Information, Coordination, and the Industrialisation of Countries*

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Preliminary Version

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Abstract

The industrialisation process of a country is often plagued by a failure to coordinate firms' investment decisions. Using the Global Games approach we can solve this coordination problem and eliminate the problem of multiple equilibria. We show how appropriate information provision enhances efficiency. We argue that subsidies may be a property of a signalling equilibrium to overcome credibility problems in information provision. We point at possible problems with overreaction to public information and sequencing of the industrialisation process. Furthermore we suggest a new focus for development policy.

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1 Introduction

Industrialisation of an economy is widely considered as central for its lasting development. All now developed countries went through a phase of industrialisation at one point in their history. The UK did so in the early 19th century, the US, Germany and France in the second part of the 19th century. And the Asian Countries industrialised before - as in the case of Japan - or after the 2nd world war as South Korea, Singapore or Taiwan[1]. But apparently not all countries manage to enter this process and so initially similar countries take very different courses of development. Whereas industrialised economies tend to grow faster and more sustainably, the non-industrialised economies lag behind. Therefore it is often argued that industrialising countries is an integral part of a good development policy.

Why there are some countries that manage to industrialise while there are at the same time apparently similar countries that fail to do so has been explained by the possible presence of multiple equilibria. In a pioneering work Rosenstein-Rodan (1943) argued that industrialising a country only works if many sectors at once are industrialised as one industrialised sector alone would not be available to earn profits. Hence he argued for a "Big Push".

He argued that one firm's decision to invest to industrialise a sector had positive effects on other firms' profits from investing to industrialise other sectors. Using game

[1]This is of course by no means an exhaustive list of all industrialised economies but features just some prominent examples.

theoretic vocabulary investors' decisions to industrialise a sector are strategic complements, i.e. one investor's expected profit increases in the other's decision to invest. Consequently there are multiple equilibria. Simplifying, if nobody invests it is optimal not to invest either. If everybody else invests it is optimal to invest as well. So the observation that some countries did not industrialise can - ceteris paribus - be explained by a failure to coordinate.

This idea has been formalised by Murphy, Shleifer and Vishny (1989) who have shown under which conditions this multiplicity of equilibria can arise, i.e. what the nature of these strategic complementarities driving this result is. In their paper the effects on domestic markets account for this effect. More firms investing in a country create a domestic market with higher demand and more purchasing power and as a consequence higher profits for firms[2].

We use Murphy, Shleifer and Vishny (1989) as a starting point for our analysis but alter and extend their model in several respects. Basically their paper serves as our justification for assuming strategic complementarities between firms' investment decisions.

We alter their model in several respects and use the Global Games approach to solve the aforementioned coordination problem. We show how appropriate information provision enhances efficiency and argue that subsidies may be a property of a signalling equilibrium to overcome credibility problems in information provision. Then we extend

[2]Recently Hoff (2001) has shown that these effects persist in open market economies, too.

the model and point out possible problems with overreaction to public information and suggest a sequence for the industrialisation process. Again there is a role for subsidies in equilibrium.

Our first major departure from Murphy, Shleifer and Vishny (1989) is to assume that the expected profit of a firm does not only depend on the number of other firms investing, which we believe is a fairly strong assumption. In general it will be the case that the profit of an investment in a country depends on many other factors like the political stability of the country, its degree of openness, the quality of contract enforcement or the existing infrastructure. Simplifying we summarise these factors in one variable: a country's "quality".

Dependent on this quality we assume that there exist three distinct categories of countries. There are very "low quality" countries where investing never pays even if all investors would manage to coordinate. For these countries there exists a unique equilibrium in which nobody invests. Think of areas with long lasting political unrest or even civil wars like some states in Sub Saharan Africa.

In "high quality" countries in contrast an investment pays off even if nobody else is going to invest. Therefore here the unique equilibrium has everybody investing. Examples could be the former Eastern Bloc states of Eastern Europe with a well trained labour force like for example the Czech Republic.

Only for countries of mediocre quality the above discussed problem of multiple equilibria persists, as there the number of others investing determines whether or not an

investment is worthwhile. One might well argue that a large fraction of countries lies in that intermediate region and is therefore plagued by this coordination problem.

Our second major departure from Murphy, Shleifer and Vishny (1989) is that we relax the assumption that the quality of a country is common knowledge but introduce private information. Although there may be a lot of publicly observable data on a country's quality, potential investors are likely to interpret these observed facts in a slightly different manner. Think of the different firms' research departments producing country reports. Another interpretation is that a potential investor requesting information from a country never can be sure whether he gets the same information as other potential investors. That is, agents receive private signals over a country's quality.

Summing up, our set-up has the following features: 1) The payoff of the agents' actions depends on an underlying variable, i.e. the country's quality. 2) The players hold private information on the true quality of a country. 3) The players' actions are strategic complements, and for some intermediate levels of quality there is a coordination problem. These features make our set-up suitable to apply the techniques of the Global Games Approach, which was pioneered by Carlsson and vanDamme (1993) and further extended by Morris and Shin (1998)[3].

This approach can be used to eliminate multiple equilibria in a setting like ours described above. And it has the additional attractive feature that it opens the scope

[3]Like Morris and Shin (1998) most applications of the Global Games Approach are set in financial markets or currency crises models. We think our paper is the first to use this approach in a development context.

for an interesting policy tool to mitigate the coordination problem - the provision of information.

The Global Games approach starts from the insight that the basic problem in coordination problems is the Knightian nature of the strategic uncertainty, i.e. players cannot assign probabilities to different events (here other players' actions). Conventional game theory deals with this problem by only analysing equilibrium behaviour, where there is no problem as players' actions are perfectly correlated. Introducing private information renders common knowledge infeasible and turns the Knightian uncertainty into Bayesian uncertainty and so agents can form expectations over gains and losses from their actions. So we get an additional equilibrium constraint that allows us to eliminate multiple equilibria and end up with a unique equilibrium prediction.

Morris and Shin (2002b) show for coordination problems like ours that it is possible to derive a unique threshold for the agents' beliefs about the value of the underlying variable (in our model the country's quality), which determines whether or not they take a specific action. This threshold in turn depends on the agents' private information. In terms of our model that says that if and only if the potential investors believe the country's quality to be above this threshold are they going to invest. If they receive a signal below this threshold they don't invest. Therefore there is no longer a problem of multiple equilibria.

While that might have some appeal from a theoretical point of view – as we now can predict the equilibrium of the game – it does not help too much in terms of

providing policy advice. In general the threshold for the signal will be somewhere within the region of medium quality countries. That is there are countries that are below that threshold but are still in the region where industrialising is efficient as long as coordination is ensured.

Fortunately the Global Games Approach allows us to do more than just equilibrium refinements. An "appropriate" information policy can reduce the inefficiency arising from an inappropriate threshold. So while Murphy, Shleifer and Vishny (1989) suggested subsidising investments in order to overcome the coordination problem, we now offer another more appealing way to deal with the problem. Providing information in the right way mitigates the problem and achieves a more efficient allocation.

A natural question to ask is who should provide information. The apparently obvious answer is the government. But one can well argue that governments have misguided incentives in this context. They may prefer to have their country industrialised even if it is in the poor quality region where it is not efficient to do so. The reason for the government's preference for an industrialised economy may be guided by benevolent motives towards its citizens, or by bribes or other perks it can collect more easily. So a credibility problem arises.

One way to cope with that would be to transfer the provision of information to intermediaries that do not have a direct interest in the outcome. Rating agencies or international bodies like the Worldbank or the IMF could be seen as such institutions. Another solution would be to find ways for the government to credibly signal the

country's true quality. In this context there may again be some scope for subsidies but now with a quite different notion than in Murphy, Shleifer and Vishny (1989). Here the government does not take away the financial risk of a coordination failure from the firm but subsidies are an equilibrium property of a signalling game. If it is easier for a high quality country to recoup subsidies than for a low quality country, subsidies are a less costly signal for such a high quality country. These differing signalling costs allow for a separating equilibrium. That is subsidies might again be a second best policy instrument. This is also the case when they are used in a sequential game to first attract key investors. This is discussed in one of our extensions.

Another fact should not be overlooked. In our set-up countries exist which should not be industrialised from an efficiency point of view as their "quality" is simply too poor for an investment to pay off. This again points at a specific role for development policy: Improving those countries' "quality", i.e. creating political stability, improving the enforceability of contracts, etc., opens up the possibility for those economies to become industrialised and thus develop faster.

The remainder of the paper is structured as follows: Section 2 discusses the assumptions and develops the basic model. In section 3 we deal with the problem of multiple equilibria and derive the unique equilibrium threshold. In section 4 we analyse the scope for efficiency enhancing informational policy and in section 5 we discuss credibility problems and possible solutions associated with this informational policy. Section 6 deals with two extensions of the model. First we introduce heterogeneous agents and a

dynamic structure, then we allow for a richer informational structure. Furthermore we discuss possible objections to our model before we conclude in section 7. The appendix contains the proofs.

2 The Model

There is a continuum of firms with mass 1. Each firm can decide whether to invest in one sector of a non–industrialised country or not. If one firm invests in a sector this sector is called industrialised. The industrialisation of the country is only profitable and successful – at least for medium "qualities" – if sufficiently many sectors are industrialised. We assume there are no coordination problems among firms in what sector to invest[4].

Each firm i's profit depends on the share α of other firms investing in the country and on the quality z of a country. This dependence on the share of other firms investing follows the line of Murphy, Shleifer and Vishny (1989).

We think of the quality z in very broad terms and subsume basically all factors which are important for successful investment in it. On the one hand we think of institutional features like political stability, quality of contract enforcement, or security of property rights. But also the existing infrastructure[5] and the stock of human capital could be

[4]Relaxing this assumption would considerably complicate the analysis without contributing to a better understanding of the problem.

[5]Although the analysis in Murphy, Shleifer and Vishny (1989) suggests that a well developed

subsumed in it.

Each firm has to bear fixed costs C of investing. The profit of an investing firm is therefore given by

$$\Pi = \pi(z, \alpha) - C, \tag{1}$$

with $\frac{\partial \pi}{\partial z} > 0$ and $\frac{\partial \pi}{\partial \alpha} > 0$.

$\frac{\partial \pi}{\partial \alpha} > 0$ expresses the fact that firms' investment decisions are strategic complements.

Furthermore we impose that

$$\frac{\partial^2 \pi}{\partial z \partial \alpha} > 0. \tag{2}$$

This states that there is complementarity between z and α, i.e. the effect on profit of having more firms investing is stronger in economies of higher quality[6].

If the firm does not invest its profit is normalised to 0.

z is uniformly distributed between $\underline{z}$ and $\bar{z}$, where $\underline{z}$ denotes very low quality and $\bar{z}$ very high quality[7]. Moreover we impose two additional assumptions:

$$\exists \breve{z} > \underline{z} \qquad s.t. \qquad \pi(z, 1) < C \qquad \forall z \leq \breve{z}. \tag{3}$$

This means that there exists a threshold such that for every value of z below $\breve{z}$ it does

infrastructure is a property of equilibrium in our game as in an industrialised economy it is possible for a monopolist to profitably provide infrastructure.

[6]We need this assumption for our proofs to go through. However, we do not feel that this assumption is especially unrealistic.

[7]It is in principle possible to allow for more general informational structures. See e.g. Morris and Shin (2002b). However, to ease the exposition we stick to this simple setting.

not pay for firm i to invest because the quality is so bad that it would make losses even if all other firms would invest. Therefore it is a dominant strategy not to invest in this region.

$$\exists \hat{z} < \bar{z} \qquad s.t. \qquad \pi(z, 0) > C \qquad \forall z \geq \hat{z}. \tag{4}$$

If quality is above $\hat{z}$ it pays for firm i to invest even if it is the only one to do so and it is therefore a dominant strategy to invest. This may be motivated by export oriented industrialisation where a country's quality may lie in well established trade links, a reputation as a reliable trading partner or a good transport system.

To make the problem interesting assume $\check{z} < \hat{z}$. Now we have two regions with dominant strategies at the extremes of the support and only for the intermediate region $z \in [\check{z}, \hat{z}]$ the initial coordination problem persists. We will call the region above $\hat{z}$ and below $\check{z}$ henceforth the "dominance regions". If there is common knowledge on the true quality of the country we have two equilibria in this region where either all firms invest or no firm invests.

Figure I

Now we introduce private information. Each player i knows the support and distribution from which the realisation of z is drawn but has only a noisy signal z^i of the true value of z. These signals are only privately observable.

The signal z^i is uniformly distributed between $[z - \epsilon, z + \epsilon]$[8]. All private signals are independent. Furthermore it is common knowledge that every firm receives such a private signal[9].

Each firm can now decide dependent on z^i whether or not to invest or whether to play a mixed strategy over the two alternatives. The strategy of firm i is therefore a function $s^i(z^i) : [\underline{z}, \bar{z}] \rightarrow [0, 1]$.

Now we have a complete description of the game and can start to analyse the equilibrium.

[8]This modelling is based on Morris and Shin (1998). Again richer information structures are possible. See e.g. Morris and Shin (2002b).

[9]It is possible to allow for heterogeneity among firms with respect to the quality of the private signals, i.e. have better or less well informed firms.

3 Uniqueness of Equilibrium

It can be shown that there exists a unique Bayesian Nash Equilibrium in the game with private information. In this equilibrium firms invest if and only if their signal is above a threshold $z^\star$. To show that we first assume that every firm follows a simple switching strategy and invests if and only if it receives a signal above a threshold k[10]. Now assuming that everybody else uses such a switching strategy one can calculate expected profits of investing or not investing given certain signals. Then iterated elimination of dominated strategies starts.

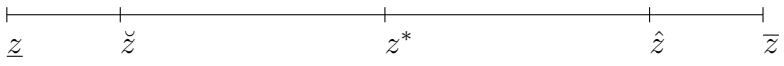

Figure II

If one gets a signal close to one of the dominance regions there is a positive probability that some other players received a signal in the dominance region and therefore have a dominant strategy. This is enough to ensure that one has oneself a dominant strategy, too. Iterating this process starting from both dominance regions eventually results in a unique threshold where a firm is just indifferent between investing and not investing. The following equation

$$\Pi^i(z^\star, I_{z^\star}) = \frac{1}{2\epsilon}\int_{z^\star-\epsilon}^{z^\star+\epsilon} \pi(z, \alpha(z))dz - C = 0$$

[10]By continuity arguments it is easy to show that indeed such a simple switching strategy is optimal. That is, imposing it in the first place is without loss of generality.

captures that the the expected profit from investing has to equal the fixed investing cost C. Thereby the threshold is implicitly defined. This finding is captured in the following proposition.

Proposition 1 *There exists a unique threshold $z^\star$ where all firms with $z^j < z^\star$ do not invest and all firms with $z^j \geq z^\star$ invest.*

Proof The proof can be found in the appendix.

Note that the expected profit from investing - and therefore the equilibrium threshold $z^\star$ - depends on the precision ϵ of the private signal.

By applying the Global Games Approach we have got rid of the multiplicity of equilibria and can make unambiguous predictions for the outcome of the game, i.e. the industrialisation process. This outcome depends on the underlying quality of the country **and** on the precision of the private signal. Although that might be interesting from a theoretical point of view so far we have not gained much from a policy point of view. But fortunately this is not all that can be done.

4 Scope for Informational Policy

A more "transparent" information policy increases the chances to ensure industrialisation of a country. Why is that? As pointed out earlier, the location of the threshold

depends on the precision of the private signal[11]. Fortunately this dependence is locally monotonic and is a property of the equilibrium threshold[12].

But what does more transparency mean? The argument is that if more data are made available, if generation and sources of information are easily comprehensible, the quality of the private signals, generated on basis of these data, increases.

The above finding that transparency increases the chances of industrialisation is captured in the following Lemma.

Lemma 1 *In equilibrium it holds that* $\frac{\partial z^\star}{\partial \epsilon} > 0$.

Proof The proof can be found in the appendix.

This Lemma says that the location of the threshold depends on the precision of private information. The precision of the private signals can be expressed with ϵ. A higher ϵ means a bigger support of the distribution of signals and therefore a higher variance. If ϵ decreases the private signals get more precise and the threshold shifts to the left, i.e. for more values of z it is now a dominant strategy to invest. From an ex ante perspective the probability of industrialisation increases.

But this implies that a country can make up for inferior innate quality by a superior information policy, i.e. by providing more precise information. To illustrate this

[11] Heinemann and Illing (2002) analyse – in a Morris and Shin (1998) framework – a similar situation. In their model a central bank tries to minimise the risk of a speculative attack on a currency.

[12] Unfortunately however this feature does not necessarily carry over to richer informational structures. E.g. Morris and Shin (1999b) discuss problems with normally distributed states and errors.

consider two countries A and B where A's quality is slightly worse. If A now provides sufficiently better information – in terms of precision – it is more likely for A to be industrialised than for B. This is captured in the following proposition.

Proposition 2 *Sufficiently more precise information policy can compensate for innate quality disadvantages.*

Proof The proof can be found in the appendix.

This now gives scope for an additional policy instrument. To reach a more efficient situation a country no longer has to rely only on undifferentiated subsidies but informational policy can be used to increase efficiency.

5 Credibility of Information

Now we know that informational policy can be used to enhance efficiency. But the question arises how that policy should be performed and who should provide this information. The straightforward answer seems to be national governments. But one can easily argue that these governments have misguided incentives. They may strictly prefer their country to be industrialised, either for benevolent reasons as raising standards of living or for the fact that they can collect bribes or taxes from industries. Therefore they may provide wrong, i.e. too positive, information in order to attract investors.

There are two possible ways of doing this. On the one hand a country can simply

withhold disadvantageous information and it may well be impossible to observe whether or not information has been withheld. On the other hand it may be possible to simply make up good news without the possibility of this window dressing being exposed. Therefore credibility of information is a serious problem here[13].

One approach could be to rely on external bodies to provide this information. External bodies are institutions that have no such credibility problems as national governments. One could think of the World Bank, the UN or the IMF as such institutions[14]. Another approach could be to resort to market institutions like rating agencies in financial markets[15]. These companies make their money from their reputation of providing reliable information. Indeed such institutions exist and offer very detailed information on numerous variables such as political stability or the quality of the judicial system. The "Economist Intelligence Unit"[16] or the "International Country Risk Guide"[17] are only two examples.

[13]Milgrom (1981) has shown that this is not the case if the only way of lying is to omit negative information and agents can observe omittance. By holding very pessimistic beliefs upon observing omittance in equilibrium all relevant information is revealed. However the environment here is more hostile.

[14]People feeling uneasy with the assumption that these bodies have a less dubious incentive structure are offered two arguments. The first is that – at least in principle – a benevolent mechanism designer could solve the incentive problems in these institutions and the second – probably more attractive – can be found in the last paragraph of this section.

[15]Although recent experience may render that doubtful as well.

[16]http://www.eiu.com/

[17]http://www.icrgonline.com/

An economic theorist however might resort to another solution to this credibility problem. If states could at some cost signal their true quality (and if the different qualities differed in their costs of signalling) it would be possible to separate countries according to quality.

Subsidies are such an instrument. The "better" a country the more likely it is that this country is able to recoup the subsidies over time through taxing the firms' profits or higher tax revenues in the whole economy. Reversely, the lower the quality of a country, the less likely it is to recoup these subsidies, i.e. the more costly it is for a low quality country to mimic a high quality country by offering generous subsidy schemes to investing firms.

Along this line of reasoning it is possible to explain observed subsidies not as ad hoc policy measures but as an equilibrium property of a signalling equilibrium[18].

Some people might claim that it is not at all clear that bodies like the World Bank have the right incentives to provide information. In this context one could interpret World Bank loans as a costly signal of a country's quality, too. If one talks to practitioners in the field and follows the political discussion this signal character of World Bank loans or IMF programs seems to be one of the most important features of these credits or programs respectively.

[18]Ongoing research is dedicated to a formal analysis of the above signalling game which will be included in the next versions of this paper.

6 Extensions and Discussion

Our model so far hinges on quite rigid assumptions. In this section we will discuss two extensions that make the model more realistic in important dimensions. Whereas the first deals with the idea of leaving the static framework with homogeneous agents and analysing industrialisation as a dynamic process with heterogeneous agents the second extension allows for a richer informational structure by adding additional publicly observable signals.

Dynamic Structure and Heterogeneity

Suppose there are many small investors and one big investor. A big investor could be interpreted as a firm industrialising a key sector of the economy and having a relatively large impact on marginal profits of other, smaller, firms[19][20]. One can show that the very presence of such a big investor makes the small investors more "aggressive", i.e. they invest more easily.

In our terms one could phrase it such that the small investors now invest at lower quality levels than they did without the big investor. If one also takes into account that big and small investors might be differently informed one gains further insights. If the large investor is better informed – and if that is common knowledge – the above mentioned effect is strengthened. If its information is worse the effect is dampened.

[19] Corsetti et al. (2002) have analysed a similar model in a currency crises setup.

[20] Another interpretation would be to view the big investor as a private firm providing infrastructure like railways or electricity, via this channel having a big impact on other firms' profits. Reading the model that way would deliver infrastructure as an equilibrium property (see footnote 5 in this paper).

If we moreover allow for a dynamic structure where the big player's decision to invest or not is publicly observable the effects are further strengthened. If the large investor is better informed and has the first move the small players follow almost blindly.

Again that bears policy implications. One should give key investors preferred access to information and this should be publicly known. Also one could aim to get key investors to decide first and settle down and make these decisions as public as possible. Again subsidies for such key sectors could be a viable instrument and such things are indeed quite commonly observed.

Additional Signals

Now we return to the basic model with homogeneous small traders but depart in another direction. Now we allow for a richer information structure. Each firm observes not only a private signal but also a public signal[21]. It can be shown that firms react stronger to the public signal than its precision would suggest. But this type of "over reaction" can be easily rationalised.

A public signal triggers two effects. On the one hand it conveys information as a private signal does, on the other hand it has a "coordination effect" as everybody now knows something about other players' information and can infer something about other players' dominant strategies. It is the latter coordination effect that triggers the "over reaction" to public signals.

This, too, could be used as a policy instrument. Revealing information publicly can

[21]This situation was first studied by Morris and Shin [2002a].

enhance efficiency. And the "over reaction" gives a high leverage to this instrument. However this effect can be dangerous as well. Even if the provided public signals are not very informative they can have large effects. So just by creating "noise" one might trigger large reactions. Therefore it is important to be careful when releasing public information.[22]

As a general rule one could take away that if one reveals information publicly then it should be sufficiently precise relative to the privately observable signals as otherwise possibly detrimental coordination effects can outweigh possible gains. Another caveat of course is the earlier discussed possibility of credibility problems with publicly provided information.

Discussion

Most of the existing literature on Global Games deals with phenomena on financial markets. One obvious criticism to our paper is to argue that industrialisation processes are in some sense more complex than investment decisions in financial markets. Exogenous variables, i.e. the quality of the country, may be more complex and more crucial for the overall success of investments in industrialising than in speculating against currencies.

[22]We are looking for evidence of detrimental effects of low quality public signals. What we could expect are things like the following: The 1994 Mexican Tequila crisis or the 1997 Asian crisis could be interpreted as signals that "investments in emerging / developing markets are not without risk". Although these signals have not much informational value we would expect a drop in investments in other emerging or developing countries in the aftermath of these crises, even if they were not affected by the original crises.

Still we believe that does not preclude the fact that we gain insights in the underlying economic effects. But we have to pay attention to what we take away from the model and how we evaluate the policy advice derived from the analysis.

7 Conclusion

In this paper we analyse how to deal with multiple equilibria occuring in the industrialisation of countries. We augment the seminal paper by Murphy, Shleifer and Vishny (1989) with an additional variable, the quality of a country. To this somewhat richer model we apply the Global Games Approach. Thereby we are able to eliminate the multiplicity of equilibria and end up with a unique equilibrium prediction dependent on the quality of the country. We show how the right information provision, namely more precise private signals, can enhance efficiency. It is argued that subsidies may be a property of a signalling equilibrium to overcome credibility problems in this information provision. We point at possible problems with overreaction to public information and suggest a sequence for industrialisation.

An interesting and natural next step would be to explicitly model the credibility problem in the provision of information and to rigorously analyse the resulting signalling game. Another desirable extension is to explicitly model the sequential game with a large investor and to analyse properties of equilibrium subsidies more rigorously.

Although, as pointed out in section 7, we think one has to be careful to use the

model directly as sole basis for policy advice we firmly belief that information plays a non trivial role in the industrialisation process. Much would be gained if attention was paid to that in development policy.

Another fact should not be overlooked. In our set-up countries exist which should not be industrialised from an efficiency point of view as their "quality" is simply too poor for an investment to pay off. Which again points at a specific role for development policy: Improving those countries' "quality", i.e. creating political stability, improving the enforceability of contracts, etc., opens up the possibility for those economies to become industrialised and thus develop faster.

Our paper can be seen as an additional argument that providing an appropriate investment environment should be the focus of development policy. And if we need subsidising, it has to be the right kind of subsidies – informative ones.

8 Appendix

Proof of Proposition 1

Proof 1 [23] *The profit of firm i depends on the fraction of other firms investing α^{-i}. This fraction can be written as*

$$\alpha^{-i} = \int_0^1 s^j(z^j)dj \qquad i \neq j.$$

[23] The proof is similar to the one in Morris and Shin (1998, 2002b).

The expected profit of firm i if it gets signal z^i and invests is therefore

$$\Pi = E[\pi(z^i, \alpha^{-i}(z^j)) - C \mid z^i]. \tag{5}$$

Call I_k a threshold strategy where each firm invests only if its private signal is above k,

$$I_k(z^i) = \begin{cases} 1 & \text{if } z^i \geq k \\ 0 & \text{if } z^i < k \end{cases}$$

If each player plays such a switching strategy I_k then the expected profit of an investing firm i can be written as

$$\Pi^i(z^i, I_k) = E[\pi(z,1) \mid z^i] prob(z^j \geq k \mid z^i) + E[\pi(z,0) \mid z^i] prob(z^j < k \mid z^i) - C. \tag{6}$$

For the next step of the proof it is necessary to show that $\Pi(z^i, I_k)$ is strictly increasing. This can be done in the following way:

First we can write (6) as

$$\Pi^i(z^i, I_k) = E[\pi(z,1) - \pi(z,0) \mid z^i] prob(z^j \geq k \mid z^i) + E[\pi(z,0) \mid z^i] - C. \tag{7}$$

Since we know that $E[z \mid z^i] = z^i$ and because of (2) we have

$$\frac{\partial E[\pi(z,1) - \pi(z,0) \mid z^i]}{\partial z^i} > 0.$$

Since $E[z^j \mid z^i] = z^i$ and z^j is triangular distributed on $[z^i - 2\epsilon, z^i + 2\epsilon]$ we have

$$\frac{\partial prob(z^j \geq k \mid z^i)}{\partial z^i} \begin{cases} = 0 & \text{if } k < z^i - 2\epsilon \text{ and } k > z^i + 2\epsilon \\ > 0 & \text{if } z^i - 2\epsilon \leq k \leq z^i + 2\epsilon. \end{cases}$$

Therefore the first term of (7) is weakly increasing in z^i. It also holds that

$$\frac{\partial E[\pi(z,0) \mid z^i]}{\partial z^i} > 0 \qquad \forall z^i.$$

Thus the second term of (7) is strictly increasing in z^i *and therefore* $\Pi(z^i, I_k)$ *is strictly increasing in* z^i*.*

We can now start with the iterative elimination of strictly dominated strategies. We know from our assumptions that there must be signals $\underline{z}_0$ *and* $\bar{z}_0$ *with*

$$E[\pi(z,1) \mid \underline{z}_0] = C \qquad E[\pi(z,0) \mid \bar{z}_0] = C.$$

Because of $\Pi(z^i, I_k)$ *strictly increasing in* z^i *there exists signals* $\underline{z}_1 \geq \underline{z}_0$ *and* $\bar{z}_1 \leq \bar{z}_0$*, such that*

$$\Pi(z, I_{\underline{z}_0}) < 0 \qquad \forall z < \underline{z}_1 \qquad \textit{and} \qquad \Pi(z, I_{\bar{z}_0}) > 0 \qquad \forall z > \bar{z}_1.$$

We can apply iterative elimination further and since the convergence $(\underline{z}_n)_{n\in\mathbf{N}}$ *is increasing and* $(\bar{z}_n)_{n\in\mathbf{N}}$ *is decreasing there exists limit values* $\underline{z}^\star = lim_{n\to\infty}\underline{z}_n$ *and* $\bar{z}^\star = lim_{n\to\infty}\bar{z}_n$*. For this values it holds that*

$$\underline{z}^\star = min\{z \mid \Pi(z, I_z) = 0\} \qquad \textit{and} \qquad \bar{z}^\star = max\{z \mid \Pi(z, I_z) = 0\}.$$

The values $\underline{z}^\star$ *and* $\bar{z}^\star$ *are the lowest and the highest solution of the equation* $\Pi(z, I_z) = 0$*. This equation can also be written as*

$$E[\pi(z,1) - \pi(z,0) \mid z^i = z^\star] prob(z^j \geq x \mid z^i = z^\star) + E[\pi(z,0) \mid z^i = z^\star] = C. \qquad (8)$$

Since $z^j \mid z^i$ *is triangular distributed between* $(z^i - 2\epsilon, z^i + 2\epsilon)$ *and therefore* $prob(z^j \geq z^\star \mid z^i = z^\star) = \frac{1}{2}$*. Thus (8) can then be written as*

$$E[\pi(z,1) - \pi(z,0) \mid z^i = z^\star] = 2C. \qquad (9)$$

The right hand side of (9) is constant while the left hand side is strictly increasing because of (2)*. Therefore it exists a unique value of* $z^\star$*.* ■

Proof of Lemma 1

Proof 2 [24] *In equilibrium the value* $z^\star$ *is defined by*

$$\Pi^i(z^\star, I_{z^\star}) = \frac{1}{2\epsilon}\int_{z^\star-\epsilon}^{z^\star+\epsilon} \pi(z, \alpha(z))dz - C = 0. \tag{10}$$

Totally differentiating (10) and using the facts that $\alpha(z^\star+\epsilon) = 1$ *and* $\alpha(z^\star-\epsilon) = 0$ *we get*

$$\frac{\partial z^\star}{\partial \epsilon} = \frac{2C - \pi(z^\star+\epsilon, 1) - \pi(z^\star-\epsilon, 0)}{\pi(z^\star+\epsilon, 1) - \pi(z^\star-\epsilon, 0)}. \tag{11}$$

Since the denominator of (11) is always positive $\frac{\partial z^\star}{\partial \epsilon}$ *is only* > 0 *if* $2C > \pi(z^\star + \epsilon, 1) + \pi(z^\star-\epsilon, 0)$*. From (10) we know that* $\frac{1}{\epsilon}\int_{z^\star-\epsilon}^{z^\star+\epsilon} \pi(z, \alpha(z))dz = 2C$*. Therefore the numerator is positive if*

$$\int_{z^\star-\epsilon}^{z^\star+\epsilon} \pi(z, \alpha(z))dz - \epsilon\{\pi(z^\star+\epsilon, 1) + \pi(z^\star-\epsilon, 0)\} > 0.$$

To be concluded...■

Proof of Proposition 2

Proof 3 Follows immediately from Lemma 1.■

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[24] The proof is similar to the one in Heinemann and Illing (2002).

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