_K(K, \theta), \qquad (18)$$

where time subscripts and the depreciation rate have been omitted for simplicity. Equation (17) is the investment function and shows the dynamic adjustment of capital stock to innovations in q and P^i/P^o, where $\partial f / \partial(P^I / P^O) > 0$, $\partial f / \partial q > 0$, and $f(1,1) = 0$. Equation (18) shows the dynamic adjustment of equity prices to innovations in the required return to equity, the capital stock, and spill-over effects from innovations, where $\partial MP_K / \partial K < 0$, and $\partial MP_K / \partial \theta > 0$.

Figure 1 shows the dynamics of capital stock and equity. The $\dot{q} = 0$ curve is negatively sloped because the marginal productivity of capital is a decreasing function of capital stock. The EE-line defines a stable manifold and the UU-line defines an explosive path. The explosive path is ruled out by the transversality condition.

The phase diagram illustrates that the short-run and long run effects of the IT revolution on equity prices. Technology innovations affect the system via two channels. They lower the effective price of the capital stock and increase the marginal productivity of capital. The reduction in the effective price of capital shifts the $\dot{K}_t = 0$ schedule down by the reduction in the relative price of capital, because it reduces the effective acquisition price of new capital. Note, however, that share prices are unaffected by the shift. The $\dot{q} = 0$ curve shifts to the right because the positive externalities associated with new technology enhance the marginal productivity of the existing capital stock. The diagram shows that capital stock unambiguously increases whereas equity prices are unaltered in the new long-run equilibrium because the reduction in the relative price of capital has created a wedge between the shadow price of capital and equity prices.

Figure 1. The dynamics of share prices and investment.



Consider an unanticipated technology shock that leads to a higher θ and a lower I^I/P^O and that the economy is initially in equilibrium where the growth in the capital stock is zero. On impact the perfect foresight equity market jumps to the point A where it joins the stable manifold. Since $q > I^I/P^O$, investment will be positive and the capital stock starts increasing. The speed of adjustment towards the new equilibrium depends on the adjustment costs associated with the implementation of the investment project. Since the return to capital is constant, equity owners experience a capital loss along the path from A to E_1 to counterbalance the temporary higher return to capital. Equity prices stabilise in the new long-run equilibrium, E_1. The increasing profit that follows from the lower cost of investment is counterbalanced by the lower marginal productivity of capital in the new equilibrium.

In a myopic equity market that values equity based on current earnings, and therefore fails to incorporate into equity prices the fact that cash flow is only temporarily high, prices jump to the point B on impact. From B it moves along the $\dot{q} = 0$ schedule until the final equilibrium is reached at E_1. The myopic equity market overreacts substantially to productivity shocks.

The result that equity prices are unaffected in the long run by the IT revolution, or innovations in the investment producing sector in general, is generated by the assumption of diminishing returns to capital. Tobin's q can only be temporarily high, because the capital stock adjusts to bring the return to capital back to its initial equilibrium. If the assumption of diminishing returns to capital is abandoned, it can be shown that the system does not converge to a stable equilibrium. Intuitively, a positive technology innovation increases q and leads to an increase in capital stock. Since q will remain either constant (constant returns to capital), reflecting $\partial MP_K / \partial K = 1$, or increase (increasing returns to capital) the capital stock will be ever increasing without boundary. There is little evidence for constant or increasing returns at a macro level. For example, for the US Summers (1981) finds Tobin's q to fluctuate about a constant mean below one, which suggests diminishing returns to capital.

4 Returns to capital and intangibles

The previous sections assumed that firms' capital consisted of tangibles only. A significant and increasing fraction of firm's capital stock, however, consists of intangibles, especially *R&D* capital. Intangibles introduce the possibility that a productivity shock permanently increases the return to capital if there is increasing returns to the stock of knowledge. The model in the first part of this section is based on models of Paul Romer (1990), David Romer (1996), Grossman and Helpman (1991), Aghion and Howitt (1992), and Jones (1995).

Consider the extended Cobb-Douglas production function

$$Y = A[(1-a_L)L]^{\alpha}[(1-a_K)K]^{1-\alpha} \quad (19)$$

where A is the stock of knowledge developed from R&D activities, $(1 - a_L)$ is the fraction of the labour force employed in the goods producing sector, and the fraction a_L is employed in the *R&D* sector, and $(1 - a_K)$ is the fraction of the capital stock used in the goods producing, and the fraction a_K is used in *R&D* production.

The production of ideas in the representative firm is assumed to follow a generalised Cobb-Douglas production function:

$$\dot{A}_t = B(a_K K_t)^{\lambda}(a_L L_t)^{\gamma} A_t^{\psi} \tag{20}$$

or

$$g_A = \left(\frac{\dot{A}}{A}\right)_t = B(a_K K_t)^{\lambda}(a_L L_t)^{\gamma} A_t^{\psi-1}. \tag{21}$$

where g_A is the growth in knowledge and new designs, B is a firm specific parameter, $a_K K_t$ is the firm's capital stock used for *R&D*, and $a_L L_t$ is the firm's *R&D* labour. The firm's production of ideas and new designs is influenced by its own research capital stock, A_t^{ψ}. Equation (21) shows that the production of new ideas is a function of the firm's stock of knowledge, the capital stock allocated to *R&D*, and the number of *R&D* active staff.

The influence of the production of ideas on the growth in the return to capital is given by:

$$g_{MPK} = \frac{dMP_K}{MP_K} = g_A - \alpha(g_K - g_L). \tag{22}$$

From this equation it follows that investment in *R&D* will only lead to a permanent higher growth in the returns to capital if $g_A > \alpha(g_K - g_L)$ can be maintained forever, i.e. the growth in the stock of knowledge exceeds the growth in the *K*/*L* ratio. This requirement can be satisfied either if g_A is permanently growing and $(g_K - g_L)$ remains constant in the long run, or if g_A converges to a steady state that exceeds $(g_K - g_L)$, and that there is no mechanism in the economy that generates adjustment in the capital stock until the condition of $g_A = \alpha(g_K - g_L)$ is met.

First it is investigated whether g_A converges to a steady state. Differentiating Equation (22) yields the following first order differential equation:

$$\dot{g}_A = g_A[\lambda g_K + \gamma g_L + (\psi - 1)g_A], \tag{23}$$

from which it follows that g_A is growing if:

$$g_A < \frac{\lambda g_K + \gamma g_L}{1-\psi} = g_A^* \tag{24}$$

where g_A^* is the solution to the differential equation given by (23). The equation only has a stable solution for $\psi < 1$, that is, the growth in the idea capital stock is a declining function of the stock of *R&D* capital. From Equation (23) it follows that g_A is growing if it is below g_A^*, and it is falling if it is above g_A^*, and therefore that g_A^* is a stable equilibrium. Firms can increase the growth rate in the production of ideas by increasing the growth rate of research workers and research capital. However, a firm cannot permanently increase the production of ideas by allocating a higher fraction of its workforce to *R&D* activities. In other words there are diminishing returns to *R&D* capital. Hence, the more the firm invests in *R&D* the lower is the return to one extra unit of *R&D*.

If $\psi = 1$ then the productivity of research is proportional to the stock of ideas and the productivity of researchers increases over time given a fixed stock of researchers. Finally, if $\psi > 1$ then output of the firm will be ever increasing. The growth rate in *R&D* knowledge will be increasing exponentially implying, on an aggregate level, that the GDP *growth rate* should have been increasing over the past century. As pointed out by Jones (1995) this is clearly not what we have observed. In fact the growth in total factor productivity in the OECD economies has been fairly constant over the last century. Furthermore, not only have empirical studies have found diminishing returns to *R&D* inputs but also that the patent output per *R&D* worker has been decreasing (Griliches, 1990). From these observations it follows that the possibility that $\psi \geq 1$ can be ruled out on empirical grounds, and there is diminishing returns to *R&D* capital.

Given that g_A tends to a steady state, g_A^*, the next question is whether capital adjusts endogenously until the condition $g_A^* = \alpha(g_K - g_L)$ is satisfied. Intuitively, one would expect this to happen. Suppose that the economy starts up from $g_A^* = \alpha(g_K - g_L)$ and that a technological innovation leads to an increase in the growth rate of the production of ideas so that $g_A^* > \alpha(g_K - g_L)$ and therefore that the growth rate in the marginal productivity of capital increases. The resulting increase in Tobin's *q* leads to an increase in the *R&D* capital stock. Due to diminishing returns to *R&D* capital, the higher *R&D* input lowers the marginal productivity of R&D capital and therefore q. The process terminates when Tobin's q is back to its initial level. This is a similar result to Section 3.

More formally, assuming that the firm's capital stock consists only of *R&D* capital stock, which is accumulated by research labour, then the firm's optimisation problem is given by:

$$\max \Pi = \int_{t=0}^{\infty} e^{-rt}[MP_A(A_t, \Phi_t)a_t - w_t a_{L,t} L_t - C(a_L L)_t]dt \tag{25}$$

s.t.

$$a_t = MP_{RL,t} a_{L,t} L_t + a_{t-1}, \tag{26}$$

where w is the real product wage of *R&D* workers and MP_{RL} their marginal productivity, A is industry-wide *R&D* capital and MP_A its marginal productivity, a is the *R&D* capital for the individual firm, and Φ is spill-over effects of a technology break-through that leads to an increase in the marginal productivity of *R&D* capital such as the IT revolution and the electrification in the beginning of the last century. The *R&D* capital stock is assumed not to appreciate or depreciate for simplicity. Profit per unit of *R&D* capital is assumed to be a negative function of the industry wide *R&D* capital stock, $\partial MP_A / \partial A < 0$, but a positive function of major technology innovations that are assumed to enhance profits, $\partial MP_A / \partial \Phi > 0$.

The firm's adjustment costs, $C(\dot{a})$, are assumed to be convex functions of the change in the firm's *R&D* capital stock and proportional to real wages to allow for the fact that relocation, training and advertising costs are growing in real wages. In Equation (26) the *R&D* capital stock is assumed to increase by the quality adjusted number of *R&D* workers. An increase in the marginal productivity of *R&D* workers will reflect an increase the quality of their input and therefore the value of the *R&D* investment.

The current-value Hamiltonian is given by:

$$H = MP_A(A_t, \Phi_t)a_t - w_t a_{L,t} L_t - w_t C(a_L L_t) + \widehat{q}_t (MP_{RL,t} a_L L_t - \dot{a}_t) \tag{27}$$

where $\widehat{q}$ is the shadow value of *R&D* capital stock for the constraint given by Equation (26) and relates to Tobin's q by the marginal productivity of *R&D* workers.

This equation yields the first order conditions for optimality as follows:

$$w_t + w_t C'(a_{L,t}L_t) = \hat{q}_t MP_{RL,t} \tag{28}$$

$$MP_A(A_t, \Phi_t) = r\hat{q}_t - \dot{\hat{q}}_t . \tag{29}$$

Equation (28) is the demand for *R&D* workers, which depends on the real shadow price of *R&D* capital. In equilibrium the shadow price of additional *R&D* capital stock, $\hat{q}$, equals the marginal cost on the left hand side. Since $C'(a_{L,t}L_t) > 0$ there is a positive relationship between demand for *R&D* workers and real equity prices modified by the marginal productivity of R&D workers, $\hat{q}$. From the assumption that $C'(0) = 0$, it follows that employment of *R&D* workers is zero when $\hat{q}_t = 1$ and research workers are paid their marginal productivity. Equation (29) says that the firm employs *R&D* workers up to the point at which the marginal product of *R&D* workers equals the modified opportunity cost of a unit of *R&D* capital, which equals the rental cost of capital, $r\hat{q}_t$, minus the modified capital gain from owning the capital.

Letting the shadow price of capital be referred to as Tobin's *q* for simplicity so that $\tilde{q} = q$, then Equations (28) and (29) form the simultaneous first-order differential equation system as follows:

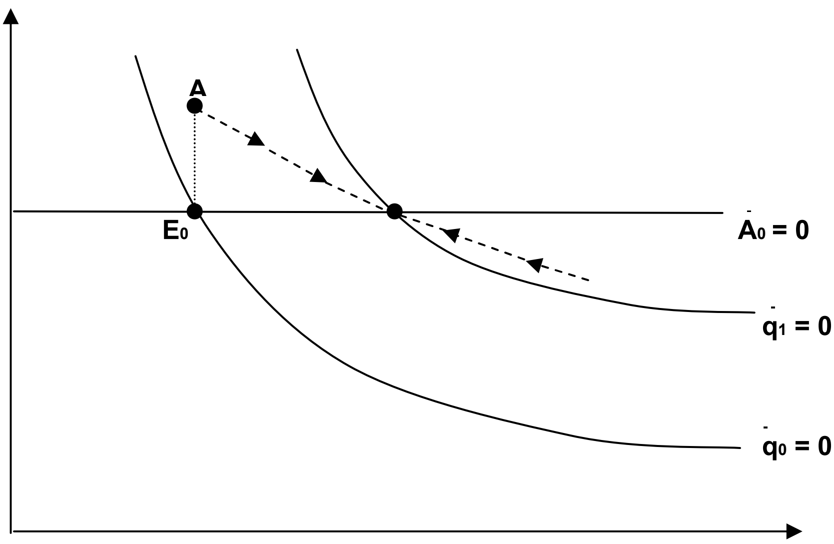
$$\dot{A} = f\left(q, w, MP_{RL}\right) \tag{30}$$

$$\dot{q} = qr - \frac{MP_A(A, \Phi)}{q} \tag{31}$$

Equation (30) is the *R&D* investment function which shows the dynamic adjustment of *R&D* capital stock to innovations in *w* and MP_{RL}, where $\partial f / \partial MP_{RL} > 0$, $\partial f / \partial q > 0$, $\partial f / \partial w < 0$, and $f(1,1,1) = 0$. If *R&D* workers are paid their marginal productivity, $\dot{A}$ is independent of *w* and MP_{RL}. Equation (31) shows the dynamic adjustment of equity prices to innovations in the required return to equity, *R&D* capital stock, and spill-over effects from technology innovations, where $\partial MP_A / \partial A < 0$, and $\partial MP_A / \partial \Phi > 0$.

Corresponding to Figure 1, Figure 2 shows the effects of a technology innovation on equity prices and the stock of knowledge. Starting from equilibrium, a positive innovation increases Φ and MP_{RL} and therefore shift the $\dot{q} = 0$ schedule to the right. The $\dot{A} = 0$ schedule may shift downwards depending on the real wage response to the increasing marginal productivity of research workers. If real wages adjust instantaneously to the shift in their marginal productivity, the $\dot{A} = 0$ schedule remains unaffected by the technology innovation. It is most likely that the $\dot{A} = 0$ schedule initially shifts down because the innovation is unexpected, but thereafter shifts back as *R&D* workers' wages catch up to the increased productivity. For simplicity the $\dot{A} = 0$ schedule is assumed unaffected by the technology shock.

Figure 2 The dynamics of R&D capital stock and equity prices



On impact, the perfect foresight equity market jumps to the point *A* where it joins the stable manifold. Since *q* is in excess of one the *R&D* capital stock will start increasing. The speed of adjustment towards the new equilibrium depends on the adjustment costs associated with the implementation of the investment project and may be slowed down substantially by a potential shortage of *R&D* workers. Since the return to capital, *r*, is constant, equity owners experience a capital loss along the path from *A* to E_1 to counterbalance the temporary higher return to capital. Equity prices stabilise in the new long-run equilibrium, E_1. The increasing profit that follows from spillover effects of the technology shock is counterbalanced by the lower marginal productivity of *R&D* capital in the new equilibrium.

From this analysis it follows that the inequality $g_A^* > \alpha(g_K - g_L)$ can only be binding for a limited period of time. The increasing *R&D* capital stock triggered by the higher equity prices will bring down the return to capital and hence g_A^* until the condition $g_A^* = \alpha(g_K - g_L)$ is met. The only way a technology shock can have persistent effects on the growth in the marginal productivity to capital is if there is increasing returns to knowledge. However, the latter case was ruled out by the above-mentioned fact that total factor productivity growth has not been increasing over the past century.

5 Empirical results

We now go on to test the model, with a particular focus on the predictions from the intangibles model of Section 4. This is of particular relevance given the growing importance of knowledge in the modern firm's profitability.

5.1 Data

Standard data on GDP, long rates, share prices, the CPI and dividends are used. The principal novelty in our data set is use of an estimated *R&D* and fixed capital stock. *R&D* capital stock is available from 1965 to date using estimates of *R&D* investment from OECD's *Science and Technology Indicators*. An important aspect in its derivation is the depreciation rate of *R&D* capital and the deflator used for *R&D* capital. Cockburn and Griliches (1988) use a 15% depreciation rate, Coe and Helpman (1995) use 5%. Megna and Mueller (1991) use a binominal distribution and therefore allow the *R&D* stock to appreciate before it starts depreciating. Coe and Helpman deflate *R&D* expenditure with the GDP deflator and total hourly wages, given half weight to each. We use the value added deflator and a 5% depreciation rate and set the initial *R&D* capital stock to *R&D* expenditure in 1965 and divided by the depreciation rate minus the average growth in real *R&D* over the period from 1965 to 2001.

As shown in Table 2, the implied levels of aggregate *R&D* capital productivity (GDP divided by *R&D* capital) are plausible, in that they start high in low income per capita industrial countries, which would be expected to have little *R&D* capital in 1970, but converge by the end of the sample on levels typical of established industrial countries such as France, the UK and US. Note that in these countries *R&D* also includes military related R&D expenditure that is minor elsewhere. The figures in Table 2 are consistent with diminishing returns to *R&D* capital. In no case does a rise in the *R&D* capital stock, which has risen at least 70% in real terms in all countries, lead to higher *R&D* productivity. Looking at the data inversely, we have typically seen *R&D* capital rising in line or faster than GDP. However, as shown in the right hand columns, it has not risen faster than tangible capital in all countries, the exceptions being again the military powers France, the UK and US.

Table 2: Estimated *R&D* capital productivity (GDP/R&D capital stock)

	1970	1985	1999	*R&D* capital stock 1999 (1970=100)	*R&D* capital/tangible capital 1970 (%)	*R&D* capital/tangible capital 1999 (%)
Australia	8.1	8.1	6.7	312	0.7	0.9
Canada	6.1	6.9	5.6	283	1.9	2.0
Germany	12.5	4.0	3.0	791	0.3	2.1
Denmark	18.9	8.9	5.3	677	0.5	2.3
France	3.7	3.8	3.3	224	3.7	3.5
Italy	30.2	11.5	6.9	882	0.2	1.1
Japan	10.4	4.8	3.0	931	1.0	2.0
Netherlands	4.2	3.8	3.8	230	2.2	2.2
Sweden	6.4	4.1	2.6	406	0.9	1.8
UK	2.9	3.1	3.4	163	3.3	2.4
US	2.3	2.8	3.0	170	4.9	3.2

5.2 Empirical implications

Key aspects of the model of intangibles in Section 4, as well as the more general model of Section 3, are that productivity shocks are only temporary and therefore have only temporary effects on equity prices. Furthermore, productivity shocks lead to higher tangible and intangible capital stock in the long run, which drive capital productivity back to its base level. These allow us to derive the following testable hypotheses:

Hypothesis 1. Share markets predict *R&D* and tangible capital productivity. This follows for the fact that share markets react instantaneously to news of innovations, which owing to adjustment costs are only embodied later in capital.

Hypothesis 2. The response of *R&D* and tangible capital productivity to share prices is temporary and soon reversed, consistent with the dynamic path in share prices analysed in the phase diagrams.

Our main focus is on *R&D* capital, although we also present results relevant for assessing these hypotheses for tangible capital. The hypotheses are tested using a combination of Granger causality and VAR methodologies. A preliminary to estimation is testing for unit roots, since variables entering a Granger Causality or VAR system should normally be stationary, while trend stationary variables are relevant for cointegration. The results of Dickey-Fuller tests for the period 1965-99 over which we have data for *R&D* capital are shown in Table 3. They indicate that the second difference of the log of prices and the first difference of the log of productivity growth, real long term interest rates and real share price growth are stationary. Share market volatility (the standard deviation of monthly share price changes, deflated by the CPI) and real equity returns are stationary in levels. The deviation of GDP from a Hodrick-Prescott (HP) filter, justification for which is discussed below, is also stationary in levels by construction. Whereas most of these results are as expected, note that real long term interest rates would generally be expected to be stationary in levels and the price level stationary in differences. The short sample explains why these results are not obtained – we choose to retain the conventional variables on the basis that the fact that these variables are difference stationary implies stationarity in variance. This is consistent with them being *I*(0) about a trend or drifting *I*(0) variables, which can still be bounded over a longer-term sample.

Table 3 Unit root tests (1965-99)

	US	DE	CA	UK	FR	IT	JP	DK	AU	NE	SE
RLR	-2.6	-2.3	-1.6	-2.4	-1.3	-2.1	-2.6	-1.9	-1.4	-1.9	-1.7
DRLR	-4.6	-4.5	-4.2	-5.3	-4.0	-5.1	-6.4	-5.5	-5.5	-5.5	-6.1
VOL	-5.2	-3.2	-4.1	-3.3	-3.1	-4.0	-2.7	-3.7	-3.9	-4.8	-3.5
EQR	-4.5	-5.0	-5.6	-6.2	-5.1	-4.3	-5.2	-4.7	-5.8	-4.2	-3.9
DLRSP	-4.4	-5.2	-5.2	-4.9	-4.2	-4.2	-5.0	-4.7	-4.9	-4.1	-4.1
LYD	-4.6	-4.0	-3.6	-3.8	-3.4	-4.7	-3.1	-4.1	-3.3	-3.0	-4.2
DLCPI	-2.6	-2.6	-1.8	-2.0	-1.4	-1.5	-2.0	-1.3	-1.4	-1.7	-1.5
DDLCPI	-5.0	-3.5	-4.3	-4.8	-3.6	-4.2	-6.1	-5.3	-5.0	-4.6	-5.5
DLRDKP	-4.2	-1.5	-2.5	-4.1	-2.0	-1.9	-3.5	-2.4	-3.0	-2.8	-2.8
DLTKP	-5.3	-4.2	-4.0	-3.9	-3.8	-5.2	-3.7	-2.8	-4.1	-5.0	-5.4
DLTFPRD	-3.7	-3.8	-3.3	-4.0	-2.0	-5.3	-2.7	-5.9	-4.4	-2.6	-3.2

Key: *RLR* = real long rate, *EQR* = real total return on equity, *CPI* = consumer price index, *VOL* = real share price volatility, *TFPRD* = total factor productivity including *R&D*, *TKP* = tangible capital productivity, *RDKP* = *R&D* capital productivity, *YD* = deviation of GDP from the Hodrick-Prescott filter. A "*D*" before the variable name indicates first difference, an "*L*" stands for log.

For testing of Hypothesis 1 we initially ran Granger causality tests on the relationship between the real return on equity and the marginal productivity of *R&D* capital under the assumption of Cobb-Douglas technology. Real returns to equity were computed as the proportional change in the share index less inflation plus the dividend yield. The Granger causality test assesses whether there is a consistent pattern of shifts in one variable preceding the other. Such tests do not give any proof on causality, but nevertheless where causal mechanisms based e.g. on expectations can be suggested, as outlined above, then a positive result gives grounds for further investigation.

Granger causality can only be a starting point in empirical investigation for at least two reasons. First, there are a number of additional influences on real equity prices, as outlined above, so a multivariate regression approach needs to be adopted before reaching any conclusions. In addition, the absence of a short-term relationship may not preclude a long run link in a cointegrating framework. On the other hand VAR analysis as undertaken below has some disadvantages, such as the problem of recursive ordering etc., that are not present in the Granger analysis and it is therefore an invaluable complement to the VAR analysis.

To run the Granger causality test, the following equations are estimated for each country:

$$X_t = \alpha_0 + \alpha_1 X_{t-1} + \alpha_2 X_{t-2} + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \varepsilon_t \qquad (32)$$

where X is either log productivity growth or real equity returns and Y is the other variable in question, and ε is a disturbance term. If there is Granger causality from *Y* to *X*, then some of the *ß* coefficients should be non-zero; if not then all of the *ß* coefficients should be zero. Testing whether the coefficients on the lagged indicator variables are zero can be readily performed using standard *F*- or *t*-tests.

Tests were undertaken with two lags and data from 1968 to 1999, with the log of productivity differenced to ensure stationarity. As shown in Table 4 below, the broad conclusion is that we can reject the hypothesis that the equity return does *not* Granger cause *R&D* productivity growth, for the vast majority of countries. On the other hand, realised *R&D* productivity growth does not precede equity returns. This is wholly in line with our theory as set out in the phase diagram 2. News of a technical innovation gives rise to increases in share prices, which stimulate actual increases in R&D productivity via investment. This is consistent with the forward-looking nature of equity returns.

Table 4: Granger causality tests for equity returns and *R&D* productivity (*F*-test and *P*-value)

	Equity return does not Granger cause *R&D* productivity growth	*R&D* productivity growth does not Granger cause equity return
Australia	3.60 (0.04)**	1.24 (0.31)
Canada	6.51 (0.00)**	0.21 (0.81)
Germany	2.66 (0.09)*	1.26 (0.30)
Denmark	2.74 (0.08)*	0.48 (0.62)
France	2.49 (0.10)*	0.46 (0.68)
Italy	0.85 (0.39)	1.51 (0.24)
Japan	6.24 (0.01)**	1.73 (0.20)
Netherlands	8.88 (0.00)**	2.17 (0.13)
Sweden	3.01 (0.07)*	0.06 (0.94)
UK	3.89 (0.03)**	1.88 (0.17)
US	8.60 (0.00)**	0.73 (0.49)

** indicates rejection of the hypothesis at 5% and * at 10% level.

A key problem associated with the estimation of predictive links between variables, is that they are almost always conditioned on the other variables incorporated in the related equation (Davis and Fagan, 1997). A criticism of Granger causality tests is naturally that only two variables and their interrelations are assessed, while as shown above these should only be a subset of the set of variables, which combine to determine real share prices. Accordingly, to cast further light on Hypothesis 1 and also to address Hypothesis 2 we proceeded to wider estimation using multiple variables.

A standard VAR system is the reduced form of a linear dynamic simultaneous equation model in which all variables are treated as endogenous. Each variable is regressed on lagged values of itself and on lagged values of all other variables in the information set. In the light of the discussion of equity price determination above we sought to assess the relation between the log difference of real equity prices, the log difference of *R&D* capital productivity, the real long bond yield, and real equity price volatility as a proxy for the equity risk premium. The real bond yield is calculated as nominal bond yield minus the rate of consumer price inflation. We added to these variables the difference between the log of GDP and a HP filter to allow for cyclical and "real business cycle" effects and the log difference of consumer prices.

The aim is to provide some quantitative estimates of the relationship between *R&D* productivity and equity returns in the presence of related variables. To do this we need to orthogonalise the estimated reduced form VAR model to identify the effect of shocks to the innovations of the variables in the VAR. The standard Choleski decomposition is used to identify the responses in VAR models. Identification then uses the Sims's triangular ordering. In more detail, the means of identification used in this paper is set out in Sims (1986) and reviewed in Davis and Henry (1993). A general form for a structural model with stationary variables is:

$$A_0 Y_t = \sum^{M} A_i Y_{t-i} + e_t \qquad (33)$$

The A matrix incorporates simultaneous feedbacks amongst all the Y variables. The matrix A_0 will not normally be diagonal. The unrestricted VAR is then:

$$Y_t = A_0^{-1} \sum A_i Y_{t-i} + A_0^{-1} e_t \qquad (34)$$

$$= \sum C_i Y_{t-i} + u_t \ . \qquad (35)$$

The variance/covariance matrix of the unrestricted VAR or reduced form is *u'u*=Σ, and again in general this will not be diagonal. Although Equation (35) can be estimated, this cannot be used to identify effects of shocks or for policy analysis (i.e. identifying the effects of innovations in the structural disturbances e_t on the Y_t. The question is what are the minimum identification restrictions necessary to establish effects of innovations in e_t on Y_t, if we have previously estimated the reduced form effects of innovations in u_t on Y_t. From Equations (34) and (35) we know that

$$u_t = A_0^{-1} e_t \Rightarrow A_0 u_t = e_t . \tag{36}$$

The variance/covariance matrix of the structural innovations is *e'e* = Ω but is unknown. But it is linked to the estimated reduced form variance/covariance matrix by the equation:

$$A_0 \sum A_0^{'} = \Omega \tag{37}$$

The method Sims proposed uses the Choleski decomposition of Σ whereby the unique decomposition

$$\sum = LDL^{'} \tag{38}$$

is applied, where *L* is lower triangular and *D* is a diagonal matrix. Then from (37) and (38) we get

$$A_0 =: L^{-1} , \tag{39}$$

and Ω = *D*. Hence inverting the estimated VAR as an infinite moving average process, which by Wold's decomposition theorem will always be possible for a stationary series, gives

$$Y_t = u_t + G_1 u_{t-1} + G_2 u_{t-2} + ... \tag{40}$$

where

$$G_i = (1 - Ci)^{-1} \tag{41}$$

Then the response of Y_t to an innovation in a structural disturbance et is given from the relation $A_0^{-1} e_t = u_t$, i.e.

$$Y_t = A_0^{-1} e_t + G_1 A_0^{-1} e_{t-1} + ... \tag{42}$$

Hence the impulse response is:

$$\frac{\delta Y_{t+s}}{\delta e_t} = G_s A_0^{-1} = G_s L \tag{43}$$

A well-known problem with the Sims triangular ordering is that it is arbitrary, and requires a justification for the ordering chosen. The presence of common shocks and co-movements among the variables makes the decision on ordering a crucial one.

Following Canova and De Nicolo (1995) and Nasseh and Strauss (2000) it is assumed that exogenous shocks are largely technology driven and hence affect *R&D* productivity and output. Stock returns, in line with the present value model, respond according to the effect of these shocks on future cash flow. Stock prices may also respond to changes in inflation, long-term real rates and volatility (risk premium), which may all also be affected by technological factors and other shocks. Hence, we order the variables with *R&D* productivity first, followed by output deviation from the HP filtered trend, change in inflation, change in long rates and real equity price volatility before real equity prices themselves. Real equity returns are thus constrained to only feed back on the other variables with a lag. Note that this need not exclude a marked leading indicator property of share prices, if the data suggest it. We also tested for sensitivity by reversing the ordering for the US, as reported in the tables, which did not substantively change the results. Lag length chosen was 2.

We began with tests for lag length, using the sequential modified LR test statistic, the final prediction error, the Akaike information criterion, the Schwarz information criterion and the Hannan-Quinn information criterion. In France, the Netherlands and the US the tests were unambiguous in selecting two as the appropriate lag length. In all other countries all but the Schwarz criterion lead to this conclusion. Accordingly, we selected two lags as appropriate in all cases.

Looking at the significance of variables, as shown in Table 5, there are significant lags of equity returns in the equation for *R&D* productivity in France, Japan, the Netherlands and the US, consistent with the results for Granger causality, and lags of productivity are significant in the equity returns equation for Japan and the US. One explanation for the latter may be that these are two countries that have experienced equity price bubbles during the estimation period, consistent with equity returns continuing to increase even after the rise in *R&D* capital productivity was realised.

Table 5: Significant lags in the VAR system

Dependent variable	*EQR*	*DLRDKP*
Independent variable	*DLRDKP*	*EQR*

Australia		
Canada		
Germany		
Denmark		
France		*
Italy		
Japan	**	**
Netherlands		*
Sweden		
UK		
US	**	**
Memo: US with ordering reversed	**	**

Key: See Table 3.

* indicates significance at the 90% level and ** at the 95% level

The key outputs of a VAR for the purposes of our current exercise are the variance decomposition and impulse responses. There may be effects in the whole system that are hidden from individual equations. With a model of this sort there is a large amount of output generated by this exercise: six equations, subject to six different shocks give 36 solutions. Therefore, only a few key results are presented. Given the focus of the work on real equity returns and *R&D* productivity, we report only the variance decomposition of real equity returns to shocks in the innovations to productivity, and of productivity to real equity returns, together with the impulse response of productivity to equity returns.

The variance decompositions show the degree to which the variance of the "independent variables" explain the forecast variance of the "target" variable in the VAR system. Table 6 shows that equity returns help explain a significant proportion of *R&D* productivity, in Canada, Italy, Japan and the US, suggesting forward looking behaviour by equity holders in response to expected increases in productivity. The opposite result is found in Japan and Sweden. This may of course relate to the lesser development of equity markets in the latter, only responding in the wake of actual real developments, rather than in line with expectations. Sweden is a small country whose markets are subject to strong international influences. Also the Japanese market has been severely depressed in a decade despite a highly innovative environment.

Table 6: Variance decompositions for real share prices and *R&D* capital productivity (percent of forecast variance accounted for by variance in each variable)

	DLRDKP on EQR	EQR on DLRDKP

Years	4	4
Australia	16	8
Canada	7	19*
Germany	13	1
Denmark	4	4
France	4	11
Italy	6	10*
Japan	23*	31**
Netherlands	14	4
Sweden	26**	16
UK	15	1
US	10	13**
Memo: US with ordering reversed	1	19**

Key: See Table 3.

* indicates significance at the 90% level and ** at the 95% level

Turning to impulse responses, as shown in Table 7, a remarkable result emerges for effects of shocks to share prices on *R&D* capital productivity, in that a rise in real equity returns tends to raise R&D capital productivity in year 2 but then depress it markedly in succeeding years. This is consistent with the valuation ratio effect as highlighted in the theory section, whereby high equity returns in response to a technical innovation prompt increasing *R&D* investment, which given diminishing marginal productivity of *R&D* capital leads to lower R&D capital productivity. The pattern is common to all countries except Germany and is significant at least in part of the cycle in Australia, Canada, Denmark, France, Italy, Japan, the Netherlands, Sweden, and the United States.

Table 7: Impulse response functions for effect of change in real equity returns on change in *R&D* capital productivity (percent responses to 1 standard deviation shocks in real equity returns)

Year	**1**	**2**	**3**	**4**	**5**
Australia	0	0.03	-0.5**	0.2	0.1
Canada	0	0.5	-0.7**	-0.7*	-0.05
Germany	0	-0.07	-0.2	-0.1	0.2
Denmark	0	0.4*	-0.3	0.1	0.5
France	0	0.4**	-0.3	-0.3	-0.1
Italy	0	0.2	-0.6*	-0.7*	0.03
Japan	0	0.9**	-0.6**	-1.0**	-0.4
Netherlands	0	0.4*	-0.1	-0.08	-0.01
Sweden	0	0.7*	-0.07	-0.7*	-0.6
UK	0	0.2	0.03	-0.05	-0.3
US	0	0.6**	-0.4*	-0.5*	-0.08

Memo: US with ordering reversed	-0.36	0.82**	-0.26	-0.56	0.18

Key: See Table 3.

** significant at 5%, * significant at 10% level.

To compare and contrast with these results, we present a similar set of estimates featuring tangible capital productivity and the same additional variables. In this case we may test the corresponding hypotheses to those set out above as drawn from Section 2.

As was the case for R&D productivity, the results for Granger causality are unequivocal in suggesting that equity returns cause capital productivity but the opposite is not the case. Only in Denmark and Italy are conventional significance levels not attained, and even there the result is far closer to rejection of the null than for a causal role for capital productivity.

Table 8: Granger causality tests for equity returns and capital productivity (*F*-test and *P*-value)

	Equity return does not Granger cause capital productivity growth	Capital productivity growth does not Granger cause equity return
Australia	3.39 (0.047)**	1.88 (0.17)
Canada	5.61 (0.0089)**	0.32 (0.73)
Germany	7.62 (0.002)**	0.01 (0.91)
Denmark	2.05 (0.15)	0.47 (0.63)
France	2.81 (0.08)*	0.63 (0.54)
Italy	1.69 (0.2)	0.44 (0.65)
Japan	4.03 (0.03)**	1.18 (0.32)
Netherlands	12.8 (0.0001)**	0.43 (0.66)
Sweden	9.49 (0.0006)**	0.70 (0.50)
UK	4.16 (0.03)**	1.19 (0.32)
US	9.06 (0.0008)**	0.65 (0.53)

** indicates rejection of the hypothesis at 5% and * at 10% level.

As regards tests of lag length, as set out above, in virtually all cases, the tests all indicate two lags to be selected with the exception of the Schwarz test. For Germany also the Schwarz test suggested two lags while in Japan and Canada, the Hannan-Quinn test also indicated one lag, and in Canada also the LR test. On balance, we considered two lags to be justified for all countries. As shown in Table 9, in the VAR there are much more widespread significant lags of the real equity return on changes in capital productivity, with all countries except Australia, Germany and the UK featuring such lags. Reverse effects are seen for Germany and the Netherlands.

Table 9: Significant lags in the VAR system

Dependent variable	EQR	DLKP
Independent variable	DLKP	EQR
Australia		
Canada		*
Germany	**	
Denmark		**
France		**
Italy		**
Japan		*
Netherlands	*	**
Sweden		**
UK		
US		**
Memo: US with ordering reversed		**

Key: See Table 3.

** indicates rejection of the hypothesis at 5% and * at 10% level.

Table 10 shows that the variance decomposition results suggest equity returns explain the variance of capital productivity significantly in Canada, France, Italy, Japan, the Netherlands and the US. Again this is more countries than for *R&D* capital productivity. Only in Australia and the UK is the opposite the case.

Table 10: Variance decompositions for real share prices and *R&D* capital productivity (percent of forecast variance accounted for by variance in each variable)

	DLKP on EQR	EQR on DLKP
Years	4	4
Australia	20**	6
Canada	5	23**
Germany	10	2
Denmark	6	8
France	6	16**
Italy	6	14**
Japan	16	21**
Netherlands	9	16**
Sweden	9	22**
UK	22**	1
US	6	20**

Memo: US with ordering reversed	3	31**

Key: See Table 3.

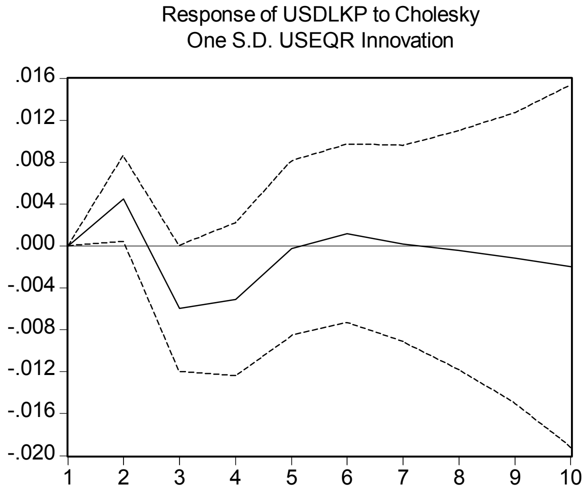
** indicates rejection of the hypothesis at 5% and * at 10% level.

A particularly relevant result for the model in Section 3 was again the impulse response from share prices to productivity, which for a number of countries shows a dynamic pattern as predicted by the phase diagrams, with an initial rise soon reversed, with a zero net effect. This result is shown in Table 11, and Figure 3 highlights the pattern for the US. Note that the percentage changes are comparable to those for *R&D* productivity, despite the larger size and, possibly, lesser flexibility of fixed capital formation.

Table 11: Impulse response functions for effect of change in real share prices on change in tangible capital productivity (percentage responses to 1 standard deviation shocks in real share prices)

Year	**1**	**2**	**3**	**4**	**5**
Australia	0	0.06	-0.41*	0.25	0.26
Canada	0	0.51	-0.99**	-0.53	0.19
Germany	0	0.17	-0.22	-0.07	0.33
Denmark	0	0.13	-0.58**	0.04	0.15
France	0	0.31**	-0.30*	-0.14	-0.07
Italy	0	0.43	-0.52	-0.39	0.35
Japan	0	0.44	-0.82*	-0.69	-0.10
Netherlands	0	0.72**	-0.16	-0.41	0.07
Sweden	0	0.6**	-0.13	-0.73*	-0.42
UK	0	0.18	-0.03	-0.13	-0.24
US	0	0.45**	-0.60**	-0.51*	-0.02
Memo: US with ordering reversed	-0.1	0.69**	-0.62*	-0.63	0.22

Figure 3: Impulse response of tangible capital productivity to equity prices, United States



6 Conclusions

We have presented a model of technological innovations and share prices, which has the implication that productivity advances will only have temporary effects on share prices, since increased fixed and *R&D* capital stock in the presence of diminishing returns drives capital productivity back to its original level. The results of an empirical investigation are strongly consistent with the model. It is worth noting that our dataset ends in 1999 and hence we are not taking into account recent falls in share prices in our estimation. On the other hand, those declines in share prices observed since the peak of the bull market in early 2000 are wholly consistent with the predictions of the model. Initial rises in share prices owing to the innovations fell back once the capital stock had built up and the level of capital productivity had returned to baseline.

Data Appendix

Investment in equipment and non-residential structures in fixed and current prices. The data based on the inventory perpetual method using data going back more than a century for most countries. A separate appendix is available upon request. From 1950 the following source is used: *OECD, National Accounts, Vol. 2. (NA)*; Investment in research and development in fixed and current prices. *OECD, Science and Technology Indicators*; Real GDP. *NA*; Consumer Prices. *IMF, International Financial Statistics (IFS)*; Interest rates. *IFS*. Share returns. Canada. Panjer, Harry H and Kieth P Sharpe, 2001, "Report on Economic Statistics 1924-1998," Canadian Institute of Actuaries. Denmark. Claus Parum, "Aktieindeks, aktieafkast og risikoprmier, Manuscript, 98-7, Institute of Finance, Copenhagen Business School, Claus Parum, "Estimation af Realkreditobligationsafkast i Danmark i Perioden 1925-1998," *Finans/Invest* 1999/7, Claus Parum, "Historisk Afkast af Aktier og Obligationer i Danmark, *Finans/Invest* 1999/3. Italy. Panetta, Fabioo and Robert Violi, 1999, "Is there an Equity Premium Puzzle in Italy? A look at Asset Returns, Consumption and Financial Structure Data over the Last Century," Termi di Discussione 353, Bank of Italy (data received by personal correspondence with Fabioo Panetta). Netherlands. Eichholtz, Piet, Kees Koedijk and Roger Otten, 2000,"De Eeuw van Het Aandeel," *Economisch Statistische Berichten*, January (data received by personal correspondence with Piet Eichholtz and Roger

Otten). Sweden. Per Frennberg and Bjørn Hansson, 1992, "Computation of a Monthly Index for Swedish stock returns: 1919-1989," *Scandinavian Economic History Review*, XL, No 1, 3-27 (data received by personal correspondence with Bjørn Hansson). United Kingdom. Barclays Capital, 2001, "Equity Guild Study," Barclays Capital. United States. Shiller's homepage. Australia, Germany, France, and Japan: Global Financial Data. Share market volatility is computed as the variance of the log of the monthly change in nominal share prices deflated by consumer prices within each year. *IFS*.

References

Abel, Andrew B, 1982, "Dynamic Effects of Permanent and Temporary Tax Policies in a *q* Model of Investment," *Journal of Monetary Economics*, 9, 353-373.

Aghion, Philippe, and Peter Howitt, 1992, "A Model of Growth through Creative Destruction," *Econometrica*, 60, 323-351.

Barsky, Robert B and J Bradford De Long, 1993, "Why does the Stock Market Fluctuate?", *Quarterly Journal of Economics*, 108, 291-311.

Bodie Z, Kane A and Marcus A J (1999), *"Investments, fourth edition*", Irwin McGraw-Hill, Boston

Bond, Tim, 2001, "Demographics, Borrowing and the Equity Risk Premium,"*Barclays Capital*, 39-57.

Campbell, John Y and Robert J Shiller, 2001, "Valuation Ratios and the Long Run Stock Market Outlook, an Update", NBER Working Paper No 8221.

Canova, Fabio and Giovanni De Nicolo, 1995, "Stock Returns and Real Activity, a Structural Approach", *European Economic Review*, 39, 981-1015

Cochrane, John H, 1991, "Production-Based Asset Pricing and the Link between Stock Returns and Economic Fluctuations," *Journal of Finance*, 46, 209-237.

Cochrane, John H, 1996, "A Cross-Sectional Test of an Investment-Based Asset Pricing Model," *Journal of Political Economy*, 104, 572-621.

Cockburn, Iain and Zvi Griliches, 1988, "Industry Effects and Appropriability Measures in the Stock Market's Valuation of *R&D* and Patents," *American Economic Review: Papers and Proceedings*, 78, 419-423.

Coe, David T, and Elhanan Helpman, 1995, "International R&D Spillovers," *European Economic Review*, 39, 859-887.

Copeland, T E and J Fred Weston, 1992, *Financial Theory and Corporate Policy*, New York: Addison-Wesley Publishing Company.

Davis E Philip and Gabriel Fagan (1997), "Are financial spreads useful indicators of future inflation and output growth in EU countries", *Journal of Applied Econometrics*, 12, 701-714

Davis E Philip and S G Brian Henry (1993), "The use of financial spreads as indicators of real activity", in ed Philip Arestis, "Contemporary issues in money and banking", MacMillan, London.

Economist, 2001, "A Spanner In The Productivity Miracle," 11 August, 63-64.

Gordon, Robert J, 1999, "Has the 'New Economy' Rendered the Productivity Slowdown Obsolete?," Unpublished Paper, Northwestern University.

Gordon, Robert J, 2000, "Does the 'New Economy' Measure up to the Great Inventions of the Past?," *Journal of Economic Perspectives*, 14, 49-74.

Greenwood. Jeremy and Jovanovic, Boyan, 1999, "The Information-Technology Revolution and the Stock Market", *American Economic Review*, *Papers and Proceedings*, 89, 116-128.

Grossman, Gene M and Elhanan Helpman, 1991, *Innovation and Growth in the Global Economy*, Cambridge: MIT Press.

Hall Robert E, 2001, "Struggling to Understand the Stock Market," *American Economic Review, Papers and Proceedings*, 91, 1-11.

Hayashi, Fumio, 1982, "Tobin's Marginal *q* and Average *q*: A Neoclassical Interpretation," *Econometrica*, 50, 213-224.

Hulten, Charles R, 1992, "Growth Accounting When Technical Change is Embodied in Capital," *American Economic Review*, 82, 964-980.

International Monetary Fund (IMF), 2000, "Asset Prices and the Business Cycle," in *World Economic Outlook*, April, 101-149.

Jones, Charles I, 1995, "R&D-Based Models of Economic Growth," *Journal of Political Economy*, 103, 759-784.

Kennedy, Mike, Angel Palerm, Charles Pigott and Flavia Terrible, 1998, "Asset Prices and Monetary Policy," Economics Department Working Papers No. 188, OECD.

Keon, Edward F, 1998, "Is the US Market Irrationally Exuberant?," *Journal of Investing*, 7/3, 71-83.

Megna, Pamela and Dennis C Mueller, 1991, "Profit Rates and Intangible Capital," *Review of Economics and Statistics*, 73, 632-642.

Nasseh, Alireza and Jack Strauss, 2000, "Stock Prices and Domestic and International Macroeconomic Activity; a Cointegration Approach", *Quarterly Review of Economics and Finance*, 40, 229-245.

Oliner, Stephen D and Daniel E Sichel, 2000, "The Resurgence of Growth in the Late 1990s: Is Information Technology the Whole Story?", Working Paper, Board of Governors of the Federal Reserve, 2000-20.

Romer, David, 1996, *Advanced Macroeconomics*, New York: McGraw-Hill.

Romer, Paul M, 1990, "Endogenous Technological Change," *Journal of Political Economy*, 98, S71-S102.

Shiller, Robert E, 2000, *Irrational Exuberance*, Cambridge: MIT Press.

Sims, Christopher A, 1986, Are Forecasting Models Usable for Policy Analysis? *Federal Reserve Bank of Minneapolis Quarterly Review. Vol. 10 (1). p 2-16. Winter 1986.*

Summers, Lawrence H, 1981, "Taxation and Corporate Investment: A *q*-Theory Approach," *Brooking Papers on Economic Activity*, No 1, 67-127.