The University *of* Manchester

Discussion Paper Series

Information, Imitation and Growth

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January 2001
Number 005

THE UNIVERSITY *of* MANCHESTER

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January 10, 2001

Abstract

This paper presents an analysis of the role of information in determining the growth and development prospects of economies. In an overlapping generations model, producers of capital choose between two types of technology - safe and risky. Depending on the information available, decision making may or may not be characterised by herd behaviour whereby each producer imitates the decisions of others in an information cascade. Multiple development regimes arise when the quality of information is determined endogenously through purposeful, but costly, activities. It is shown that both the prospect of transition between these regimes and the characteristics of the transition path can be very di¤erent in imitation-free and imitation-prone economies.

1 Introduction

The conventional approach to modelling individual decision making in dynamic general equilibrium analysis is to assume that each agent chooses her own course of action without regard for the actions chosen by others. In reality, of course, decision making is a far more complex process than this and the way that one person behaves may well be in‡uenced strongly by the behaviour of those around her. Indeed, the choice made by any single individual may have as much to do with her observations of the choices made by others as it has with her own private information. If such observations

[¤] The authors are grateful for the …nancial support of the ESRC (Grant no.R000222871). The usual disclaimer applies.

convey additional information that the individual does not possess, then it is perfectly rational for her to pay heed to what others are doing. Recently, a number of authors have sought to incorporate explicitly this pervasive aspect of human behaviour into microeconomic models of decision making (e.g., Banerjee 1992; Bikhchandani et al. 1992; Gul and Lundholm 1995; Lee 1993; Scharfstein and Stein 1992; Welch 1992). In this paper we build on those analyses to explore the implications of social interactions in a dynamic general equilibrium model of growth and development.

The contributions cited above share a common analytical framework for studying social in‡uence on choice, whereby decision making takes place sequentially through an ordered population of imperfectly-informed agents. Each agent faces a choice between alternative courses of action, the outcomes of which are uncertain. The information set of each agent consists of some privately-observed signal about these outcomes plus the publicly-observed actions of others ahead of her. Based on this information set, each agent applies Bayes' rule to learn about the economic environment and to decide optimally on which action to take. A probable consequence of this decision making process is that, sooner or later, and for better or for worse, an individual will …nd it optimal to follow the behaviour of the preceding individual irrespective of her private signal. This is because the information conveyed by her signal is overwhelmed by the information conveyed by the actions of those before her. Her own behaviour will therefore convey no additional information to the next individual who will be led to behave in the same way as well, and so and so forth. In other words, there is likely to come a point at which one agent decides rationally to ignore her own information and, by doing so, in‡ict an externality on all subsequent agents, each whom simply does what everyone else is doing. This is known as an information cascade which leads to the sort of herd behaviour that has been alleged to occur in many areas of social, scienti…c, economic and political life.[1]

In the analysis that follows we exploit the above insights to compare and contrast the macroeconomic implications of alternative informational scenarios in a simple model of growth based on technology adoption. We imagine an environment in which economic agents, belonging to overlapping generations, choose between two types of technology (or project) - safe and risky - for producing capital which serves as an input to …nal manufacturing. Agents make decisions in turn according to their positions in the population, to which they

[1] Examples in economics include the investment decisions of …rms (Scharfstein and Stein 1992) and the pricing of stocks in …nancial markets (Welch 1992). For numerous other examples, see Bikhchandani et al. (1992) who also document other possible explanations of clustering behaviour (such as the presence of network externalities, as in the models of Arthur (1989), Farrell and Saloner (1986) and Katz and Shapiro (1985)).

are assigned exogenously and of which they are perfectly informed. Relative to the return on the safe technology (which is …xed and common knowledge), the return on the risky technology (which is random with known probability distribution) can be either high or low and is unobservable to an agent unless she adopts that technology. Conditional on available information, each agent forms a posterior belief about this return and decides on which project to invest in so as to maximise her expected lifetime utility.

We distinguish between two types of economy according to the information that agents possess. The …rst type is one in which each agent's information set consists solely of a privately-observed signal about the return on the risky technology. This is an economy that is free from any herd-like behaviour. The second type is one in which each agent's information set comprises not only a privately-observed signal about the risky project's return, but also a publicly-observed list of the decisions made by all other agents ahead of her. This is an economy that is prone to display herd-like behaviour. Such behaviour is the result of an information cascade that begins from the …rst indivdual to ignore her own signal and choose a technology based solely on the choice made by the individual before her. Depending on whether she makes the right or wrong decision, all subsequent individuals are in either a correct cascade (adopting the best technology and rejecting the worst technology) or an incorrect cascade (adopting the worst technology and rejecting the best technology).

In both types of economy the key factor in determining equilibrium capital accumulation is the quality of signals that agents privately observe. The more precise are these signals, the more likely it is that agents will make correct decisions. In our imitation-prone economy this implies a greater probability of there emerging a correct cascade and a lower probability of there emerging an incorrect cascade. If the precision of signals is constant and given exogenously to agents, then capital accumulation takes place along a simple linear growth path that converges towards a unique steady state equilibrium. This path is always higher in our imitation-prone economy than in our imitation-free economy.

Matters become more interesting when one allows signal precision to be endogenous by treating it, in part, as an object of choice for individuals who have the opportunity of improving the quality of their private information through costly investment activities (such as education and training). When agents disregard each other's behaviour, the decision as to whether or not to take up such an opportunity is relatively straightforward to model. This is because the bene…t accruing to an agent from an improvement in her own signal quality is independent of the signal qualities of all other agents. By contrast, when agents do pay heed to what others are doing, the issue is much less straightforward because the bene…t to an individual from an improvement in signal quality depends fundamentally on the circumstances surrounding her - that is, whether or not she is in a cascade. Moreover, the prospects of di¤erent circumstances arising are determined, in turn, by the qualities of the signals of all other individuals' ahead of her. For these reasons, the problem of information acquisition in an imitation-prone economy entails additional dimensions that make it far from trivial.

Our analysis indicates that, in both types of economy, the propensity of individuals to undertake costly information acquisition increases with the level of development. This leads to multiple development regimes associated with di¤erent grades of signal precision. As above, the growth paths of the two economies are not the same, however, because the rate at which signal quality improvement spreads throughout the population is very di¤erent in each case. The implication is that both the prospects of transition between regimes and the characteristics of any such transition can also be very di¤erent in each case. When transition does take place, the process is smooth in our imitation-prone economy but discontinuous in our imitation-free economy. In addition, there is an intermediate period during this process when the former (latter) economy is on a relatively low (high) development path which nevertheless leads eventually to a relatively high (low) steady state equilibrium. In the absence of transition, there are multiple long-run outcomes which depend crucially on initial conditions. One of these outcomes is a poverty trap in which signal quality improvement is undertaken by no-one. Such an outcome is less likely to occur in our imitation-prone economy than in our imitation-free economy.

The paper is organised as follows. In Section 2 we describe the basic economic environment. In Sections 3 and 4 we derive the results for our two di¤erent economies. In Section 5 we make a few concluding remarks.

2 The Basic Set-up

Time is discrete and indexed by t. We consider an archipelago-type environment in which there is a large number, M, of identical islands each of which is inhabited by a constant population, N, of two-period-lived agents belonging to dynastic families of overlapping generations connected through altruism. Each agent has one parent and one child, inheriting wealth from the former when young and bequeathing wealth to the latter when old. Young agents are suppliers of labour and producers of capital, while old agent are manufacturers and consumers of …nal output. Trade between agents takes place within perfectly competitive markets.

All agents have identical preferences defined over consumption and bequests.[2] An agent born at time t derives lifetime utility, U_t, according to

$$U_t = c_{t+1} + u(b_{t+1}); \tag{1}$$

where c_{t+1} denotes consumption, b_{t+1} denotes bequests and $u(\cdot)$ is a strictly concave function that satisfies the usual Inada conditions. Given (1), we proceed to describe the life-cycle behaviour of each generation t agent by considering in reverse order the decision problems confronted during youth and adulthood.

In the second period of life, each old agent manufactures final output using a common, non-stochastic technology. The inputs to manufacturing are labour (hired from the young of the next generation) and capital (acquired from investment projects undertaken previously by the current generation). An adult employing l_{t+1} units of labour and k_{t+1} units of capital is able to produce y_{t+1} units of output according to

$$y_{t+1} = Ak_{t+1}^{\alpha} l_{t+1}^{1-\alpha} K_{t+1}^{1-\alpha}; \qquad A > 0; \alpha \in (0;1) \tag{2}$$

where K_{t+1} denotes the aggregate stock of capital in the economy.[3] We assume that both capital and labour are perfectly mobile across islands. This ensures that each agent faces the same competitively-determined wage rate, w_{t+1}, and the same competitively-determined rental rate, r_{t+1}. If an adult produced $\hat{k}_{t+1}$ units of capital when young, then she is a net borrower of capital if $k_{t+1} - \hat{k}_{t+1} > 0$ and a net lender of capital if $k_{t+1} - \hat{k}_{t+1} < 0$. Her budget constraint may therefore be written as

$$c_{t+1} + b_{t+1} = Ak_{t+1}^{\alpha} l_{t+1}^{1-\alpha} K_{t+1}^{1-\alpha} - w_{t+1} l_{t+1} - r_{t+1}(k_{t+1} - \hat{k}_{t+1}): \tag{3}$$

For given values of K_{t+1} and $\hat{k}_{t+1}$, an adult maximises (1) subject to (3) by choosing b_{t+1}, l_{t+1} and k_{t+1} so as to satisfy $u'(\cdot) = 1$, $w_{t+1} = (1 - \alpha)Ak_{t+1}^{\alpha} l_{t+1}^{-\alpha} K_{t+1}^{1-\alpha}$ and $r_{t+1} = \alpha Ak_{t+1}^{\alpha-1} l_{t+1}^{1-\alpha} K_{t+1}^{1-\alpha}$. Hence $b_{t+1} = b$ for all t and factor demands are determined by the usual marginal productivity conditions. Since we assume that each young agent supplies one unit of labour, and since the total population of the economy is MN, market clearing requires $l_{t+1} = 1$ and $K_{t+1} = MNk_{t+1}$ (i.e., all manufacturers employ the same quanitites of inputs in equilibrium). Accordingly, we may write

[2] As in other models, we account for intergenerational altruism in the simplest way by assuming that parents derive utility from the size of their bequests, as opposed to the utility of their offspring. For further discussion, see Andreoni (1989).

[3] Thus we allow for an externality in the production of goods, as in many types of endogenous growth model (e.g., Romer 1986).

$$w_{t+1} = (1-\alpha)A(MN)^{1-\alpha}k_{t+1}; \tag{4}$$
$$r_{t+1} = \alpha A(MN)^{1-\alpha}. \tag{5}$$

In the first period of life, each young agent has a total amount of income equal to the bequest, b, that she receives from her parent, plus the wage, w_t, that she earns from supplying labour to old manufacturers of the previous generation. This income is converted into capital next period, $\hat{k}_{t+1}$, through the operation of an investment project. There are two types of project, or technology, available for producing capital - a risky project, which yields a random return of Λ_t, and a safe project, which yields a certain return of λ. Unless the risky project is taken on, an agent is unable to observe the realisation of Λ_t and knows only its probability distribution which we assume to be identical and independent across islands, and to be given by $\Lambda_t = \underline{\Lambda}$ with prior probability q and $\Lambda_t = \overline{\Lambda}$ with prior probability $1-q$, where $0 \leq \underline{\Lambda} < \lambda < \overline{\Lambda}$. The value of λ, which is public knowledge, is also assumed to be the same across islands. Without loss of generality, we set $q = \frac{1}{2}$ and assume further that $q\underline{\Lambda} + (1-q)\overline{\Lambda} = \frac{1}{2}(\underline{\Lambda} + \overline{\Lambda}) = \lambda$. It is evident that, given this set-up, agents do not enjoy any extra advantage in locating themselves in a particular island for the purpose of producing capital or output. To reduce notation, therefore, we imagine that each agent engages in each type of production on the island where they were born.

Depending on which technology is adopted, either $\hat{k}_{t+1} = \Lambda_t(w_t + b)$ or $\hat{k}_{t+1} = \lambda(w_t + b)$. By virtue of (4), we may summarise these processes governing the production of capital by each agent as

$$\hat{k}_{t+1} = \begin{cases} [(1-\alpha)A(MN)^{1-\alpha}k_t + b]\Lambda_t; \\ [(1-\alpha)A(MN)^{1-\alpha}k_t + b]\lambda. \end{cases} \tag{6}$$

In turn, with additional use of (3) and (5), we may convert (1) into the following expression for indirect utility:

$$U_t = \begin{cases} V(k_t)\Lambda_t - b + u(b); \\ V(k_t)\lambda - b + u(b); \end{cases} \tag{7}$$

where $V(\cdot) = \alpha A(MN)^{1-\alpha}[(1-\alpha)A(MN)^{1-\alpha}k_t + b]$. A young agent chooses between alternative investment projects so as maximise $E(U_t|\Omega_t)$, the conditional expected value of utility, where E is the expectations operator and Ω_t is the agent's information set. Evidently, this is a problem of comparing $E(\Lambda_t|\Omega_t)$ with λ.

Henceforth we distinguish between agents according to their positions in the population for making investment choices. Specifically, we assume that, on each island, agents are ordered arbitrarily in an observable sequence defined by $i = 1, 2, \ldots, N$. Conditional on available information, each agent, i, forms the posterior belief $E(\alpha_t|\Omega_{it})$ and reaches a decision, $d_{i,t}$, about whether to accept or reject the risky project. With probability 1, the decision is to accept ($d_{i,t} = A$) if $E(\alpha_t|\Omega_{it}) > \lambda$, and to reject ($d_{i,t} = R$) if $E(\alpha_t|\Omega_{it}) < \lambda$. As a tie-breaking convention, we assume that each project is adopted (and rejected) with equal probability $\frac{1}{2}$ if $E(\alpha_t|\Omega_{it}) = \lambda$. An agent's position in the population may or may not be important depending on exactly what information is available to her - in particular, whether she has information about the investment decisions of other agents ahead of her. If not, then her own choice of technology will not be influenced by the choices made by others so that herd behaviour will never arise. If so, however, then it may be rational for her to pay heed to what others are doing and to consciously imitate their actions. The remainder of the paper is devoted to the study of these two different informational environments.

3 An Imitation-Free Economy

The first scenario that we consider is one in which all information is private information. This is the simplest case to analyse and serves as a useful benchmark. To be precise, we assume that the information set of each agent consists solely of a private, conditionally-independent and identically-distributed binary signal, $s_{i,t}$, about the unobservable return on the risky technology, α_t. This signal can be either good ($s_{i,t} = G$), indicating that $\alpha_t = \overline{\alpha}$, or bad ($s_{i,t} = B$), indicating that $\alpha_t = \underline{\alpha}$. With probability $p_t > \frac{1}{2}$ the signal is correct, while with probability $1 - p_t$ the signal is incorrect: that is, $p_t = \Pr(s_{i,t} = G|\alpha_t = \overline{\alpha}) = \Pr(s_{i,t} = B|\alpha_t = \underline{\alpha})$ and $1 - p_t = \Pr(s_{i,t} = G|\alpha_t = \underline{\alpha}) = \Pr(s_{i,t} = B|\alpha_t = \overline{\alpha})$.[4] Our immediate concern is to solve the problem of technology choice faced by each individual for any given value of p_t. Subsequently, we extend our analysis to the case in which this signal probability is determined endogenously.

3.1 Technology Adoption

Solving for agents' optimal investment decisions is a relatively straightforward exercise under the present set of circumstances. From the perspective of agent i, the posterior probability that α_t is truly equal to $\overline{\alpha}$ is $\Pr(\alpha_t = \overline{\alpha}|s_{i,t})$. This implies a conditionally expected value of α_t equal to

$$E(\alpha_t|s_{i,t}) = \Pr(\alpha_t = \overline{\alpha}|s_{i,t})\overline{\alpha} + [1 - \Pr(\alpha_t = \overline{\alpha}|s_{i,t})]\underline{\alpha}. \quad (8)$$

[4] The restriction $p_t > \frac{1}{2}$ ensures merely that the signal is informative.

Based on (8), each agent makes a choice between alternative projects in accordance with the same simple criteria - namely, to adopt the risky project on receipt of a good signal, and to reject the risky project on receipt of a bad signal.[5]

Given the above, one may proceed to derive the equilibrium path of capital in the economy. To do so, define $E(Z_{i,t})$ as the unconditionally expected value of the return to agent i who is an investor in a project at time t. With a certain probability, this agent is an operator of either the risky technology (decision $d_{i,t} = A$) or the safe technology (decision $d_{i,t} = R$). The return on the former is either $\underline{\Lambda}$ or $\overline{\Lambda}$ with equal prior probability $\frac{1}{2}$, while the return on the latter is λ. It follows that

$$E(Z_{i,t}) = \tfrac{1}{2}[\Pr(d_{i,t} = A|\Lambda_t = \underline{\Lambda}) + \Pr(d_{i,t} = A|\Lambda_t = \overline{\Lambda}) + \Pr(d_{i,t} = R|\Lambda_t = \underline{\Lambda}) + \Pr(d_{i,t} = R|\Lambda_t = \overline{\Lambda})]. \quad (9)$$

Since the decision to adopt (reject) the risky technology is taken only if a good (bad) signal is received, we have $\Pr(d_{i,t} = A|\Lambda_t) = \Pr(s_{i,t} = G|\Lambda_t)$ ($\Pr(d_{i,t} = R|\Lambda_t) = \Pr(s_{i,t} = B|\Lambda_t)$). Consequently, (9) may be computed as

$$E(Z_{i,t}) = \tfrac{1}{2}[(1 - p_t)\underline{\Lambda} + p_t\overline{\Lambda} + \lambda]. \quad (10)$$

In turn, the (ex ante) expected amount of capital produced by agent i can be established from (6) as $E(k_{i,t+1}) = [(1 - \alpha)A(MN)^{1-\alpha}k_t + b]E(Z_{i,t})$.

Now, observe that each ith-positioned agent on each island faces an identical and independent probability distribution over investment choices. By assumption, the return on the risky project is also identically and independently distributed across islands. Thus, since the number of islands, M, is assumed to be large, we may appeal to the law of large numbers to deduce an expression for the total amount of capital produced by all agents in the ith position: that is, $K_{i,t+1} = M[(1 - \alpha)A(MN)^{1-\alpha}k_t + b]E(Z_{i,t})$. Aggregating over N, the size of the population on each island, will then give us an expression for the economy-wide capital stock, K_{t+1}, from which we may determine the per-capita stock of capital, $k_{t+1} = \frac{K_{t+1}}{MN}$, as

$$k_{t+1} = G(k_t; p_t) = [(1 - \alpha)A(MN)^{1-\alpha}k_t + b][F(p_t) + \tfrac{1}{2}\lambda], \quad (11)$$

where

$$F(p_t) = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{(1 - p_t)\underline{\Lambda} + p_t\overline{\Lambda}}{2}\right] = \frac{(1 - p_t)\underline{\Lambda} + p_t\overline{\Lambda}}{2}.$$

[5] To be sure, simply substitute, in turn, $\Pr(\Lambda_t = \overline{\Lambda}|s_{i,t} = G) = p_t$ and $\Pr(\Lambda_t = \overline{\Lambda}|s_{i,t} = B) = 1 - p_t$ into (8) to obtain $E(\Lambda_t|s_{i,t} = G) = p_t\overline{\Lambda} + (1 - p_t)\underline{\Lambda} > \lambda$ and $E(\Lambda_t|s_{i,t} = B) = (1 - p_t)\overline{\Lambda} + p_t\underline{\Lambda} < \lambda$.

Evidently, $F'(\cdot) > 0$.

Expression (11) shows that the equilibrium path of capital depends on p_t, the probability that agents receive the correct signal about the risky technology. If this signal probability is constant (i.e., if $p_t = p$ for all t), then $G(\cdot) = g(k_t)$ and there is a unique equilibrium in which the economy either converges to a stationary (zero growth) steady state or develops perpetually along a constant positive growth path, depending on whether $g'(\cdot) \in (0; 1)$ or $g'(\cdot) > 1$.[6] For given values of other parameters, an increase in p both raises the steady level of capital and makes the latter condition more likely to be satisfied. Intuitively, higher values of p imply better quality signals and greater chances of making the correct decision. This suggests that changes in signal quality could have significant effects on the prospective fortunes of the economy, an idea that provides the motivation for our subsequent line of inquiry.

3.2 Endogenous Signal Quality

An important extension of the above analysis is to make the plausible assumption that individuals have some control over the initial information that they receive. We do this by considering the case in which each agent is able to improve the quality of her own private signal by undertaking some purposeful, but costly, activity (such as education, training and research). Under such circumstances, signal quality is an endogenous variable that must be solved for as part of agents' optimisation problems. Our aim is to characterise the equilibrium of the economy by determining the precise conditions under which all, some or no individuals undertake costly information acquisition.

To fix ideas, we assume that signal quality can take on one of two values. Each agent on each island may choose to receive either a low quality signal free of charge, or a high quality signal at a fixed disutility cost of $\delta > 0$. We denote by $p_{i;t}$ the signal probability chosen by agent i at time t. The low precision signal is correct with probability p_L, while the high precision signal is correct with probability $p_H > p_L$. In accordance with our previous analysis, we assume that, in each case, an agent is sufficiently well-informed ($p_{i;t} > \frac{1}{2}$) as to adopt (reject) the risky project if her signal is good (bad).

From (10), an individual's (ex ante) expected return on project investment, conditional on the quality of her signal, is given by

[6] Since $F(\cdot) \geq \frac{1}{2}\lambda \geq 1$, then $g(0) \geq b\lambda$ and the steady state value of capital in the absence of long-run growth is $\frac{b[F(\cdot)+\frac{1}{2}\lambda]}{1-(1-\alpha)A(MN)^{1-\alpha}[F(\cdot)+\frac{1}{2}\lambda]}$.

$$E(Z_{i,t}) = \begin{cases} \frac{1}{2}[(1-p_L)\underline{\Lambda} + p_L\overline{\Lambda} + \lambda]; & \text{if } p_{i,t} = p_L; \\ \frac{1}{2}[(1-p_H)\underline{\Lambda} + p_H\overline{\Lambda} + \lambda]; & \text{if } p_{i,t} = p_H. \end{cases} \tag{12}$$

The difference between these expected returns is $z_{i,t} = \frac{1}{2}(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda})$. By virtue of (7), the (ex ante) expected utility of an agent, exclusive of information costs, is determined as $E(U_{i,t}) = V(\cdot)E(Z_{i,t}) - b + u(b)$. Thus, since all agents are alike, we can immediately deduce the following result.

Proposition 1 $p_{i,t} = p_L$ $(p_{i,t} = p_H)$ for all $i = 1, ..., N$ if and only if $\frac{1}{2}V(k_t)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) < \delta$ $(\frac{1}{2}V(k_t)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) \geq \delta)$.

Proof. he benefit to agent i from an improvement in signal quality is $V(\cdot)z_{i,t} = \frac{1}{2}V(\cdot)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda})$, for which the agent incurs the cost δ. If $\frac{1}{2}V(\cdot)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) < \delta$ $(\frac{1}{2}V(k_t)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) \geq \delta)$, then the agent will forego (undertake) such an improvement. ■

Intuitively, the greater (smaller) the difference between p_H and p_L, the more (less) valuable is an improvement in signal quality and the greater the likelihood of there emerging an equilibrium in which all (none) of the population will be willing to incur the cost of undertaking such improvement.

Given the above, we may identify a critical level of capital, k_l^c, which satisfies $\frac{1}{2}V(k_l^c)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) = \delta$ such that $p_i = p_L$ for all $i = 1, ..., N$ if $k_t < k_l^c$, and $p_i = p_H$ for all $i = 1, ..., N$ if $k_t \geq k_l^c$. In accordance with (11), we can then write

$$\begin{aligned} k_{t+1} &= G(k_t; p(k_t)) \\ &= \begin{cases} g_l(k_t) = [(1-\alpha)A(NX)^{1-\alpha}k_t + b][F(p_L) + \frac{1}{2}\lambda], & \text{if } k_t < k_l^c; \\ g_h(k_t) = [(1-\alpha)A(NX)^{1-\alpha}k_t + b][F(p_H) + \frac{1}{2}\lambda], & \text{if } k_t \geq k_l^c; \end{cases} \end{aligned} \tag{13}$$

where $0 < g_l(0) < g_h(0)$ and $0 < g_l'(\cdot) < g_h'(\cdot)$. Based on (13), we are led to distinguish between two types of development regime for the economy: the first - a low development regime - is characterised by low levels of capital and low qualities of signal throughout the population; the second - a high development regime - is characterised by high levels of capital and high qualities of signal throughout the population. For illustrative purposes, we focus on the case in which $g_h'(\cdot) \in (0, 1)$, implying the existence of two steady state capital stocks, k_l^* and k_h^*, corresponding to the fixed points of the mappings $k_l^* = g_l(k_l^*)$ and $k_h^* = g_h(k_h^*)$. In general, the overall evolution of the economy will depend crucially on the initial capital stock, k_0, and the relationship between k_l^c and $k_l^\star$, as portrayed in Figure 1.

Suppose that $k_0 < k_l^c < k_l^*$. In this case, the economy starts off in a situation where no agent invests in signal quality improvement and development takes place along the low growth path, $g_l(\cdot)$. At some point in time, k_t reaches k_l^c and all agents find it optimal to incur the cost of acquiring better quality information. This causes the economy to jump on to the high growth path, $g_h(\cdot)$, along which it then converges to the high steady state equilibrium, k_h^*. This chain of events describes a process of transition from the low development regime to the high development regime. But there is nothing in the model to guarantee such an outcome. To be sure, suppose that $k_0 < k_l^* < k_l^c$. In this case, the economy is destined for the low steady state equilibrium, k_l^*, being locked forever on the low growth path, $g_l(\cdot)$, without any of its citizens undertaking signal quality improvement. To the extent that the high steady state equilibrium, k_h^*, would be attained if $k_0 > k_l^c$, the model now presents a situation in which limiting outcomes depend fundamentally on initial conditions.

4 An Imitation-Prone Economy

The second scenario that we contemplate is one in which each agent has access to two, distinct pieces of information. The first is the same type of private signal, $s_{i,t}$, about the return on the risky technology as that which has appeared previously. The second is a list of observations, $D_{i-1,t} = \{d_{1,t}, d_{2,t}, \ldots, d_{i-1,t}\}$, of the decisions of all other individuals ahead of her on her own island.[7] As indicated earlier, the effect of allowing agents to possess such a list is to raise the prospect of herd behaviour. Our investigations into this follow the same pattern as before, beginning with the solution to the problem of technology choice for any given signal quality which we then endogenise on the basis of costly information acquisition.

4.1 Technology Adoption

Within the context of the present environment, each agent forms a posterior belief about the return on the risky technology by pooling together her different types of information. In terms of agent i, the posterior probability that θ_t is truly equal to $\bar{\theta}$ is $\Pr(\theta_t = \bar{\theta} | s_{i,t}, D_{i-1,t})$, implying a conditionally expected value of θ_t equal to

[7] Since θ_t is independently distributed across islands, observing the actions of individuals in other islands conveys no information about the value of θ_t in one's own island. Together with the fact that the signals of individuals are purely private information, our analysis is understood to focus on the least informative case of information transmission. As argued by Bikhchandani et al. (1992), however, to the extent that actions speak louder than words, the information conveyed by actions may well be the most credible information.

$$E(\theta_t|s_{i,t}; D_{i-1,t}) = \Pr(\theta_t = \overline{\theta}|s_{i,t}; D_{i-1,t})\overline{\theta} + [1 - \Pr(\theta_t = \overline{\theta}|s_{i,t}; D_{i-1,t})]\underline{\theta}. \quad (14)$$

Although more complicated than before, the problem of technology choice is still of manageable dimensions such that one is able to solve for the entire set of possible sequences of individuals' decisions. Since the problem is essentially the same as the example constructed by Bikhchandani et al. (1992), we omit any technical proofs and confine ourselves to an informal discussion based on Figure 2 which provides a convenient summary of all conceivable events.[8]

The first agent is like each of the agents in our previous economy, adopting the risky technology if her signal is good and rejecting this technology if her signal is bad. Thus the first agent's signal is revealed fully by her decision. If the first agent adopted, then the second agent adopts either with certainty if her signal is good or with probability $\frac{1}{2}$ if her signal is bad. Conversely, if the first agent rejected, then the second agent rejects either with certainty if her signal is bad or with probability $\frac{1}{2}$ if her signal is good. The third agent is faced with the following possibilities: both the first and second agents adopted, in which case she adopts regardless of her signal; both the first and second agents rejected, in which case she rejects regardless of her signal; the first agent adopted (rejected) while the second agent rejected (adopted), in which case she adopts if her signal is good and rejects if her signal is bad. In each of the first two instances the third agent's decision does not depend on her own signal and this marks the onset of an information cascade - either an up-cascade (where even a bad signal does not prevent adoption), or a down-cascade (where even a good signal does not prevent rejection). Should this occur, then the third agent's decision conveys no information to the fourth agent who is therefore led to draw exactly the same inference and who is therefore also in a cascade. By induction, this is true for all subsequent agents. In the last instance the third agent is in the same position as the first agent and her choice of action is determined by her signal. The fourth agent is then in the same position as the second agent, the fifth as the third, and so and so forth. From this perspective, therefore, all odd-numbered agents are alike and all even-numbered agents are alike, and the possibility of a cascade arising occurs after each one of the latter.

We may calculate explictly the unconditional ex ante probabilities of an up-cascade (where all agents adopt the risky project), a down-cascade (where all agents reject the risky project) and a non-cascade after any even number of individuals, m. We write these probabilities as $\pi^{uc}_m(p_t) = \frac{1-(p_t - p_t^2)^{\frac{m}{2}}}{2}$,

[8] It can be shown that this decision structure remains valid for any $q \in (0,1)$ that satisfies $q\overline{\theta} + (1-q)\underline{\theta} = \lambda$.

$\pi^{dc}_m(p_t) = \frac{1-(p_t - p_t^2)^{\frac{m}{2}}}{2}$ and $\pi^{nc}_m(p_t) = (p_t - p_t^2)^{\frac{m}{2}}$, respectively. In turn, we may also compute the ex ante probabilities of being in a correct cascade (where all agents adopt (reject) the risky technology when $\theta_t = \overline{\theta}$ ($\theta_t = \underline{\theta}$)), an incorrect cascade (where all agents adopt (reject) the risky technology when $\theta_t = \underline{\theta}$ ($\theta_t = \overline{\theta}$)) and a non-cascade after the same number of individuals: that is,

$$\begin{aligned} \pi^{cc}_m(p_t) &= \frac{p_t(1+p_t)[1-(p_t - p_t^2)^{\frac{m}{2}}]}{2(1-p_t+p_t^2)}; \\ \pi^{ic}_m(p_t) &= \frac{(1-p_t)(2-p_t)[1-(p_t - p_t^2)^{\frac{m}{2}}]}{2(1-p_t+p_t^2)}; \qquad (15) \\ \pi^{nc}_m(p_t) &= (p_t - p_t^2)^{\frac{m}{2}}: \end{aligned}$$

Thus the probability of a correct cascade is increasing in p_t, while the probability of an incorrect cascade is decreasing in p_t. Intuitively, low values of p_t (i.e., values close to $\frac{1}{2}$) mean that signals are noisy and not very informative to agents, while higher values of p_t imply more precise signals which make it more likely that agents will choose the correct action.[9]

Having established the above, one may proceed in the same way as before to determine the equilibrium path of capital in the economy. To begin with, recall the expression in (9) which continues to define each agent's (ex ante) expected return on project investment. Under the present set of circumstances, this expression produces a sequence of such returns with a conveniently simple and predictable pattern. Specifically, agents are coupled together into neighbouring pairs such that $E(Z_{m+1;t}) = E(Z_{m+2;t})$ for $m = 0; 2; :::; N - 2$. As well as being verifiable by computation, this result can be established informally on the basis of the following observations: first, since cascades do not start at even-numbered individuals, the only way that individual $m+2$ can be in or out of a cascade is for individual $m+1$ to be in or out of a cascade; second, whatever their circumstances, individuals $m+1$ and $m+2$ accept or reject the risky project with the same probability (which is probability one in the case of a cascade, and either probability p_t or probability $1 - p_t$ in the case of a non-cascade). Notice, however, that $E(Z_{m+1;t}) \neq E(Z_{m+s;t})$ for $s > 2$ because a cascade may start after any even-numbered agent, implying that the probability of being in a cascade is different for agents $m+1$ and $m+s$. A precise expression for each $E(Z_{i;t})$ is relatively straightforward to compute once it is recognised that (9) may be re-written in terms of the probabilities

[9] Of course, at $p_t = \frac{1}{2}$, signals are completely uninformative. It is also noted that the probability of a cascade (of whatever sort) increases exponentially with the number of individuals, m. Even for very noisy signals, therefore, the probability of not being in a cascade is ver small after only a few agents.

of being in a correct cascade, an incorrect cascade and a non-cascade for each value of Λ_t, where these probabilities are the same for each pair of $m+1$ and $m+2$ agents. Thus, taking $\Lambda_t = \underline{\Lambda}$ first and $\Lambda_t = \overline{\Lambda}$ second, we have

$$E(Z_{m+j,t}) = \tfrac{1}{2}\{\pi_m^{cc}(p_t)\lambda + \pi_m^{ic}(p_t)\underline{\Lambda} + \pi_m^{nc}(p_t)[p_t\lambda + (1-p_t)\underline{\Lambda}]\} + \tfrac{1}{2}\{\pi_m^{cc}(p_t)\overline{\Lambda} + \pi_m^{ic}(p_t)\lambda + \pi_m^{nc}(p_t)[p_t\overline{\Lambda} + (1-p_t)\lambda]\}; \qquad (16)$$

for $m = 0, 2, \ldots, N-2$ and $j = 1, 2$.[10] Exploiting the results in (15), we then arrive at

$$E(Z_{m+j,t}) = \frac{1}{2}\Bigg[\frac{(1-p_t)(2-p_t)[1-(p_t-p_t^2)^{\frac{m}{2}}]}{2(1-p_t+p_t^2)}\underline{\Lambda} + \frac{p_t(1+p_t)[1-(p_t-p_t^2)^{\frac{m}{2}}]}{2(1-p_t+p_t^2)}\overline{\Lambda} + (p_t-p_t^2)^{\frac{m}{2}}[(1-p_t)\underline{\Lambda} + p_t\overline{\Lambda}] + \lambda\Bigg]. \qquad (17)$$

The first term in $[\cdot]$ is the probability of being in an incorrect cascade multiplied by the low return on the risky project; in other words, it is the expected value of being inappropriately in an up-cascade (i.e., adopting the risky project when the project is bad). The second term in $[\cdot]$ is the probability of being in a correct cascade multiplied by the high return on the risky project; in other words, it is the expected value of being appropriately in an up-cascade (i.e., adopting the risky project when the project is good). The third term in $[\cdot]$ is the probability of not being in a cascade multiplied by a probability-weighted average of the risky returns; this is the expected value from not being in a cascade and adopting the risky project when the project is either bad or good. Finally, the fourth term in $[\cdot]$ is simply the return obtained from the safe project when the risky project is rejected. Given (17), the expected amount of capital produced by each agent is obtained from (6) as $E(k_{m+j,t+1}) = [(1-\alpha)A(MN)^{1-\alpha}k_t + b]E(Z_{m+j,t})$.

As before, we may aggregate over the M islands in the economy to obtain an expression for the total amount of capital produced by identically-positioned agents: that is, $K_{m+j,t+1} = M[(1-\alpha)A(MN)^{1-\alpha}k_t + b]E(Z_{m+j,t})$.

[10] To be sure about this expression, consider the case in which $\Lambda_t = \underline{\Lambda}$: If an agent was to be in a correct cascade, then she would receive a payoff of λ by rejecting the risky project irrespective of her own signal. If an agent was to be in an incorrect cascade, then she would receive a payoff of $\underline{\Lambda}$ by accepting the risky project irrespective of her own signal. And if an agent was to be in no cascade, then she would receive a payoff of either λ or $\underline{\Lambda}$ by either rejecting or accepting the risky project according to whether she receives either a good signal (which occurs with probability p_t) or a bad signal (which occurs with probability $1-p_t$). A similar chain of reasoning can be applied to the case of $\Lambda_t = \overline{\Lambda}$.

This remains valid since each $(m+j)$th-positioned agent on each island faces an identical and independent probability distribution over cascade and non-cascade states (as well as an identical and independent probability distribution over risky project returns). Similarly, we may then aggregate over the N number of island inhabitants to determine the economy-wide capital stock, K_{t+1}, from which we can deduce the the per-capita capital stock, $k_{t+1} = \frac{K_{t+1}}{MN}$. In doing this, it is convenient to change notation slightly by exploiting our previous result that $E(Z_{m+1;t}) = E(Z_{m+2;t})$ and defining $n = \frac{m}{2}$ so that $n = 0, 1, \ldots, \frac{N-2}{2}$. Since $K_{t+1} = MNk_{t+1} = \sum_{n=0}^{\frac{N-2}{2}} \sum_{j=1}^{2} K_{2n+j;t+1} = 2\sum_{n=0}^{\frac{N-2}{2}} K_{2n+1;t+1}$, it follows that

$$k_{t+1} = \hat{G}(k_t; p_t) = [(1-\alpha)A(MN)^{1-\alpha}k_t + b][\tilde{\Gamma}(p_t) + \tfrac{1}{2}\lambda], \tag{18}$$

where

$$\begin{aligned}\tilde{\Gamma}(p_t) = \frac{1}{N}\sum_{n=0}^{\frac{N-2}{2}} \Bigg[& \frac{(1-p_t)(2-p_t)[1-(p_t-p_t^2)^n]}{2(1-p_t+p_t^2)}\underline{\delta} \\ & + \frac{p_t(1+p_t)[1-(p_t-p_t^2)^n]}{2(1-p_t+p_t^2)}\bar{\delta} \\ & + (p_t-p_t^2)^n[(1-p_t)\underline{\delta} + p_t\bar{\delta}]\Bigg].\end{aligned}$$

Some tedious calculus and algebra reveal that $\tilde{\Gamma}'(\cdot) > 0$.

Expression (18) has the same basic implications as expression (11). If $p_t = p$ for all t, then $\hat{G}(\cdot) = \tilde{g}(k_t)$ and the economy displays either convergence to a stationary state or perpetual growth, depending on whether $\tilde{g}'(\cdot) \in (0,1)$ or $\tilde{g}'(\cdot) > 1$. An increase in p causes $\tilde{g}(\cdot)$ both to shift up and to become steeper by improving agents'.chances of taking appropriate actions. In the present context, this is reflected in a higher probability of there emerging a correct cascade (a sequence of decisions whereby the best technology is adopted and the worst technology is rejected) and a lower probability of there emerging an incorrect cascade (a sequence of decisions whereby the best technology is rejected and the worst technology is adopted). The main difference between the two scenarios is that, for a given value of p, the transition path without imitation, $k_{t+1} = g(k_t)$, always lies below the transition path with the prospect of imitation, $k_{t+1} = \tilde{g}(k_t)$. This is due to the result that the value of each $E(Z_{m+j;t})$ is lower when determined according to (10) than when determined according to (17) (except for the case in which $m = 0$, where the values of the two expressions are the same). Instinctively, one would presume that decisions based on signals alone (as in our imitation-free economy) are less likely to be correct than decisions based on signals plus actions (as in our imitation-prone economy) because of the additional information contained in those actions.

4.2 Endogenous Signal Quality

A consequence of admitting the possibility of herd behaviour is to increase considerably the dimensions of the problem of costly information acquisition. The additional complexity arises in this case because the expected net benefit to an individual from an improvement in her signal quality is state-dependent - that is, dependent on her prospects of being either in or out of a cascade. Moreover, these prospects are governed, in turn, not only by her own signal quality, but also by the signal qualities of all individuals before her. This follows from the fact that any existing cascade may be either broken or perpetuated by an agent according to whether the private information conveyed by her more precise signal either dominates or is dominated by the aggregate information extracted from the observed actions of others. In general, therefore, the prospective gain to an agent from becoming better informed depends acutely on the extent to which this may induce her towards going it alone, rather than simply going with the flow.

The basic structure of the problem is the same as before. Each agent on each island decides whether to improve the precision of her signal from a low value, p_L, to a high value, p_H, at a fixed disutility cost, δ. This decision is taken before an agent observes the investment choices made by others. As a first step towards solving the problem, we consider the situation faced by an arbitrary agent, i, who is the first to raise her signal probability, $p_{i,t}$, to the high value, p_H. The following result lays down the relationship between p_H and p_L that must be satisfied for a cascade to be broken by this agent.

Proposition 2 If $\frac{p_H}{1-p_H} > \frac{p_L(1+p_L)}{(1-p_L)(2-p_L)} \equiv a$, then an information cascade will collapse at agent i when $p_{i,t} = p_H$ and $p_{j,t} = p_L$ for all $j = 1, 2, \ldots, i-1$.

Proof. Consider a cascade that starts from individual q, where $q < i$ and odd. By definition, the actions of individuals $q, q+1, \ldots, i-1$ convey no information about θ_t to agent i. In addition, since there must have been equal numbers of adoptions and rejections among individuals $1, 2, \ldots, q-3$, then the actions of these other individuals convey no information to agent i as well. This leaves only the actions of individuals $q-1$ and $q-2$ as being relevant to agent i when deciding on her choice of technology. In the case of an up-cascade, agent i will reject the risky project if $E(\theta_t | s_{i,t} =$

$B, d_{q-1,t} = A, d_{q-2,t} = A) < \lambda$, while in the case of a down-cascade, agent i will accept the risky project if $E(\Lambda_t | s_{i,t} = G, d_{q-1,t} = R, d_{q-2,t} = R) > \lambda$. Since $p_{q-1,t} = p_{q-2,t} = p_L$ and $p_{i,t} = p_H$, both of these conditions compute to the same expression, $\frac{p_H}{1-p_H} > \frac{p_L(1+p_L)}{(1-p_L)(2-p_L)}$. ■

Intuitively, cascades are more fragile the greater the precision of any new information relative to old information.

Given the above, our next step is to compute the ex ante expected return on project investment under each set of circumstances that each agent could face. In keeping with the notation used earlier, we denote this expected return by $E(Z_{m+j,t})$ for $m = 0, 2, \ldots, N-2$ and $j = 1, 2$. Likewise, we denote by $\pi_m^{cc}(p_L)$, $\pi_m^{ic}(p_L)$ and $\pi_m^{nc}(p_L)$ ($\pi_m^{cc}(p_H)$, $\pi_m^{ic}(p_H)$ and $\pi_m^{nc}(p_H)$) the probabilities that agent $m+j$ will be in a correct cascade, an incorrect cascade and a non-cascade, given that $p_{q,t} = p_L$ ($p_{q,t} = p_H$) for all $q = 1, 2, \ldots, m+j-1$.[11] By virtue of (16), we are able to infer the following. Suppose that $p_{q,t} = p_L$ for all $q = 1, 2, \ldots, m+j-1$. Then

$$E(Z_{m+j,t}) = \begin{cases} \frac{1}{2}\{[\pi_m^{ic}(p_L) + \pi_m^{nc}(p_L)(1-p_L)]\underline{\Lambda} \\ \quad +[\pi_m^{cc}(p_L) + \pi_m^{nc}(p_L)p_L]\overline{\Lambda} + \lambda\}, \text{ if } p_{m+j,t} = p_L; \\ \frac{1}{2}\{[\pi_m^{ic}(p_L) + \pi_m^{nc}(p_L)(1-p_H)]\underline{\Lambda} \\ \quad +[\pi_m^{cc}(p_L) + \pi_m^{nc}(p_L)p_H]\overline{\Lambda} + \lambda\}, \text{ if } p_{m+j,t} = p_H, \ \frac{p_H}{1-p_H} \leq \Psi; \\ \frac{1}{2}[(1-p_H)\underline{\Lambda} + p_H\overline{\Lambda} + \lambda], \text{ if } p_{m+j,t} = p_H, \ \frac{p_H}{1-p_H} > \Psi; \end{cases} \tag{19}$$

where Ψ is defined in Proposition 2. The first situation is where agent $m+j$, like each agent before her, receives the low quality signal, in which case we are back to our previous analysis. The second situation is where agent $m+j$ is the first to receive the high quality signal but this signal is not strong enough to break a cascade, in which case the only difference from the first situation is the higher probability of making the correct decision in a non-cascade state, implying an increase in expected return from signal quality improvement of size $z_{m+j,t}^1 = \frac{1}{2}\pi_m^{nc}(p_L)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda})$. The third situation is where agent $m+j$ is the first to receive the high quality signal and this signal does possess sufficient strength to cause a cascade to collapse, in which case the agent is in a non-cascade state with certainty so that signal quaility improvement yields an increase in expected return of size $z_{m+j,t}^2 = \frac{1}{2}\{[p_H - \pi_m^{cc}(p_L) - \pi_m^{nc}(p_L)p_L]\overline{\Lambda} + [1 - p_H - \pi_m^{ic}(p_L) - \pi_m^{nc}(p_L)(1-p_L)]\underline{\Lambda}\}$. For the scenario in which $p_{q,t} = p_H$ for all $q = 1, 2, \ldots, m+j-1$, we have

[11] Recall that each pair of neighbouring agents, $m+1$ and $m+2$, face the same probabilities (given in (15)) of being in a cascade and not being in a cascade when the signal probabilities of all previous agents are the same.

$$E(Z_{m+j,t}) = \begin{cases} \frac{1}{2}\{[\pi_m^{ic}(p_H) + \pi_m^{nc}(p_H)(1-p_L)]\underline{\Lambda} \\ \quad +[\pi_m^{cc}(p_H) + \pi_m^{nc}(p_H)p_L]\overline{\Lambda} + \lambda\}, \text{ if } p_{m+j,t} = p_L, \\ \frac{1}{2}\{[\pi_m^{ic}(p_H) + \pi_m^{nc}(p_H)(1-p_H)]\underline{\Lambda} \\ \quad +[\pi_m^{cc}(p_H) + \pi_m^{nc}(p_H)p_H]\overline{\Lambda} + \lambda\}, \text{ if } p_{m+j,t} = p_H. \end{cases} \tag{20}$$

Since a cascade can never be broken in this case, the only difference to an agent between receiving the low quality signal and the high quality signal is the difference between the respective probabilities of making the correct decision when not in a cascade state. Accordingly, signal quality improvement raises an agent's expected return by the amount $z_{m+j,t}^3 = \frac{1}{2}\pi_m^{nc}(p_H)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda})$. Observe that each of the terms $z_{m+j,t}^1$, $z_{m+j,t}^2$ and $z_{m+j,t}^3$ can be computed with the aid of (15) which establishes each of them to be a decreasing function of m. At $m = 0$, we have $\pi_0^{cc}(\cdot) = \pi_0^{ic}(\cdot) = 0$ and $\pi_0^{nc}(\cdot) = 1$ so that $z_{j,t}^1 = z_{j,t}^2 = z_{j,t}^3 = \frac{1}{2}(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda})$.

We are now in a position to derive the conditions under which different types of equilibria will emerge in the economy from the costly acquisition of information by all, some or no individuals. As before, we may determine from (7) the (ex ante) expected utility of each agent, exclusive of information costs, as $E(U_{m+j,t}) = V(k_t)E(Z_{m+j,t}) - b + u(b)$. Given this, together with the foregoing results, we arrive at the following characterisation of alternative outcomes.

Proposition 3 (i) $p_{m+j,t} = p_L$ for all $m = 0, 2, \ldots, N-2$ and all $j = 1, 2$ if and only if $\frac{1}{2}V(k_t)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) < \delta$;

(ii) $p_{m+j,t} = p_H$ for all $m = 0, 2, \ldots, N-2$ and all $j = 1, 2$ if and only if $\frac{1}{2}V(k_t)(p_H - p_H^2)^{\frac{N-2}{2}}(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) \geq \delta$;

(iii) $p_{m+j,t} = p_H$ for some $m = 0, 2, \ldots, N'-2$ and some $j = 1, 2$, where $N' < N$, if and only if $\frac{1}{2}V(k_t)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) \geq \delta > \frac{1}{2}V(k_t)(p_H - p_H^2)^{\frac{N-2}{2}}(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda})$.

Proof. i) Suppose that $p_{q,t} = p_L$ for all $q = 1, 2, \ldots, m+j-1$. For $\frac{p_H}{1-p_H} < \Psi$, the benefit to agent $m+j$ from an improvement in her signal quality is $V(\cdot)z_{m+j,t}^1$. If $V(\cdot)z_{m+j,t}^1 < \delta$, then she will forego such an improvement, in which case $p_{m+j,t} = p_L$ as well. Since $z_{m+j,t}^1$ is monotonically decreasing in m, it follows that $V(\cdot)z_{j,t}^1 = \frac{1}{2}V(\cdot)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) < \delta$ is a necessary and sufficient condition to ensure that $p_{m+j,t} = p_L$ for all $m = 0, 2, \ldots, N-2$ and all $j = 1, 2$. For $\frac{p_H}{1-p_H} > \Psi$, the benefit to agent $m+j$ from an improvement in her signal quality is $V(\cdot)z_{m+j,t}^2$. Since $z_{m+j,t}^2$ is also monotonically decreasing in m, then $V(\cdot)z_{j,t}^2 = \frac{1}{2}V(\cdot)(p_H - p_L)(\overline{\Lambda} - \underline{\Lambda}) < \delta$ provides the same necessary and sufficient condition to ensure that $p_{m+j,t} = p_L$ for all $m = 0, 2, \ldots, N-2$ and all $j = 1, 2$.

(ii) Suppose that $p_{q,t} = p_H$ for all $q = 1, 2, \ldots, m + j - 1$. The benefit to agent $m + j$ from an improvement in her signal quality is $V(\cdot)z^*_{m+j,t}$. If $V(\cdot)z^*_{m+j,t} \geq \delta$, then she will undertake this improvement, in which case $p_{m+j,t} = p_H$ as well. Since $z^*_{m+j,t}$ is monotonically decreasing in m, it follows that $V(\cdot)z^*_{N-2+j,t} = \frac{1}{2}V(\cdot)(p_H - p_H^2)^{\frac{N-2}{2}}(p_H - p_L)(\bar{\Lambda} - \underline{\Lambda}) \geq \delta$ is a necessary and sufficient condition to ensure that $p_{m+j,t} = p_H$ for all $m = 0, 2, \ldots, N - 2$ and all $j = 1, 2$.

(iii) Since $z^*_{m+j,t}$ is monotonically decreasing in m, then provided that $V(\cdot)z^*_{j,t} = \frac{1}{2}V(\cdot)(p_H - p_L)(\bar{\Lambda} - \underline{\Lambda}) \geq \delta > \frac{1}{2}V(\cdot)(p_H - p_H^2)^{\frac{N-2}{2}}(p_H - p_L)(\bar{\Lambda} - \underline{\Lambda}) = V(\cdot)z^*_{N-2+j,t}$, there exists an $N' \leq N - 2$ such that $V(\cdot)z^*_{N'+j,t} \geq \delta$. Thus $p_{m+j,t} = p_H$ for all $m = 0, 2, \ldots, N' - 2$ and all $j = 1, 2$, while $p_{m+j,t} = p_L$ for at least some $m = N', N' + 2, \ldots, N - 2$ and $j = 1, 2$. ■

As before, the general implication is that the greater (smaller) the difference between p_H and p_L, the greater the likelihood of there emerging an equilibrium in which all (none) of the population invest in the acquisition of better quality private information. In contrast to before, it is also now possible to obtain an equilibrium in which there is diverse behaviour among agents, some of whom engage in signal quality improvement and some of whom do not.

It follows from the above that there are two critical levels of the capital stock, k^c_l and k^c_h, which satisfy $\frac{1}{2}V(k^c_l)(p_H - p_L)(\bar{\Lambda} - \underline{\Lambda}) = \delta$ and $\frac{1}{2}V(k^c_h)(p_H - p_H^2)^{\frac{N-2}{2}}(p_H - p_L)(\bar{\Lambda} - \underline{\Lambda}) = \delta$, and which imply the following: $p_i = p_L$ for all $i = 1, 2, \ldots, N$ if $k_t \leq k^c_l$; $p_i = p_H$ for all $i = 1, 2, \ldots, N$ if $k_t \geq k^c_h$; and $p_i = p_H$ for some $i = 1, 2, \ldots, N$ if $k^c_l < k_t < k^c_h$. In accordance with (18), we may therefore write

$$k_{t+1} = \Psi(k_t, p(k_t)) = \begin{cases} \psi_l(k_t) = [(1-\alpha)A(MN)^{1-\alpha}k_t + b][\Phi(p_L) + \frac{1}{2}\lambda], & \text{if } k_t \leq k^c_l \\ \psi_h(k_t) = [(1-\alpha)A(MN)^{1-\alpha}k_t + b][\Phi(p_H) + \frac{1}{2}\lambda], & \text{if } k_t \geq k^c_h \end{cases} \tag{21}$$

where $0 < \psi_l(0) < \psi_h(0)$ and $0 < \psi_l'(\cdot) < \psi_h'(\cdot)$. Again, we may distinguish between two types of development regime for the economy - a low development regime in which all agents receive low quality signals, and a high development regime in which all agents receive high quality signals. Similarly, under the assumption that $\psi_h'(\cdot) \in (0, 1)$, we may identify two steady state levels of capital, $\hat{k}^*_l$ and $\hat{k}^*_h$, corresponding to the fixed points of the mappings $\hat{k}^*_l = \psi_l(\hat{k}^*_l)$ and $\hat{k}^*_h = \psi_h(\hat{k}^*_h)$. Given an initial capital stock, k_0, together with values for k^c_l and $\hat{k}^*_l$, we may then deduce exactly what outcomes will transpire in this type of informational environment. To facilitate comparison with our previous scenario, we refer the reader back to Figure 1. Observe that, for a given value of k_t, both $\tilde{g}_l(\cdot) > g_l(\cdot)$ and $\tilde{g}_h(\cdot) > g_h(\cdot)$ by virtue of our earlier result that the capital accumulation path is always higher when herd behaviour is a prospect than when it is not. Obviously, this implies that both $\tilde{k}_l^* > k_l^*$ and $\tilde{k}_h^* > k_h^*$.

Consider, first, the case in which $k_0 < k_l^c < \tilde{k}_l^*$. Under such circumstances, our imitation-prone economy will experience the same general evolution from a low development regime to a high development regime as our imitation-free economy did when $k_0 < k_l^c < k_l^*$. But the characteristics of the transition process are completely different in the two economies. In the absence of herd behaviour, this process entails a discrete jump from the low growth path, $g_l(\cdot)$, to the high growth path, $g_h(\cdot)$, as soon as k_t reaches k_l^c, at which point all agents invest in signal quality improvement. In the presence of herd behaviour, the process occurs continuously along a smooth trajectory that connects $\tilde{g}_l(k_l^c)$ with $\tilde{g}_h(k_h^c)$ (as indicated by the broken line) since not all agents find it optimal to improve signal quality at the same time, and information acquisition takes place gradually among the population as capital accumulation continues to take place. Given that $g_h(\cdot) > \tilde{g}_l(\cdot)$, it follows that there must be an intermediate period during which our imitation-prone economy is on a lower accumulation path than is our imitation-free economy. Thus the transition process between development regimes can be very different according to whether or not herd behaviour is a prospect: if it is, then this process will be relatively smooth and the gains in prosperity will occur relatively late. Other, more acute, differences can be identified under other circumstances. For example, if one assumes that $k_0 < k_l^* < k_l^c < \tilde{k}_l^*$, then our imitation-free economy will become irrevocably destined for the low steady state equilibrium, k_l^*, while our imitation-prone economy will still undergo transition to the high steady state equilibrium, $\tilde{k}_h^*$. To this extent, the prospect of herd behaviour makes poverty traps less likely.[12]

[12] This result can be stated in a slightly different way by considering the case in which $k_0 < k_l^* < \tilde{k}_l^* < k_l^c$. Define p^c and $\tilde{p}^c$ as the signal probabilities for which $G(k_l^c; p^c) = \tilde{G}(k_l^c; \tilde{p}^c) = k_l^c$. Since $G(\cdot) < \tilde{G}(\cdot)$ otherwise, and since both functions are increasing in p, then it must be true that $p^c > \tilde{p}^c$. Consequently, $G(k_l^c; p_L) < k_l^c \leq \tilde{G}(k_l^c; p_L)$ for any $p_L \in (\tilde{p}^c; p^c)$, in which case we have exactly the same result as above concerning the destinies of our two economies.

5 Conclusions

The general aim of this paper has been to study the role of information in determining the growth and development prospects of economies. We have sought to do this by comparing and contrasting the macroeconomic implications of alternative informational scenarios in a simple model of growth based on technology adoption. One aspect of our analysis has centred on the consequences of allowing endogenous changes in the quality of information (signal precision) for a given informational structure (signals only, or signals plus actions). Making such allowance gives rise to multiple development regimes through the mutual dependence between information acquisition and economic activity. Another aspect of our analysis has focused on the e¤ects of changes in the information structure for a given quality of information. Changing from a structure based on signals only to one based on signals plus actions alters the equilibrium path of capital accumulation by introducing the possibility of herd behaviour.

Collectively, our results suggest that the process of development in an imitation-prone economy may be very di¤erent from that in an imitation-free economy. There are two reasons that account for this di¤erence. The …rst is that decisions taken in an environment where agents are able to observe the actions of others are decisions based on a larger information set than those taken in an environment where actions are unobservable. Better informed agents are more likely to make decisions that are correct and, for a given signal quality, to produce better aggregate outcomes. The second reason is that the rate at which resources might be channelled into improving signal quality is very di¤erent in each of the environments: in the case of the former, this improvement is embarked upon by di¤erent agents at di¤erent times, inducing a gradual transition between development regimes; in the case of the latter, the improvement is undertaken by di¤erent agents at the same time, causing an abrupt transition between development regimes. Up to a certain level of development, the total volume of resources invested in information acquisition is lower when transition is smooth than when it is discontinuous. As such, an imitation-prone (imitation-free) economy, while being populated with relatively well-informed (ill-informed) agents, displays an overall capital accumulation path that is relatively low (high) during the intermediate stages of transition but relatively high (low) during later stages.

Our results may be seen as providing additional insights into the issue of cross-country convergence and the question of why some countries may permanently lag behind others. For example, a frequent observation of developing economies is that many types of extremely remunerative investment opportunities are often foregone, even though the returns on other investment projects are typically quite low (e.g., McKinnon 1973). A common account of this in the past has involved appealing to capital market imperfections and the lack of financial development in poor economies. A different interpretation, based on our own analysis, is that such economies are likely to be saddled with inferior investment decisions as a result of poor quality information which, in some circumstances, may lead investors to jump on the wrong bandwagon.

Although we have not considered policy explicitly, our analysis naturally invites one to think of policies which may be able to affect the path of development by changing the quality or type of information available to agents. For example, public investment in education and training may lead to greater signal precision by enhancing agents' abilities to understand and evaluate the economic environment. In general, any policy that is capable of raising signal quality has the potential not only to stimulate growth in the short-term, but also to push the economy permanently onto a higher growth path altogether. An alternative type of policy might be one that encourages the public disclosure of information about individuals' actions that would otherwise remain unobservable. To the extent that this would foster herd behaviour, the effect would be to smooth an economy's transition between development regimes, with better outcomes in the long-run having to be traded-off against poorer outcomes in the short-run.

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