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ABSTRACT

Implementation Cycles in the New Economy*

The economic boom of the USA in the 1990s was remarkable in its duration, the sustained rise in equipment investment, the reduced volatility of productivity growth, and continued uncertainty about the trend growth rate. In this paper we link these phenomena using an extension of the classic model of implementation cycles due to Shleifer (1986). The key idea is that uncertainty about the trend growth rate can lead firms to bring forward the implementation of innovations, temporarily eliminating expectations-driven business cycles, because delay is risky when beliefs are not common knowledge.

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1. Introduction

The macroeconomic record of the USA in the 1990s was remarkable in a number of ways. The media attention given to the Internet companies has tended to obscure the genuine achievements of the wider economy, including faster productivity growth, a rise in equipment investment, a reduction in output volatility, and an expansion that was sustained for exactly ten years – one of the longest on record. Although predictions of the ‘death’ or ‘taming’ of the business cycle were premature, there is strong evidence that the volatility of output has been declining since at least the mid-1980s (McConnell and Perez-Quiros 2000).

Another aspect of the New Economy is somewhat paradoxical, and has been less widely noted. Despite the stability of output growth, there was great uncertainty about whether this growth could be sustained, linked to uncertainty about the trend growth rate. As the duration of the boom exceeded all expectations, forecasters revised their predictions repeatedly, as we document further below. This makes the 1990s an atypical period: unusually stable output growth was combined with a high degree of uncertainty about the trend growth rate.

In this paper we interpret these stylized facts in the light of a classic model of business cycles due to Shleifer (1986). The starting point for Shleifer’s analysis is that firms must decide whether to implement innovations immediately, or wait for a period of higher aggregate demand. As well as an equilibrium in which firms implement immediately, there can also exist multiple short-cycle equilibria, and sometimes also longer cycles. The cycle is entirely driven by expectations about the timing of a boom.

Recent work on expectations and multiple equilibria in macroeconomics has tended to emphasize the fragility of multiplicity results. With this in mind, we extend Shleifer’s model to incorporate the possibility of uncertainty about the underlying growth rate. We will show that this uncertainty can eliminate cyclical equilibria,

leaving immediate implementation as the only possible outcome. In Shleifer's model, such an outcome would tend to be associated with unusually stable productivity growth, and a reduction in the volatility of investments associated with implementation. These are arguably features of the American boom of the 1990s, as we will discuss below.

The remainder of the paper is structured as follows. Section 2 provides a more detailed review of stylized facts about the New Economy, helping to motivate our extension of Shleifer's model. In section 3, we provide an overview of implementation cycles, emphasizing the role of expectations. Section 4 sets out the basic framework, before section 5 shows that uncertainty about the underlying growth rate leads to immediate implementation. Section 6 concludes.

2. Some stylized facts

In this section of the paper, we discuss evidence that is consistent with the model of business cycles due to Shleifer (1986), and that will inform and motivate our later theoretical analysis. We are especially interested in evidence that supports a central result of Shleifer's model. In his model, even when inventions arrive evenly over time, they are implemented in waves. The waves arise because firms have an incentive to defer implementation until aggregate demand is relatively high.

We first ask whether there is evidence to support the idea that new ideas are implemented with delays, and in waves. We review previous research, and also provide some new (though indirect) evidence, by examining the behaviour of IPOs and MFP growth over the business cycle. We will argue that the cyclical patterns of these variables support the idea that innovations take place in waves.

More direct evidence on this point is hard to obtain. Survey-based counts of the successful commercialisation of inventions sometimes reveal a pattern of distinct

peaks and troughs, as pointed out by Van Reenen (1996, p.219) using the data set for the UK described in Robson, Townsend and Pavitt (1988). This does not establish, however, that innovation clustering is the outcome of strategic delays.

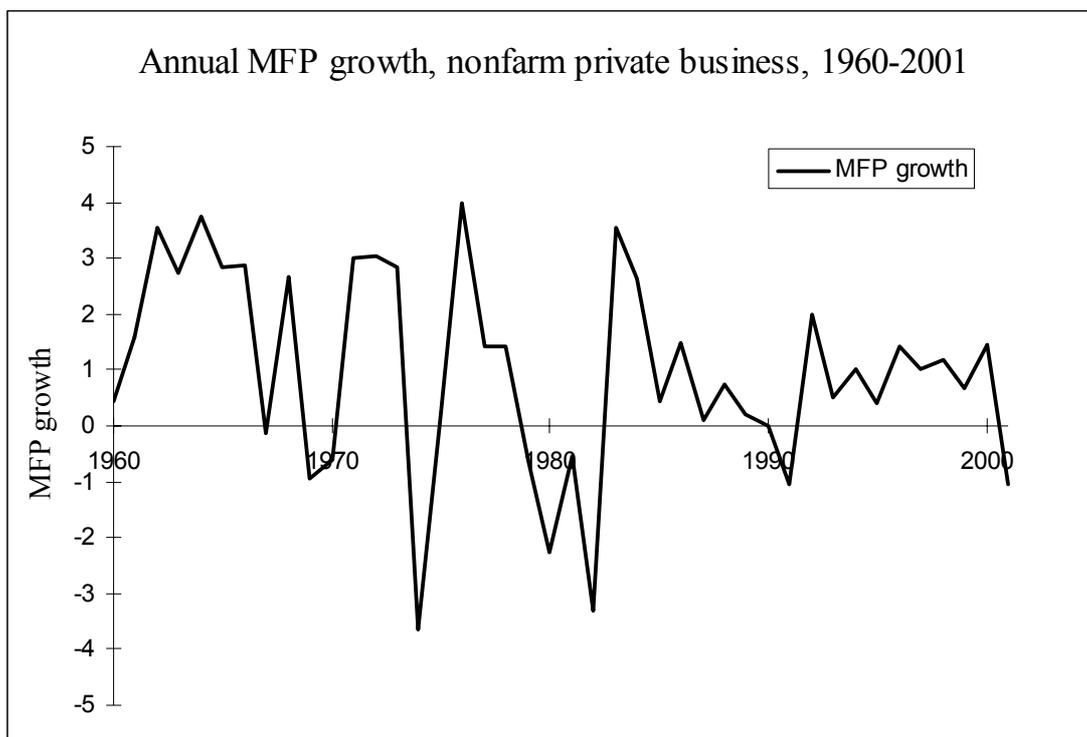
In this respect, some interesting evidence is provided by the behaviour of stock markets in the wake of technological changes. Hobijn and Jovanovic (2001) explain major changes in US stock market valuations in terms of a delay between the creation of new technologies (such as information and communications technologies) and their implementation by new entrants. They argue that the potential of new technologies may be widely known several years before the technologies are implemented. This helps to explain the substantial decline in US stock valuations in the 1970s, given declines in expected profitability for incumbents and the market's rational anticipation of entrants exploiting new technologies. This evidence is consistent with the view that implementation of new ideas involves delays, perhaps because entrepreneurs await favourable economic conditions.

In exploring this idea in more detail, we focus mainly on US time series for movements in multifactor productivity (MFP) and initial public offerings (IPOs). We use both of these as proxies for the extent of innovative activity in the economy. We will be able to show that, especially after 1980, these two alternative measures tend to fluctuate in similar ways. Furthermore, the extent of volatility in each was lower in the 1990s than previously, consistent with our claim that clustering of innovations has diminished.

First of all, figure 1 plots MFP growth in the USA, for the private non-farm business sector, between 1960 and 2001.¹ This shows the well-known tendency for marked year-to-year variation in MFP growth. This variation may reflect simply the random nature of technical progress. There could be sufficient randomness in the creation of new ideas that MFP growth varies substantially from year to year, even if

implementation of a new idea is always immediate.² An alternative view attributes the variation in MFP growth to measurement error of various kinds. Business cycles may be associated with systematic changes in measured MFP, notably through variation in factor utilization. Measured MFP growth will then vary at short horizons even when underlying technical progress follows a smooth path and new ideas are implemented without delay.

Figure 1 – Annual data on MFP growth, non-farm private business



Notes: This table shows annual data on MFP growth for the nonfarm private business sector, calculated from BLS data. See Appendix 1 for more information on the data.

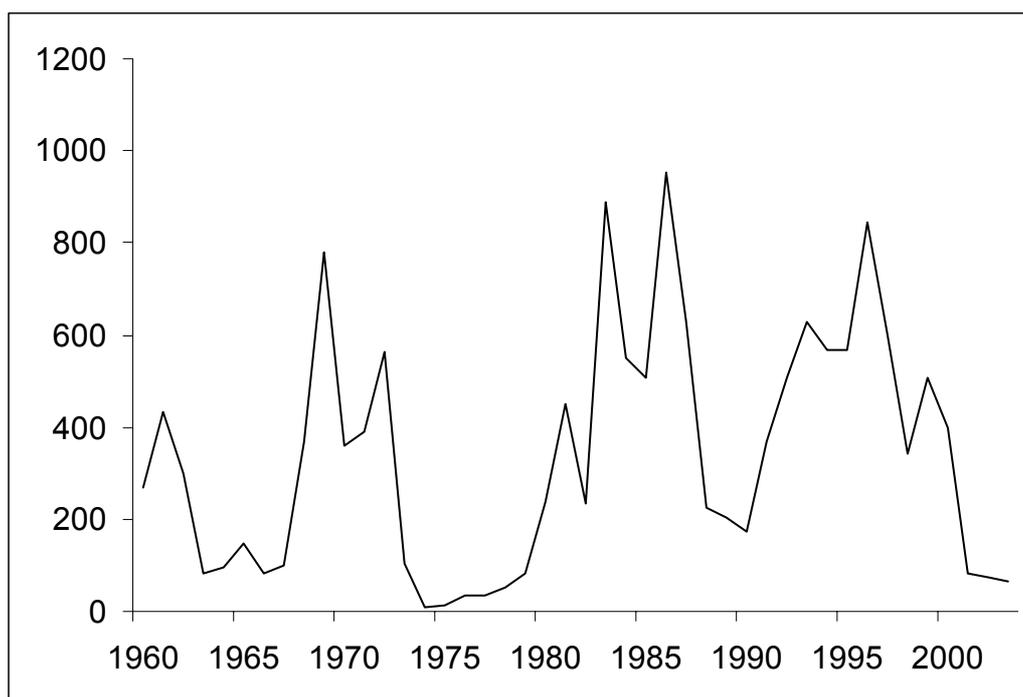
Given these limitations of data on MFP growth, we combine this information with a more direct indicator of implementation, namely the number of initial public offerings (IPOs). Although IPOs vary in nature, a substantial fraction are clearly

¹ The MFP growth series is constructed from Bureau of Labor Statistics data on MFP levels. See the data appendix for the data sources.

² The main problem for this view is that it does not explain the significant positive autocorrelation seen in MFP growth, unless there are major technological shocks that have an economy-wide impact sustained over several years. As sometimes discussed in the real business cycle literature, it is not clear that innovations are sufficiently pervasive to generate the cyclical patterns seen in the aggregate data (see for example Stadler 1994).

motivated by the desire to raise capital in the course of implementing a new business idea. Pástor and Veronesi (2005) note that around two-thirds of the leaders of IPOs cite the raising of capital as the main reason for an offering. Moreover, capital growth in the two years around the IPO is substantially higher than for comparable firms.

Figure 2 – Annual data on Initial Public Offerings



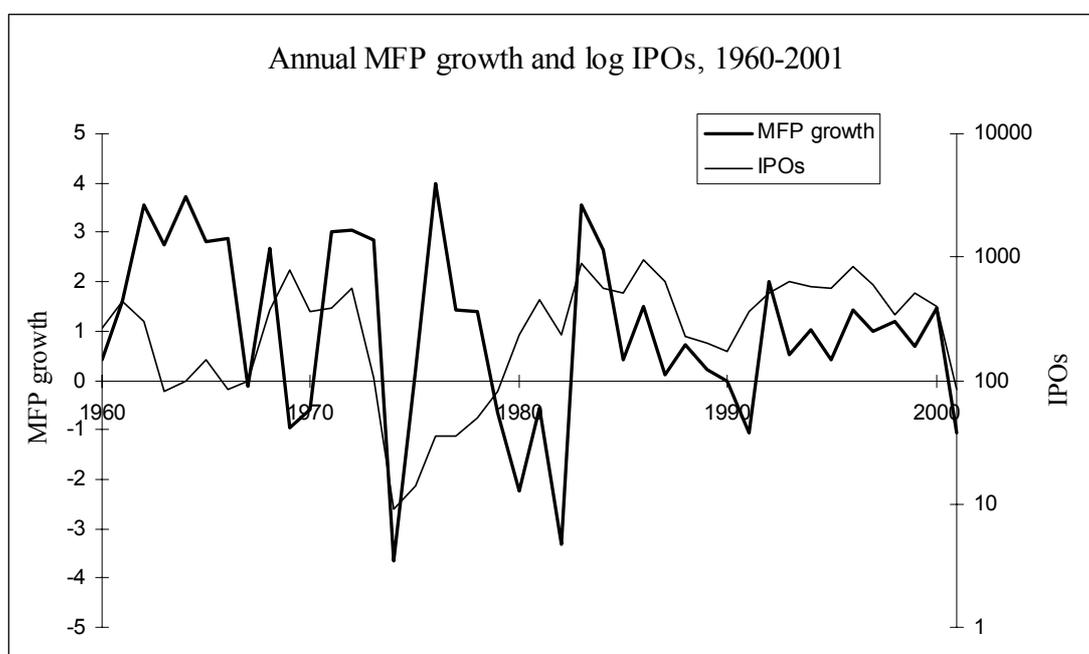
Notes: This table shows annual data on IPOs for the US economy, using data collected by Jay Ritter. See Appendix 1 for more details.

As with MFP growth, there is significant variation from year to year in the number of IPOs. There is also a tendency for IPOs to cluster together in distinct waves. Both the year-to-year variation and the tendency for significant autocorrelation are apparent in figure 2, which plots annual data on the number of IPOs in the USA since 1960 (see Appendix 1 for the source of these data). At first glance, this supports a story in which entrepreneurs are willing to defer bringing an idea to the market.

Again, there are several possible explanations for the observed waves in IPOs. These include the possibility that entrepreneurs wish to take advantage of mispricing in

equity markets. As Pástor and Veronesi (2005) argue, it is not clear why the mispricing is clear to entrepreneurs but less readily observable to other market participants. Their preferred explanation is that the decision to go public can be seen as exercising a real option. Entrepreneurs might wish to delay an IPO, exercising the option only when there is a favourable change in market conditions. They present evidence that movements in expected aggregate profitability, including revisions to analysts' earnings forecasts, are one determinant of the timing of IPOs. This endogeneity in the timing of investment can be seen as a specific instance of the general argument in Shleifer (1986).

Figure 3 – The co-movement of IPOs and MFP growth

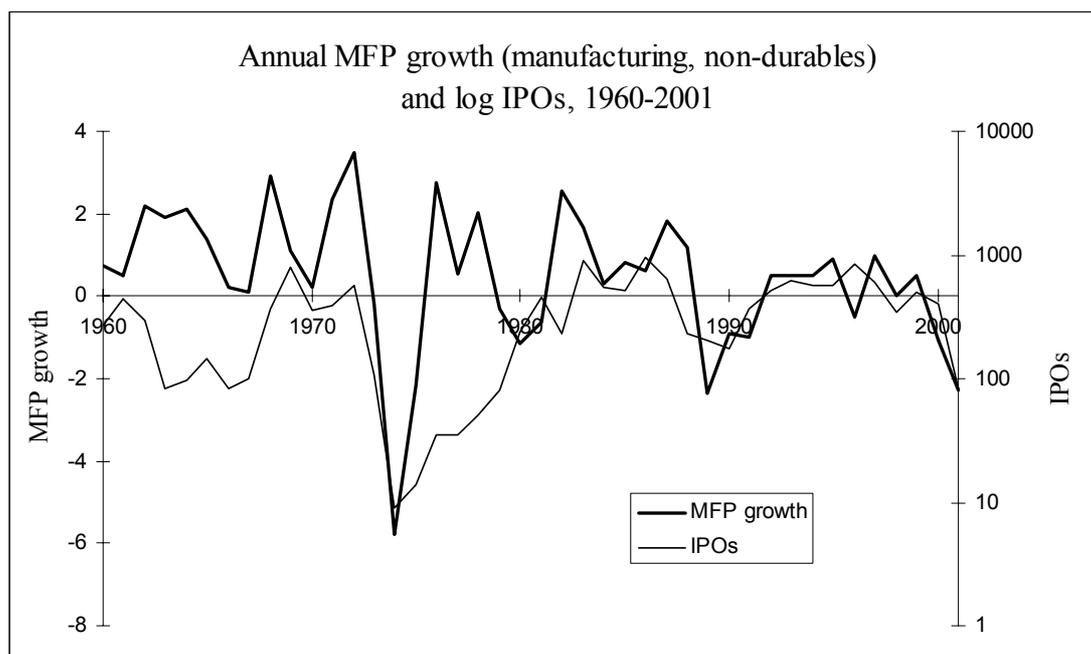


Notes: This table shows the co-movements of annual data on MFP growth for the private nonfarm business sector, and annual IPOs. See Appendix 1 for data sources.

If we see MFP growth and the number of IPOs as two alternative measures of the level of innovative activity in the economy, it is natural to ask whether the two are closely related. Figure 3 combines the annual data on IPOs (in logarithms) with that on MFP growth. The correspondence between the two is weak for the 1960s and 1970s, but greatly strengthens thereafter, with a slight tendency for IPOs to anticipate movements in MFP growth. This relationship is stronger when we restrict

attention to MFP growth in the manufacturing sector, disaggregated into durables and non-durables. Figures 4 (for non-durables) and 5 (for durables) again reveal the tendency for IPOs (for the whole economy) and MFP growth to move together after 1980.

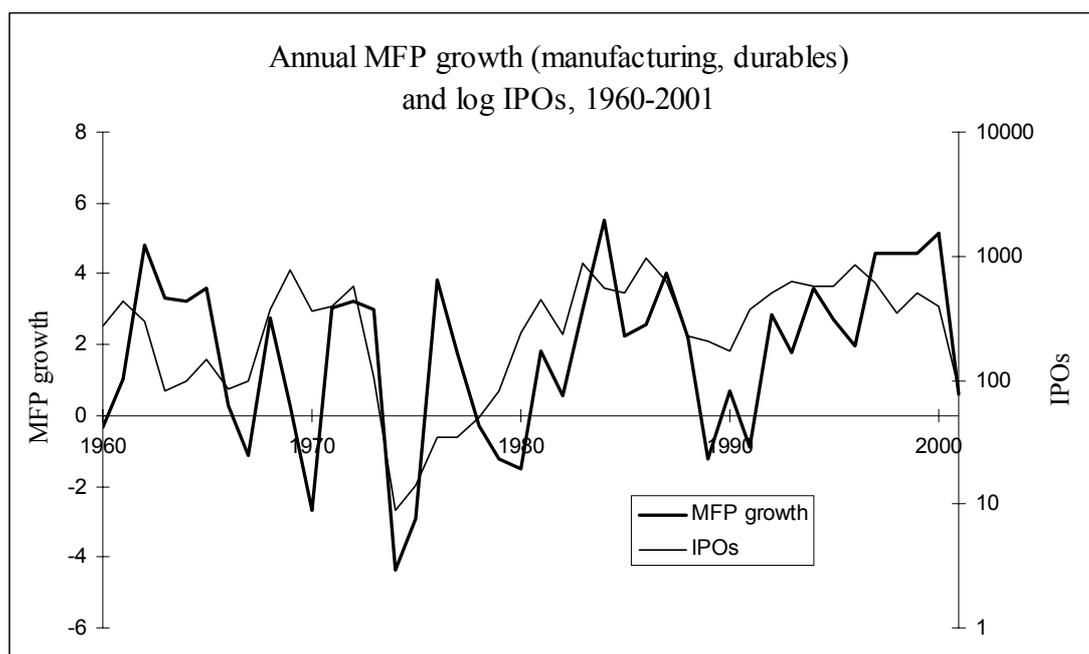
Figure 4 – Annual MFP growth (manufacturing, non-durables) and log IPOs



Notes: This table shows the co-movements of annual data on MFP growth for the non-durables manufacturing sector, and annual IPOs. See Appendix 1 for data sources.

The visual impression is confirmed by two further ways of looking at the data. First, we report simple correlations between MFP growth and lagged IPOs. Second, we will show that the number of IPOs helps to forecast MFP growth, even when conditioning on past MFP growth rates.

Figure 5 – Annual MFP growth (manufacturing, durables) and log IPOs



Notes: This table shows the co-movements of annual data on MFP growth for the durables manufacturing sector, and annual IPOs. See Appendix 1 for data sources.

Table 1 shows the correlations between MFP growth and lagged IPOs for the whole period (1963-2001) and for the subperiod 1980-2001. Given the likely measurement error in MFP growth, and the various influences on decisions to go public, the contemporaneous correlation for the post-1980 data is surprisingly high at 0.63. There is also some evidence that MFP growth is correlated with past numbers of IPOs, especially for the post-1980 period.

We now carry out simple Granger-causality tests, by regressing annual MFP growth on two lags of MFP growth and one lag of the number of IPOs. We test the null hypothesis that the coefficient on lagged IPOs is equal to zero, using Newey-West standard errors to construct our test statistics.³ The results are shown in Table 2. For the whole period, IPOs help to forecast MFP growth only in the durables manufacturing sector (the zero restriction is not rejected in the other two cases). For

³ For these test statistics to have their standard limiting distributions, the series must be stationary. For the various MFP growth series, we can easily reject the null of a unit root under a range of assumptions, using augmented Dickey-Fuller tests. For the IPO series, the results are slightly less clear-cut, but DF-GLS tests reject the null at the 10% level for a wide range of lag choices.

the period after 1980, however, the IPO series helps to forecast all three MFP growth series (business, durables manufacturing, and non-durables manufacturing).

Table 1 – Correlations between MFP growth and lagged IPOs

1963-2001				
	<i>IPO(t-3)</i>	<i>IPO(t-2)</i>	<i>IPO(t-1)</i>	<i>IPO(t)</i>
<i>Business MFP(t)</i>	0.14 (0.39)	-0.02 (0.89)	-0.00 (0.98)	0.10 (0.53)
<i>Durables MPF(t)</i>	0.30 (0.07)	0.25 (0.13)	0.46 (0.00)	0.39 (0.01)
<i>Non-durables MFP(t)</i>	-0.16 (0.34)	-0.08 (0.62)	0.14 (0.39)	0.24 (0.13)
1980-2001				
<i>Business MFP(t)</i>	0.37 (0.09)	0.29 (0.19)	0.34 (0.12)	0.63 (0.00)
<i>Durables MPF(t)</i>	0.28 (0.21)	0.29 (0.20)	0.71 (0.00)	0.46 (0.03)
<i>Non-durables MFP(t)</i>	-0.18 (0.43)	0.20 (0.37)	0.49 (0.02)	0.46 (0.03)

Notes. This table shows correlations between three MFP growth series (row) and IPOs in different periods (column) using annual data. Data sources are described in Appendix 1. Figures in parentheses are significance levels. Correlations significantly different from zero at the 10% level are shown in bold.

Table 2 – Do IPOs help to predict future MFP growth?

Regression	(1)	(2)	(3)	(4)	(5)	(6)
Sector	Business	Nondur	Durables	Business	Nondur	Durables
Time period		1961-2001			1980-2001	
Observations	41	41	41	22	22	22
Constant	0.01 (0.01)	0.00 (0.00)	0.00 (0.01)	-0.01 (0.01)	-0.01 (0.01)	-0.01 (0.01)
$MFPG(t-1)$	0.17 (0.15)	0.40** (0.11)	0.22 (0.12)	-0.28 (0.21)	0.20 (0.21)	-0.04 (0.20)
$MFPG(t-2)$	-0.06 (0.19)	-0.41 (0.22)	-0.22 (0.15)	0.10 (0.25)	-0.38 (0.22)	0.18 (0.13)
$IPO(t-1)$	-0.02 (0.10)	0.08 (0.09)	0.37* (0.17)	0.33* (0.16)	0.27* (0.10)	0.59** (0.14)
R ²	0.03	0.24	0.27	0.35	0.37	0.53
LM(1)	0.85	0.43	0.49	0.66	0.70	0.23
LM(2)	0.53	0.69	0.45	0.50	0.26	0.46
Lagged IPO	0.85	0.36	0.04	0.05	0.01	0.00

Notes. Dependent variable: MFP growth, MFPG. * significant at 5%; ** significant at 1%. Newey-West standard errors in parentheses, corrected for heteroscedasticity and serial correlation up to two lags. LM(n) is the p -value for a Breusch-Godfrey LM test for serial correlation, where the null hypothesis is no serial correlation of order n . “Lagged IPO” is the p -value for the null that lagged IPOs have a zero coefficient, based on Newey-West standard errors. For presentation of the results, the IPO series is rescaled by dividing by 10000.

This result is not necessarily surprising, given that IPOs are inherently forward-looking, and we do not intend to claim that we have identified a causal effect. We are interested in these correlations for the more general relationship that is revealed: the extent to which IPOs and MFP growth fluctuate in similar ways over the business cycle. Their co-movements support the idea of distinct waves of innovations, initially reflected in the observed timing of IPOs and subsequently in MFP growth.

We now turn to a further set of stylized facts, related to a central argument of our paper. We will argue that implementation cycles were weakened in the 1990s, and replaced by a tendency for innovations to be implemented rapidly rather than

deferred to better times. This shows how Shleifer's model might be used to interpret the stylized facts of the New Economy period. Although a direct test of this hypothesis is hard to implement, we can at least examine whether the aggregate data are consistent with weaker implementation cycles.⁴

It is well known that the 1990s were a period of unusual stability for the US economy, as documented in McConnell and Perez-Quiros (2000) and Blanchard and Simon (2001) among others. To the extent that implementation is now smoother and less subject to distinct waves, we would expect to see reduced volatility in our proxies for implementation, namely MFP growth and IPOs. Figure 6 plots a 5-year rolling standard deviation of MFP growth in the private non-farm business sector.

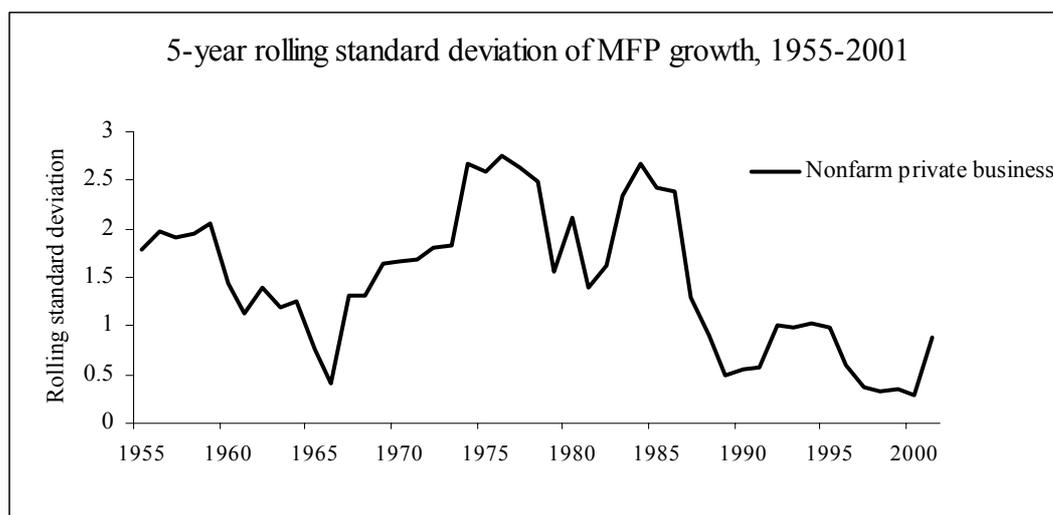
Figure 7 restricts attention to the volatility of MFP growth in the manufacturing sector, disaggregated into durables and non-durables, using a 9-year rolling standard deviation for each series. Figure 8 plots a rolling standard deviation for IPOs, again using a 9-year rolling standard deviation. All three figures reveal the same pattern, namely a clear reduction in volatility over the course of the 1990s, before an increase as the boom finally draws to a close.

In the remainder of the paper, we will present a theoretical argument that could explain this reduced volatility. The argument relies on uncertainty over the underlying rate of productivity growth, which can eliminate the multiplicity of equilibria obtained by Shleifer. At first sight, our argument might appear to be on unsafe ground, because superficially the 1990s were a period of stability rather than uncertainty. Here, however, the distinction between volatility and predictability is crucial. It is well known that a series can be volatile but predictable, but in the 1990s the reverse obtained. The New Economy period was one in which major macroeconomic variables were unusually stable, to an extent that caught out many

⁴ Jorgenson and Stiroh (2000, p. 158) note a shortening in the product cycle of microprocessors, with new processors brought to market more quickly in the 1990s than previously. This may reflect, however, an acceleration in technical change rather than an elimination of implementation lags.

observers. Moreover, since growth consistently exceeded expectations, there was speculation that trend growth had increased, and disagreement over the extent to which this had happened.

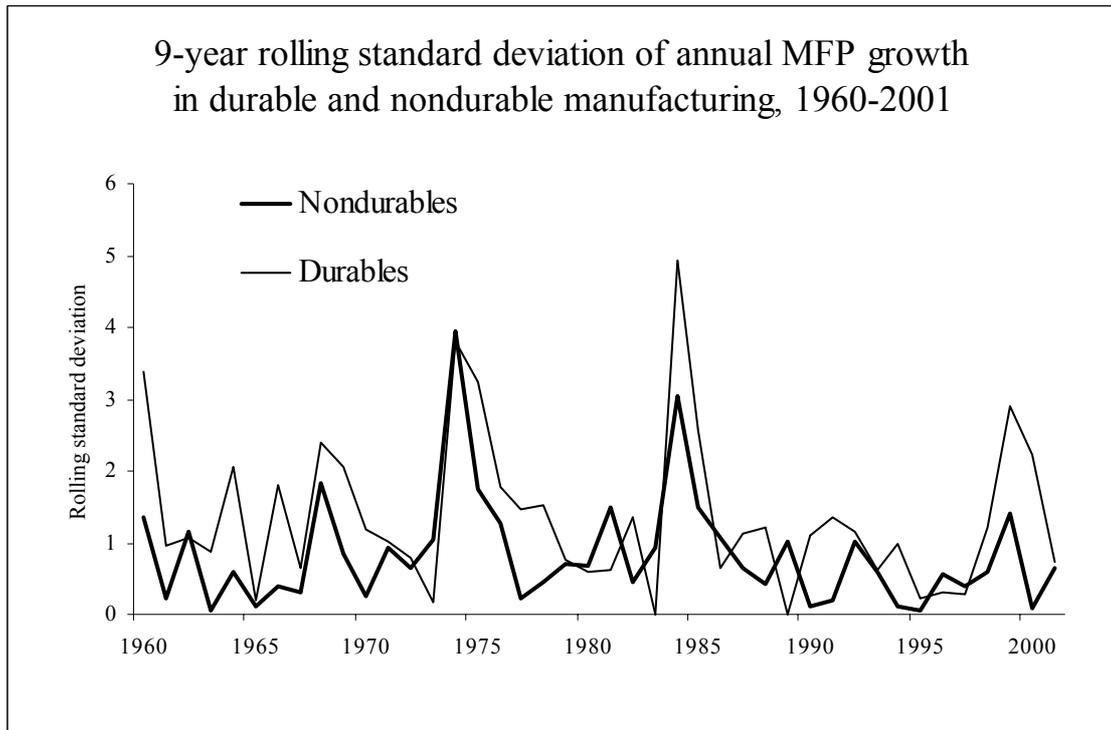
Figure 6 – The declining volatility of MFP growth



Notes: the plotted value at date T is the five-year rolling standard deviation of annual MFP growth in the private nonfarm business sector, using data from year T-4 to year T. See Appendix 1 for data sources.

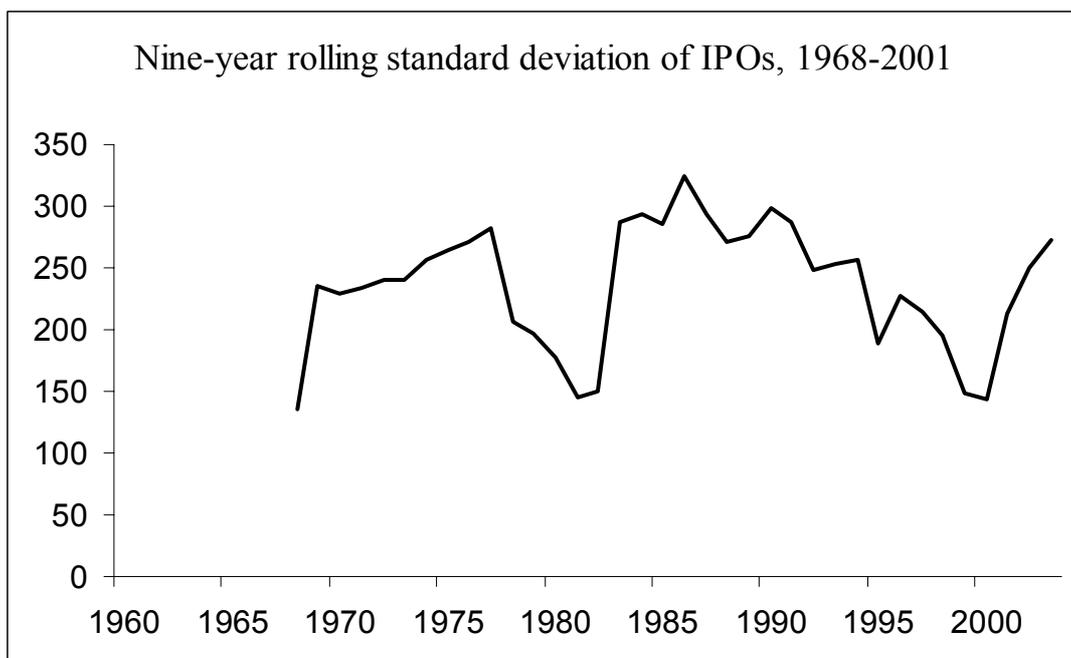
As stated by Robert Hall in his comments on Blanchard and Simon (2001), five-year and ten-year forecast errors for the US economy were unusually large in the 1990s. Much the same point is made in Jorgenson and Stiroh (2000, p. 162-165). They note that forecasters repeatedly had to raise growth projections, and that the Congressional Budget Office revised forecasts of TFP growth upwards on a number of occasions. The uncertainty arose partly because the 1990s expansion was sustained to an unusual extent, making it harder to rely on past cycles as a guide.

Figure 7 – The declining volatility of MFP growth in manufacturing



Notes: the plotted values at date T are the nine-year rolling standard deviation of the two MFP growth series using data from year T-8 to year T. See Appendix 1 for data sources.

Figure 8 – The declining volatility of IPOs



Notes: the plotted value at date T is the nine-year standard deviation of the annual IPO series using data from year T-8 to year T.

The combination of a sustained expansion, and a massive stock market boom, led to wide discussion of the possibility that trend growth had increased, in both the business press and more academic commentary. Views differed, indicating the uncertainty even among close observers. In reviewing productivity growth in the 1990s, Jorgenson and Stiroh (2000) argued that there was a case for an upwards revision of medium-term growth forecasts. In contrast, Gordon, in his comments on the same paper, argued that some of the productivity gains of 1995-99 were likely to prove transient, and that the reputation of the New Economy had been inflated by cyclical factors. More recently, productivity growth appears to have grown strongly even in the 2001 recession, another departure from previous cyclical patterns.

As noted by Sichel in his commentary on Jorgenson and Stiroh (2000), the decomposition of output growth into trend and cyclical effects is particularly difficult when the length and nature of an expansion has departed so sharply from previous norms. Stiroh (1999), in discussing the possibility of a rise in trend growth, argued that conclusions would have to await new evidence. Combined, the lack of consensus illustrates the uncertainty about the trend growth rate that was an important feature of the late 1990s.

The theoretical analysis in the remainder of the paper will explain why uncertainty of this kind could have implications for Shleifer's explanation of business cycles. Although it may seem paradoxical at first sight, the Shleifer model can explain the unusual stability of the 1990s, if we appeal to contemporaneous uncertainty about the underlying trend growth rate.

3. Implementation cycles

In this section, we provide an overview of the arguments in the remainder of the paper. The arguments build on a long tradition in macroeconomics, emphasizing the importance of expectations and beliefs for macroeconomic behaviour. This has been

stressed at least since Keynes (1936) argued that "animal spirits" may give rise to instability. Expectations of booms and recessions can be self-fulfilling, as agents bring forward or postpone their investment decisions, depending on their perceptions of how the economy will evolve in the future. If some firms anticipate an increase in aggregate demand, they may decide not to invest in the present period and delay their investment to some future date. This will enable those firms to maximize the revenue from their sales during a boom. If other firms in the economy share the same expectations about future demand, they will also postpone their investment to the future. This will bring about a recession in the current period and a boom at a later date.

Based on this kind of intuition, there is now a large literature on self-fulfilling prophecies, stemming from the theoretical analyses of Azariadis (1981) and Cass and Shell (1983), and surveyed by Farmer (1993), Matsuyama (1995) and Silvestre (1993). Many of these models imply that, under some conditions, there are several possible outcomes or even a continuum of equilibria.

The practical relevance of multiplicity has been questioned by examining the role of higher order beliefs (beliefs about beliefs). Recent contributions emphasize that certain equilibria will be observed only under restrictive assumptions on the informational structure of the economy.⁵ Coordination on certain equilibria often requires an assumption that agents have common knowledge about the fundamentals of the economy and about the beliefs (of all orders) of the other agents. In particular, the expectations of all the agents in the economy should be common knowledge, in the technical sense of that term.

⁵ The fragility of some equilibria in the presence of uncertainty and correlated signals has been analyzed by several authors in different contexts. Shin (1995) considers a decentralized economy with search externalities. Morris and Shin (1998) look at the timing of speculative attacks against a currency. Scaramozzino and Vulkan (2004) examine a model of local oligopoly with correlated noise about the competitive advantage of firms. See Morris and Shin (2000, 2003) for details of more applications, especially to macroeconomic issues.

This is clearly an unrealistic assumption to make in macroeconomic models. A more satisfactory assumption is that agents have imperfect knowledge of the fundamentals of the economy and of the beliefs held by everybody else. Their beliefs may still be related to those of other agents: individuals can learn about the information and beliefs of others, simply by observing their actions. Furthermore, they share access to public information. The key point, however, is that the beliefs of all agents are unlikely to be common knowledge.

This apparently minor change in assumptions has dramatic implications. Imagine that agents receive noisy signals about the same key parameter, and the noise affecting the signal is idiosyncratic so that agents' signals may be different. In this case, and under quite general conditions, agents will select what they perceive to be their least risky course of action. As a consequence, some of the equilibria in the economy can be ruled out.

In the analysis that follows, we apply these ideas to the multiplicity of equilibria in Shleifer's model of implementation cycles. His framework is particularly appropriate for looking at the role of information assumptions in macroeconomics, since the cyclical equilibria rely on expectations about expectations.

In Shleifer's model, the rate of technological progress is a known constant. In the analysis that follows we demonstrate that, if there is uncertainty about the rate of technological progress, and if signals about this variable are correlated across agents, then agents will coordinate on a single equilibrium. Under relatively general conditions, immediate implementation is the only undominated strategy for firms. According to this result, it would never be profitable for firms to delay the implementation of their innovations. The potential relevance to the New Economy period should be clear. The uncertainty about the trend growth rate, by encouraging firms to implement immediately rather than delay, could eliminate implementation cycles and be associated with a sustained expansion.

The intuition for our results can be summarized as follows. Suppose that we are in a situation where the fundamentals of the economy are only consistent with immediate implementation, and this is the dominant strategy for firms. Suppose now that the fundamentals change slightly, and that immediate implementation is only "almost" dominant. Firms might choose to delay the implementation of their innovations. Yet, if there is some noise about the fundamentals, and if agents are uncertain regarding the beliefs of the other agents in the economy, delaying the implementation is a riskier strategy than immediate implementation. Firms will therefore tend to implement immediately.

More generally, the optimal strategy depends on what other firms will do in nearby states of the world, including those in which immediate implementation is a dominant strategy. Taking these into account, the *ex ante* dominant strategy is not to wait for a boom. The logic applies even to circumstances in which the fundamentals of the economy are not close to making immediate implementation "almost" dominant, as we clarify below.

4. The basic setup

The basic structure of the model is identical to Shleifer (1986), and we refer the reader to that paper for full details. Briefly, an infinitely-lived representative consumer maximizes utility:

$$(1) \quad \sum_{t=1}^{\infty} \rho^{t-1} \frac{\left(\prod_{j=1}^N x_{tj}^{\lambda} \right)^{1-\gamma}}{1-\gamma}$$

where $0 < \rho < 1$ is the subjective discount factor, $0 \leq \gamma < 1$ indexes the extent of relative risk aversion, x_{tj} is the consumption of good j in period t , N is the number of

commodities, and $\lambda \equiv 1/N$, where N is a large number. The lifetime budget constraint of the representative agent is:

$$(2) \quad \sum_{t=1}^{\infty} \frac{y_t - \sum_{j=1}^N p_{tj} x_{tj}}{D_{t-1}} = 0$$

where p_{tj} is the price of commodity j in period t , y_t is income, and $D_t = (1+r_1) \dots (1+r_t)$ is the inverse of the discount factor, where $1+r_t$ is the rate of interest paid in period $t+1$ and where D_0 is set equal to unity. Consumption at time t is given by $c_t = \sum_{j=1}^N p_{tj} x_{tj}$.

The structure of preferences implies constant expenditure shares:

$$(3) \quad p_{tj} x_{tj} = \lambda c_t$$

No storage technology is assumed to exist: hence, $c_t = y_t$ and the consumer is neither a borrower nor a saver. As in Shleifer (1986), the equilibrium interest rate is:

$$(4) \quad 1 + r_t = \frac{1}{\rho} \cdot \left(\frac{y_{t+1}}{y_t} \right)^{\gamma} \cdot \left(\frac{\prod_{j=1}^N p_{j,t+1}^{\lambda}}{\prod_{j=1}^N p_{j,t}^{\lambda}} \right)^{1-\gamma}$$

Let Π_t be aggregate profits. Labor is inelastically supplied at L . A unit of labor is the numeraire and so the wage rate is normalized to unity. The income identity is then given by:

$$(5) \quad y_t = \Pi_t + L$$

There are N ordered sectors in the economy. In the first period, one firm in each of the sectors $1, 2, \dots, n$ generates an invention (so there are n inventions in the first

period). In the second period, one firm in each of the sectors $n+1, n+2, \dots, 2n$ generates an invention. In period $T^* = \text{mod}(N/n)$, one firm in each of the sectors $(T^*-1) \cdot n+1, (T^*-1) \cdot n+2, \dots, T^* \cdot n$ generates an invention, and so forth. An invention in period t enables firms to produce output using a fraction $1/\mu$ of the labor input which was previously required, where $\mu > 1$ is the rate of technical progress. It is this rate that we will consider to be uncertain in the analysis of the next section.

Firms that invent can implement immediately or delay. When a firm implements its invention, it becomes a monopolistic supplier in its sector. Its profits are

$$(6) \quad \pi_t = m \cdot y_t$$

where $m \equiv \lambda(1 - 1/\mu)$. In the period following the implementation, imitators enter the market and drive the profits of the innovating firm down to zero. Hence, firms have an incentive to maximize the short-run returns from implementing the innovation. They will trade off the opportunity cost of delaying the innovation to the future against the potential gain from implementing during a period of high aggregate demand.

Let $0 \leq \alpha_t \leq 1$ be the fraction of the n firms receiving an invention at time $t = 1, \dots, T-1$ that implement immediately. Let $\beta_T = \left(T - \sum_{i=1}^{T-1} \alpha_i \right)$ so that $\beta_T \cdot n$ denotes the number of firms that implement at time T : those who received an invention during the cycle and waited, and those who received an invention at time T . Note that $\beta_T = 1$ when all firms implement immediately and $\beta_T = T$ when they all wait until time T .

Cycles of period $T \leq T^*$ are an equilibrium if and only if $\pi_T / D_{T-1} > \pi_1$, or

$$(7) \quad f(T) \equiv \rho^{T-1} \left(\frac{1 - nm\beta_T}{1 - nm\alpha_1} \right)^{\gamma-1} \mu^{\lambda n \cdot (1-\gamma) \cdot \sum_{t=1}^{T-1} \alpha_t} > 1$$

Note that equation (7) collapses to Shleifer's equation (12) - $f(T) \equiv \rho^{T-1} (1 - nTm)^{\gamma-1} > 1$ - if π_T and D_{T-1} are computed on the assumption that everybody believes that everybody else will invest at T , that is, $\alpha_1 = \alpha_2 = \dots = \alpha_{T-1} = 0$ and $\beta_T = T$.

By investigating the left-hand-side of equation (7) we can make a number of useful observations about the degree of coordination required to sustain a T -boom equilibrium.

First, if $\alpha = 1$ and $\beta_T = 2$ the LHS is always smaller than 1 (using Shleifer's condition (14), p. 1173) and so cycles (of size $T=2$ or more) are not possible.

Even if $\alpha_t < 1$ the LHS is often smaller than 1. More specifically:

- For a fixed $T > 1$, the LHS increases when $\sum_{t=1}^{T-1} \alpha_t$ decreases, and
- For a fixed $\sum_{t=1}^{T-1} \alpha_t$ the LHS decreases when T increases.

That is, the longer the T -boom the larger the number of firms that must wait before it is optimal for a firm receiving an innovation at period $t < T$ to wait. Since the LHS is continuous in $\sum_{t=1}^{T-1} \alpha_t$ then there exists a $0 \leq k \leq 1$ such that $\text{LHS} < 1$ if and only if

$\frac{\sum \alpha_t}{T-1} \leq k$. In other words, a T -boom can be supported as a Nash equilibrium if and

only if at least a fraction k of the $n(T-1)$ firms receiving an innovation at periods

1,...,T-1 wait. The precise value of k will depend on the parameters of the model, and from now on we will restrict attention to the case where k is greater than $\frac{1}{2}$.⁶

5. Extending the basic model

Unlike Shleifer (1986), we assume that the rate of technical progress μ is not known to firms. Instead, they receive a *noisy* signal of μ , and hence a noisy signal of m . The real values of μ and m are fixed in periods 1 to T^* . In period T^*+1 new values are drawn which are independent of the values in the previous periods, and again at period $2T^*+1$ and so on. Shleifer's model does not allow for cycles that are longer than T^* (see p. 1173 of his paper). Hence the decision of firms whether to implement or delay is made independently every time they receive an innovation, and is independent of past realizations. We write m as the real value for the current T^* periods we are in and focus on firms' decisions to wait or not within this length of time.

Since the rate of technical progress is no longer common knowledge, this means that firms are uncertain about the function $f(T)$ in (7). To be more precise, firms observe the noisy signal $m_{it} = m + x_{it}$, where x_{it} are continuous random variables independent of each other with support $x_{it} \in (-\varepsilon, \varepsilon)$, $E(x_{it})=0$ $i=1,2,\dots,N$, $t = 1,2,\dots,T^*$. These can be quite general - the only relevant property of x_{it} we need is that the x_{it} 's are symmetrically distributed. Formally:

$$(8) \quad P(m_{i,t} < m) = \frac{1}{2}$$

$\forall i \in \{1, 2, \dots, N\}$ and $\forall t \in \{1, 2, \dots, T^*\}$.

A pure strategy for firm i in this model is a mapping, $s_{it}(m_{it})$ where $s_{it} : (m - \varepsilon, m + \varepsilon) \rightarrow \{1, 2, \dots, T^*\}$ and where 1 = immediate implementation, 2 =

⁶ This is not unduly restrictive. Numerical simulations suggest that k is substantially higher, around $\frac{3}{4}$,

implementation after delaying one period, *etc.* The vector of firms' strategies at time t is denoted by $s_t = (s_{1t}, s_{2t}, \dots, s_{Nt})$, $s_{-it} = (s_{1t}, \dots, s_{i-1,t}, s_{i+1,t}, \dots, s_{Nt})$.

Denote by M the set of all values of m for which $f(T) < 1$ for $T=2, \dots, T^*$.⁷ Let m' be the infimum of the set M . Let $m^* = m' - \varepsilon$. For a firm which – given its signal – knows that $m < m^*$, immediate implementation is the dominant strategy. To see why, note that equation (7) is computed under the most favorable conditions for waiting: both I_i and I_{-i} are computed under the assumption that all other firms wait. (By 'all other firms', we mean all other firms that have already generated an innovation and can therefore choose to implement now or later.)

If $m < m^*$ the strategy "implement immediately" yields a higher payoff than the strategy "wait", even if everybody else waits for the T -boom. Since in Shleifer's model payoffs are proportional to output, while the discount factor is proportional to output raised by γ ; then if any number of firms choose not to wait for a T -boom, I_i will increase, while I_{-i}/D_{T-1} will decrease. In other words, the payoff from waiting decreases and the payoff from implementing immediately increases. Thus when $m < m^*$ the strategy "implement immediately" yields a higher payoff than the strategy "wait" regardless of the choices of other firms. This shows that immediate implementation is the dominant strategy when $m < m^*$.

Since the noise is bounded by ε a firm receiving a signal $m_{it} < m^*$ knows for sure that $m < m^*$. The firm will therefore implement immediately.⁸ Using our notation, we can therefore say that $s_{it}(m_{it}) = 1$ for $m_{it} < m^*$, because this is a dominant strategy.

for many parameter values that satisfy Shleifer's parameter restrictions.

⁷ In fact, in many cases it is sufficient that $f(2) < 1$ for this to hold. See Figure 2, page 1176 in Shleifer and the discussion found there.

⁸ In a one-shot game it is sufficient that $m_{it} < m'$ because the firm's signal is the best predictor of m (because the noise is symmetric). In our setting, however, firms receive repeated signals. Their posterior belief of what the real value of m is will therefore shrink with probability one. This is why we use $m' - \varepsilon$ as the bound under which we can say for certain that firms will never delay implementing their invention.

However, for $m \geq m^*$ longer cycles, or T -booms ($T = 2, 3, \dots, T^*$) can also be sustained as a Nash Equilibrium, and it is this range of parameter values which is the focus of Shleifer's model and ours. We now show that when noise is introduced into the model Shleifer's result no longer holds:

Proposition. In the implementation cycle model with noisy signals, the only possible equilibrium is one with immediate implementation.

Proof. By contradiction: Assume that there exists $\tilde{m} \geq m^*$ and a symmetric Nash equilibrium S where any firm i receiving an invention at time t and a signal $m_i \geq \tilde{m}$ delays its implementation until time $T > 1$.

Denote by $\phi_i(m_{it}, s_{-i})$ the probability firm i attaches to the event that more than $kn \cdot (T-1)$ firms that receive innovations at periods $1, \dots, T-1$ wait for a T -boom, when its own signal is m_{it} and their equilibrium strategies are s_{-i} .

Lemma. $\phi_i(m_{it}, s_{-i}) > 0$

Proof. This result is intuitive since S is – by assumption – an equilibrium. A formal proof is provided in Appendix 2.

However, $\phi_i(\tilde{m}, S_{-i})$ which is the probability that at least a fraction k of the $n \cdot (T-1)$ firms who receive innovations in periods $1, \dots, T-1$ are waiting for a T -boom cannot exceed the probability that at least a fraction k of these firms receive a signal $> \tilde{m}$ because firms which receive a signal $m_j < \tilde{m}$ implement immediately (because it is a dominant strategy).

The probability that firm i attaches to the event that any of the other firm receives a signal $> \tilde{m}$ is $\frac{1}{2}$ by (8). The probability that at least $kn(T-1)$ firms received such a

signal is therefore $\sum_{m=kn}^n \binom{n}{m} \frac{1}{2^n}$ which converges to zero as n increases for a fixed $k > 1/2$

(formally, using the central limit theorem this sum converges to: $\frac{1}{\sqrt{2\pi}} \int_{(2k-1)\sqrt{n}}^{\infty} e^{-\frac{t^2}{2}} dt$

which essentially is a step function which is equal to 1 for $k < 1/2$ and 0 for $k > 1/2$).

Throughout Shleifer's paper it is assumed that n is large and so the limit applies. We therefore get a contradiction with our lemma 1: so \tilde{m} cannot be larger than m^* , that is, no cycles of length $T > 1$ are possible in equilibrium, and the proposition is proved. This result shows the sensitivity of the existence of cycles in the Shleifer (1986) model to changes in the assumptions about beliefs.

6. Conclusions

In this paper, we have drawn attention to the contrast between the New Economy boom of the 1990s and previous cyclical fluctuations. We argue that this contrast can be explained using Shleifer's model of implementation cycles. In the first part of the paper, we present some indirect evidence in support of Shleifer's model. For example, the co-movements of initial public offerings and MFP growth are consistent with innovations that are implemented in waves. The association between these two proxies for innovation is quite strong: lagged IPOs help to predict MFP growth, even conditional on lagged MFP growth.

The 1990s, however, clearly saw a decline in the volatility of productivity growth. There was a corresponding decline in the volatility of IPOs. Given the similar patterns shown by the two series, we argue that implementation cycles may have weakened in the 1990s. Again, we interpret this in terms of Shleifer's model: instead of strategic delays, immediate implementation may have emerged as the equilibrium outcome.

Our theoretical contribution, the second part of the paper, explains this development in the following terms. Recall that, in Shleifer's model, the timing of implementation of innovations is related to firms' expectations about future aggregate income. These expectations are self-fulfilling, and business cycles are driven by strategic delays supported by particular expectations. But when we extend Shleifer's model to incorporate uncertainty about the trend growth rate of the economy, the equilibria with delayed implementation are eliminated, because delay becomes risky. Business cycles with delayed implementation therefore rely on a strong common knowledge assumption, one that may not have been satisfied in the unusual circumstances of the 1990s. We argue that this could explain the reduced volatility in MFP growth and IPOs: uncertainty about the trend growth rate led to immediate implementation as the sole equilibrium outcome.

Although previous researchers have demonstrated the importance of informational assumptions for multiplicity, we have shown that similar arguments apply to a classic model of the business cycle. More ambitiously, we believe that our analysis could shed new light on the dynamics of the New Economy in the USA during the 1990s, helping to explain some of the most important features of that decade.

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Appendix 1. Data sources

Number of IPOs in USA, Updated data on IPOs collected by Jay Ritter, downloaded from website http://bear.cba.ufl.edu/ritter/publ_papers/IPOALL.xls on 4 May 2004.

MFP for private nonfarm business sector: series MPU750023(K), downloaded from Bureau of Labor Statistics website 29 June 2004.

MFP for manufacturing, durables (SIC codes 24-25, 32-39): series MPU320003(B), downloaded from BLS website 29 June 2004.

MFP for manufacturing, non-durables (SIC codes 20-23,26-31): series MPU310003(B), downloaded from BLS website 29 June 2004.

Appendix 2. Proof of Lemma.

Let $0 \leq j \leq n \cdot (T-1)$ denote the total number of firms who receive innovations at periods $1, \dots, T-1$ and wait until period T before implementing. Let $\Pi_T/D_{T-1}(j)$ and $\Pi_I(j)$ denote the payoffs from delaying until time T and implementing immediately (respectively) given that exactly j firms wait.

Since (by assumption) S is an equilibrium then the ex-post payoff to the firm from waiting must be higher than that of implementing immediately:

$$(9) \quad p(j=n \cdot (T-1)) \frac{\Pi_T}{D_{T-1}}(n \cdot (T-1)) + p(j=n \cdot (T-1)-1) \frac{\Pi_T}{D_{T-1}}(n \cdot (T-1)-1) + \dots + p(j=0) \frac{\Pi_T}{D_{T-1}}(0) > \\ p(j=n \cdot (T-1)) \Pi_1(n \cdot (T-1)) + p(j=n \cdot (T-1)-1) \Pi_1(n \cdot (T-1)-1) + \dots + p(j=0) \Pi_1(0)$$

Which we can re-arrange as follows:

$$(10) \quad p(j=n \cdot (T-1)) \left[\frac{\Pi_T}{D_{T-1}}(n \cdot (T-1)) - \Pi_1(n \cdot (T-1)) \right] + \dots + p(j=kn \cdot (T-1)+1) \left[\frac{\Pi_T}{D_{T-1}}(kn \cdot (T-1)+1) - \Pi_1(kn \cdot (T-1)+1) \right] > \\ p(j=kn \cdot (T-1)) \left[\Pi_1(kn \cdot (T-1)) - \frac{\Pi_T}{D_{T-1}}(kn \cdot (T-1)) \right] + \dots + p(j=0) \left[\Pi_1(0) - \frac{\Pi_T}{D_{T-1}}(0) \right]$$

Note that all the expressions in the square brackets – on both sides of the equation – are positive because $\Pi_T/D_{T-1}(j) > \Pi_1(j)$ when $j > kn \cdot (T-1)$ and $\Pi_T/D_{T-1}(j) < \Pi_1(j)$ otherwise.

Furthermore, the quantity $\Pi_T/D_{T-1}(j) - \Pi_1(j)$ increases with j (and conversely $\Pi_1(j) - \Pi_T/D_{T-1}(j)$ decreases with j). The left-hand side of (10) is therefore smaller than $\phi \left[\frac{\Pi_T}{D_{T-1}}(n \cdot (T-1)) - \Pi_1(n \cdot (T-1)) \right]$ (because the probabilities sum up to ϕ). The right-hand side of equation (10) is greater than $(1-\phi) \left[\Pi_1(kn \cdot (T-1)) - \frac{\Pi_T}{D_{T-1}}(kn \cdot (T-1)) \right]$.

Using these and the inequality (10) we get:

$$\phi \left[\frac{\Pi_T}{D_{T-1}}(n \cdot (T-1)) - \Pi_1(n \cdot (T-1)) \right] > (1-\phi) \left[\Pi_1(kn \cdot (T-1)) - \frac{\Pi_T}{D_{T-1}}(kn \cdot (T-1)) \right]$$

or $\phi A > (1-\phi)B$ where A and B are both positive. Solving for ϕ we get $\phi > \frac{B}{A+B} > 0$.