A stigmergic model of development aid: investigating herding and volatility in aid allocations

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Aid allocation, both bilateral and multilateral is known to be volatile. Herding amongst donor countries creates so-called donor darlings and aid orphans, which result in inefficient aid allocations. In this article we describe a mathematical model, known as a stigmergic interaction model, useful for investigating herding and volatility in aid allocation.

I. BACKGROUND TO AID ALLOCATION

To what extent international development aid (aid, henceforth) promotes growth, increases global welfare or reduces poverty are of central concern to policy makers and quasi governmental aid agencies. In addition to these considerations, the consequences of aid allocations and how donor countries allocate aid (optimally) remains active areas of research [1].

In this study, we formulate the aid allocation problem as a stigmergic game [2], and investigate the emergent structures as a function of the various strategies utilised by donor countries. In particular we show how aid fragmentation and herding [3] may result as a consequence of donor strategies. Induced aid transfers are represented using a bipartite network of donor (D) and recipient (R) countries, with nodes representing countries and edges representing aid relationships.

A novel feature of the model is the incorporation of migration flows into the stigmergic model. It is well-documented that economic migration takes place from developing countries to those with sophisticated and mature economies. While modelling the full impact of economic migration from developing economies to donor countries is beyond the scope of this article, we consider a simplified framework where it may be cost-effective for donor countries to provide aid in an effort to make migration a less attractive option, relative to domestic opportunities, for migrant workers.

The available literature on developmental aid highlights the considerable diversity in factors relevant to the decision making process. While economic factors and indicators of poverty play an important role, other donor-specific considerations such as political, policy, financial and strategic factors appear to be of comparable importance. The seminal study carried out by Alesina and Dollar [4] finds former colonial relationships between donor and recipient countries to be an important determinant of whether an aid relationship exists, irrespective of economic need. Recipient-specific factors influencing an aid relationship include aid use, degree of democratisation and level of institutional mismanagement (collectively known as merit [5]).

Due to the complicated and disparate factors involved in the aid decision making process, we present an alternative model to those based upon traditional *economic allocation*. In particular, the approach described here naturally allows for donor interaction, a notion which has received increased interest from international organisations of late [6, 7]. While donor coordination is seen as desirable, much evidence exists to suggest that donors do not coordinate [8, 9], which may result in donor herding [3].

A. A brief history of developmental aid and its grounding in models of economic growth

Much of the rationale for modern development aid can be traced back to explanations of why some countries experience persistent economic growth - while others stubbornly remain in poverty. Economists treat economic development as synonymous with economic *growth*, resulting in the prevailing view that development is primarily a growth problem - or said in a slightly different way - the issues economic development highlights are effectively approached using economic tools and concepts related to growth. This explains why economic growth has played a focal role in development aid: in assessing poverty levels (via measures such as GDP), devising interventions to alleviate poverty (provision of aid and identifying funding gaps), and monitoring the effectiveness of interventions.

In early models applied to economic development [10, 11], the output of an economy is considered to be the sum of the output of all firms, and the output of a firm is taken as the product of capital and labour. Since developing economies are considered to have a large labour supply it is, according to early models, the lack of capital that restricts economic output and growth.

Rostow [12] put forward an influential model, emphasising the role of investment in growing capital stocks, leading to economic growth, higher incomes and savings and back to an increase in investment. This virtuous-circle model implies that foreign aid can fill the financing gap between domestic savings and investments, in order to achieve increased investment which (according to the model) leads to economic growth, and was used as the rationale for foreign aid for much of the 1960s and 1970s.

In addition to labour and capital, Solow introduced a third component, technical change (or technology shocks), in formulating what is currently known as the neoclassical growth model [13]. Although it better fits data and is more sophisticated than the Harrod-Domar [10, 11] model, Solow's model lacks explanatory power, as it attributes economic growth to labour and capital with *exogenous* technological change acting as a residual parameter. When compared to data, the Solow model suggests that the economic divergence between developing countries is 'explained' by a disparity between the exogenous technological change variable. A major criticism of development divergence being explained by diminishing technological change, is that unlike labour and capital - technological know-how and knowledge is much easier (and cheaper) to replicate and spread, so the persistence of poverty and low economic growth becomes harder to explain.

The final major theoretical strand underlying development economics is the role of policy. Economists argue that their models are inherently accurate, and attribute policy failure as the reason for their lack of effectiveness when applied to development problems. This led to ten policy prescriptions, known as the Washington Consensus [14], formulated by the International Monetary Fund, World Bank and US Treasury Department. Alongside policy reforms, improving institutional management and governance has also been a focus of aid agencies.

II. MODEL

A stigmergic model is a flexible and generic modelling approach that allows the investigation of concepts relevant to development aid, without the specification of numerous parameters and exogenous structure. A typical stigmergic model consists of N co-adapting agents that act upon a (possibly localised) environment. Here we consider the case of $E > 1$ environments, with agents representing donor countries, and environments representing those countries in receipt of foreign development aid. Environments are represented as a 2-dimensional grid, and can be taken as a 2-dimensional cellular automata when interactions between environments is permitted (see Figure. 1).

As a base case, inter-agent interactions do not occur directly, and are instead mediated by the aforementioned environments. Environments posses a state taking values

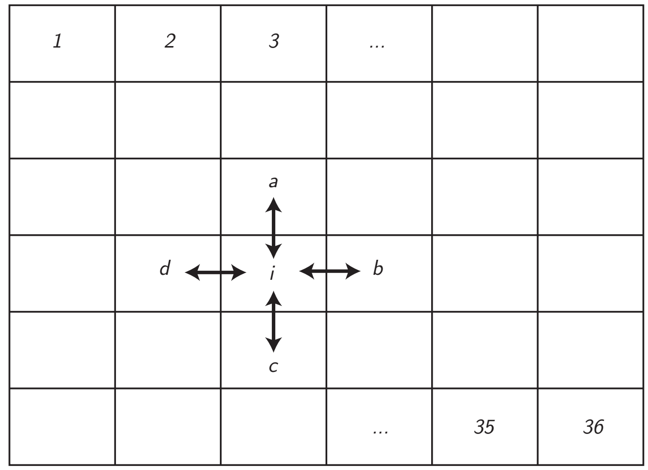

FIG. 1. Local environments representing $E = 36$ recipient countries. When environments are permitted to interact, they do so across their von Neumann neighbourhoods - shown for environment i.

in some set S (usually an integer vector subspace), and agents possess *strategies* and *payoffs*. An agent strategy is a map

$$f : S \to S$$

which transforms the state of some environment. An agent payoff is a map

$$g : S \to \mathbb{R}$$

that determines the reward (positive or negative) the agent derives from the transformed state of some environment. Agents may possess more than one strategy, and different agents may possess different strategies.

Specialising to the case of environment i and a particular agent, j, an agent is said to act upon the environment when it selects a strategy, and uses this to transform the state of the environment, accruing any reward in the process. In terms of maps this action is given by,

$$g_j(f_j) : S_i \to \mathbb{R}$$

Figure. 2 shows the induced agent-environment interactions via a network, where the agents (donor countries) are uncoupled and do not interact. Environments may be *passive* or *active*, with passive environments simply possessing a state with no ability to interact with other environments. Here, we consider environments to be active, in the sense that local interaction across their von Neumann neighbourhood (four bordering cells) is permitted (see Figure. 1).

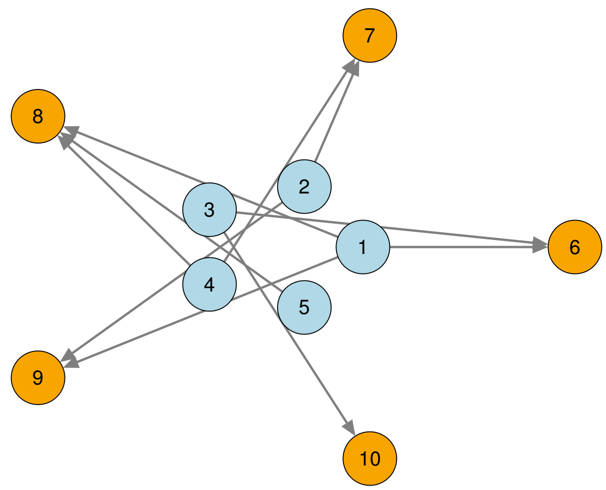

FIG. 2. Induced interaction between uncoupled donor countries (agents) represented by blue nodes, and recipient countries (local environments) by orange nodes.

A. Environment states

At any given time, the state of environment i is the $(N+1)$-vector

$$\left(G_i, M_i^1, M_i^2, ..., M_i^N\right)$$

where G_i represents the growth in economic output of environment i, and M_i^j represents the level of migration from environment i to agent j. When inter-environment interaction is permitted, the state vector above is augmented with a vector representing migration flows between its four von Neumann neighbours (see Figure. 1)

$$\left(M_a^i, M_b^i, M_c^i, M_d^i\right)$$

where each component may be negative (net outflow) or positive (net inflow). When an agent j acts upon environment i, it is rewarded via two mechanisms

- The amount of one-period change in growth G_i
- The amount of one-period change in migration from environment i to agent j

While the aggregate economic growth of recipient countries can be considered to be a global goal (of all donor countries), each agent is assumed to want to minimise economic migration to their own country (either because the retention of domestic labour benefits the economic development of a recipient environment, or it is cheaper for donor countries to provide aid rather than invest in their own infrastructure to accommodate new migrant workers).

B. Action of agent strategies

Recall, for an agent j a strategy is a map, f_j, that acts upon the state variable of a particular environment, i. Assuming the agent has multiple strategies, denoted by k,

$$\begin{aligned} & f_j : S_i \rightarrow S_i, \\ & f\left(G_i, M_i^1, M_i^2, ..., M_i^N\right) \\ & = \left(G_i + \Delta_k^G, M_i^1, M_i^2, ..., M_i^j + \Delta_k^M, ..., M_i^N\right) \end{aligned}$$

For clarity of exposition, we consider the action of the strategy above to act additively upon the environment state vector. In practice, different types of functional relationships can be used (multiplicative, or non-linear functions). It is clear the values of

$$\Delta_k^G, \quad \Delta_k^M$$

determine the action of the strategy upon the environments state.

In the most simple case, the payoff received by the agent can take one of three values $\{-1, 0, 1\}$, and the accumulation of payoffs used to define the fitness (and ranking) of an agent's strategies. In order to isolate the effect of co-adaptation between agents, the set of all strategies for each agent may be taken to be zero-sum, meaning the sum of payoffs over all strategies for any particular agent is zero.

C. Response of an active environment

Recall, when the environment is considered to be active it can also respond to agent actions, interact with other environments and update its state (and any combination of the above). One option is to keep the overall level of migration static, by redistributing any change due to the actions of one agent (donor country) amongst all other donor countries. For example, country j donates aid to environment i which reduces migration from i to j by Δ_k^M (for instance, due to increased travel restrictions being a condition of aid). Then a change of $-\Delta_k^M$ is distributed across the rest of donor countries, maintaining the total level of migration from environment i.

D. How agents select their strategy

Similar to how strategies are selected in the stigmergic game [2], agents keep track of how much reward each strategy accumulates, and are therefore ranked at any given time. It is via strategy selection that agents can be considered to co-adapt, potentially leading to the formation of mutually rewarding groups (a group of agents whose strategies are mutually complementary, in some

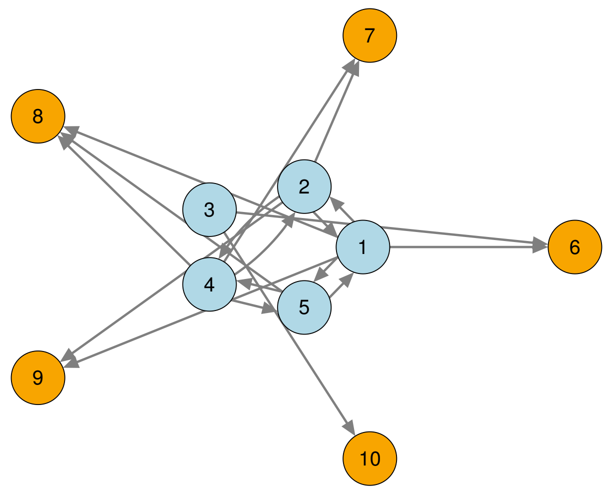

FIG. 3. Induced interaction between coupled donor countries (agents) represented by blue nodes, and recipient countries (local environments) by orange nodes.

way). Such a situation may describe aid herding and the emergence of so-called donor-darlings (groups of recipient countries that attract a disproportionate amount of aid). Alternatively, strategies may not be mutually complementary, and this may result in disordered switching of strategies due to the ranking of strategies being unstable. Such a situation may reflect aid fragmentation, and contribute to aid volatility.

E. Model extension to allow for donor interaction

The current consensus within development aid is that little donor interaction or coordination takes place. Indeed, this is one of the motivating reasons for considering a stigmergic model. Donor interaction (via network edges) can be imposed on the model presented here (see Figure. 3), and the effect on the dynamics of aid investigated. In particular, donor countries may believe it to be mutually beneficial to coordinate aid efforts when attempting to cap migration flows, where there is a risk migration may increase when some other country acts to reduce migration to their country.

[1] P. Carter, F. Postel-Vinay, and J. Temple, Journal of International Economics **95**, 291 (2015).
[2] R. Savit, M. Riolo, and R. Riolo, PloS one **8**, e71828 (2013).
[3] E. Frot and J. Santiso, Kyklos **64**, 54 (2011).
[4] A. Alesina and D. Dollar, Journal of economic growth **5**, 33 (2000).
[5] A. Hoeffler and V. Outram, Review of Development Economics **15**, 237 (2011).
[6] *Aid Effectiveness 2011* (OECD Publishing, 2012).
[7] *Paris Declaration on Aid Effectiveness* (Organisation for Economic Co-Operation and Development (OECD), 2005).
[8] P. Nunnenkamp, H. Öhler, and R. Thiele, Review of World Economics **149**, 537 (2013).
[9] I. Aldasoro, P. Nunnenkamp, and R. Thiele, Journal of International Development **22**, 920 (2010).
[10] R. F. Harrod, Econ. J. **49**, 14 (1939).
[11] E. D. Domar, Econometrica **14**, 137 (1946).
[12] W. W. Rostow, Econ. J. **66**, 25 (1956).
[13] R. M. Solow, J. Econ. Perspect. **8**, 45 (1994).
[14] D. Rodrik, Journal of Economic literature **44**, 973 (2006).