[[Incomplete]]

Ideas determining convergence clubs

by

Danny Quah *
LSE Economics Department
October 1999

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ABSTRACT

This paper develops a model of cross-country growth and distribution dynamics where sharing ideas is important. The model shows clusters of economies emerging from deliberate choices made in equilibrium. It characterizes how, over time, the cross-section distribution of countries stratifies into distinct income classes.

Keywords: coalition, distribution dynamics, endogenous technology transfer, externality, knowledge economy, polarization, stratification

JEL Classification: D30, D62, F43, O41

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1 INTRODUCTION

When economies interact with one another—through trade or technology transfer—it alters their profiles of growth and economic performance. This paper studies a specific kind of such interaction, interpreted for concreteness as sharing ideas or sharing technologies. The paper considers the effects of such interactions on the distribution dynamics in income across a broad cross section of countries. Do clusters or convergence clubs of economies emerge from the interaction, or does convergence to equality result? Does the cross section of economies polarize and stratify? What determines which economies go into which groups? What choices restrict the range and scope of externality spillovers across economies? What forces drive the emerging patterns in the cross-section distribution?

To focus on the effects that are novel relative to others already studied in the literature on economic growth, the model developed below is highly stylized and simplified. The internal structure—what happens *within* an economy—is reduced to a minimum. Emphasis instead rests on the endogenously-determined relations *across* economies.

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The model works as follows. Technology, in the form of blueprints and designs, can be used, in the first instance, domestically for production. Simultaneously, however, technology can be shared with others, freely in a nonrival or infinitely expansible way, without reducing its domestic usefulness. Does this sharing arise mechanistically and automatically, i.e., without explicit choices made by informed participants? If, conversely, the sharing is not mechanistic, why does any leading economy allow its technologies to disseminate? The idea in the model is that from the perspective of a given economy, improving others' technology levels—making them more productive—can be both beneficial and deleterious. Appropriately trading off gains and losses determines with whom a given economy chooses to share ideas. Then reconciling those choices across economies gives rise, in equilibrium, to specific patterns of growth and convergence in the cross section.

Trade in technology can occur in different ways. If ownership of technologies can be enforced—by intellectual property rights or because the technology is manifest only in a routinely-exchangeable physical object—then one might sensibly consider an explicit market for technologies. This paper does not do that. Instead, it takes technology, not as embodied in a tradeable physical machine, but instead as ideas, blueprints, and designs—nonrival objects whose reproduction costs are trivial relative to the costs of initial instantiation. The assumption made in this paper is that considered by Arrow (1962) and Thomas Jefferson (recorded in, e.g., Koch and Peden, eds, 1944, pp. 629–630) where ideas "cannot, in nature, be a subject of property". In this case, technology transfer has to occur through some non-market mechanism.

In the model, technology transfer is modelled through idea-sharing coalitions. By assumption, within coalitions there is indiscriminate sharing of blueprints and designs; across coalitions, there is complete secrecy. In the model, therefore, general openness to trade of an economy is not what matters; instead, what is critical is to whom a given economy is open. Equilibrium is an endogenous coalition structure in a strategic game, as in Burbidge, DePater, Myers and Sengupta (1997), Moldovanu and Winter (1995), and Ray and Vohra

(1997, 1999).

The problem the paper solves is therefore, in the main, a theoretical one. However, the model does deliver predictions consistent with the "emerging twin peaks" empirical regularity in cross-country income distribution dynamics (e.g., Bianchi (1997), Paap and van Dijk (1998), and Quah (1993, 1997)). Some reasons are offered below why the modelling strategy here might be preferred to other ways of explaining such regularities.

The remainder of this paper is organized as follows. Section 2 motivates the analysis and describes related literature. Section 3 sets up the model, analyzes its equilibria, and characterizes its dynamic predictions. Section 4 concludes.

2 MOTIVATION AND RELATED LITERATURE

The analysis in this paper is driven by, on the one hand, a set of empirical regularities on the dynamics of cross-country income distributions, and on the other hand, some theoretical considerations regarding knowledge dissemination. The empirical regularities can be summarized as "emerging twin peaks", a phrase used in Quah (1997) and elsewhere. The theoretical considerations have to do with the non-rivalry or infinite expansibility property of ideas, blueprints, and designs, as described in Arrow (1962), Jefferson (in, e.g., Koch and Peden, eds, 1944), and Romer (1990).

While the analysis has only these two immediate concerns, it connects to a large set of issues in the literature on economic growth. Because the model in this paper might appear so stylized and different from other work, it is useful to expend some effort drawing in the connections. That is what this Section does. Readers for whom the motivation in the Introduction already suffices can proceed directly to Section **3**.

2.1 Technology and income distribution dynamics across countries

When technology is the engine of growth, the distribution of technology levels (A in the Solow growth model) directly determines the long-run distribution dynamics of incomes across countries. Models where technology is endogenized do not overturn this statement; they provide more subtle economics underlying the empirical conclusion.

Technological development can occur in an isolated, autarkic way in each economy—the cross-section prediction is then just a bookkeeping account of that for each economy. Or, the opposite extreme can arise, when technical progress occurring anywhere flows freely and instantaneously everywhere, so that technology levels equalize worldwide. Either assumption on technology dissemination is perfectly compatible with technology otherwise evolving exogenously or endogenously *within* an economy.

Technological-based explanations for differences across countries can therefore be trivial: *All* heterogeneity is due to unobserved technology. Or, one can seek to model why technology differs across economies, even though a plausible hypothesis is that they should not.

2.2 Empirical evidence and alternative approaches

Turn next to the empirical regularities in cross-country income distribution dynamics. Fig. 1, taken from Durlauf and Quah (1999), reproduces the salient facts. It depicts the evolution through time of the cross-section income distribution across more than 120 countries. The earlier distribution, at time t, is drawn here to be unimodal, but is intended only to be nondescript. By contrast, the distribution at time $t + s$ shows the emergence of two modes, one a cluster of rich, the other a cluster of poor.

A standard regression, in its simplest form, successfully fits Fig. 1 when an emerging twin-peakedness in distribution appears in the cross section of conditioning or exogenous variables, just as it does in the left-hand side variable income. But why this should happen cannot be insightfully studied when those right-hand-side variables are taken as exogenous, and thus simply conditioned upon. This, unfortunately, is the furthest that such an approach can go. Some might therefore consider unappealing how a typical regression study "explains" the principal features of Fig. 1.

In this thinking, even less satisfactory would be a panel-data regression that conditioned out so-called "individual heterogeneities"—whether by fixed or random effects methods, by first-differencing, or by a range of other well-known econometric techniques—if it is exactly those heterogeneities that contain the twin-peakedness characteristic. Such an approach "explains" the most interesting feature of Fig. 1—the emerging clusters—by sweeping out the feature as something not even consistently estimable.

2.3 Economic structure: Technological dissemination

More insightful then for understanding Fig. 1 might be to take its emerging clusters as the objects to explain, without relying on further ad hoc conditioning variables. It is this approach that the paper follows.

Take our lead from the discussion in **2.1**. To analyze a situation intermediate between the two extremes of autarky and instantaneous dissemination in technology, one has to model explicitly the interposing frictions. Barriers in the form of intellectual property rights (IPRs) are one possibility. But such legal and social institutions are not primitive to the problem. Instead, they are the endogenous outcome of some underlying economic reasoning typically not made explicit (see, e.g., David (1993), Helpman (1993), Keely (1999, ch. 2–3), or Wright (1983)).

Similarly, gradual rather than instantaneous technology adoption (e.g., the dynamic and spatial adjustment processes studied in Bernard and Jones (1996); Cameron, Proudman and Redding (1998); or Keller (1999)) provide a useful reduced-form approach to how instantaneous technology dissemination fails. But it is an approach more appropriate for questions other than those in this paper.

Providing greater insight are models where adjustment, adaption, or adoption costs of technology matter, and where economies therefore act optimally, or at least deliberately, in how they import ideas. Examples include Acemoglu and Zilibotti (1998), Barro and Sala-i-Martin (1997), Connolly (1999), Eaton and Kortum (1999), Helpman (1993), and Parente and Prescott (1994). These analyses can be viewed as dual to that undertaken below: They take as given the identities of the economies between which technology transfer—the exchange of ideas—can occur; they then examine the characteristics of such transfers. By contrast, the model in this paper abstracts away fine details of the technology transfer, and asks instead, *Which* are the economies among whom transfers will take place?

The difference between these dual analyses can be illustrated as in Fig. 2. The result is a theory that says which economies enter which convergence clubs. The analysis delivers predictions on the dynamics of the entire cross section of economies simultaneously.

2.4 Ideas in the economics of science and technology

The duality I refer to above is one that is reflected in the economics of science and technology (e.g., Dasgupta and David, 1994).

That literature highlights a tension between two broad views on knowledge dissemination. First, there is the Arrow-Jefferson view that ideas "by their nature" should spread freely and costlessly (e.g., Arrow (1962), Koch and Peden, eds (1944, pp. 629–630)).[1]

In contrast to this, there appears also an extensive discussion of tacit knowledge and learning, where now the absorption and thus the spread of knowledge is taken to expend economic resources.

In the Arrow-Jefferson view, ideas are not just nonrival but also

[1] Indeed, Thomas Jefferson's writings are often cited by contemporary observers as a model for Internet dissemination of information. This view appears also in Lucas (1988, p. 15) where Lucas discards crude cross-country variation in knowledge and technology as a helpful explanation for the wide disparity in incomes across countries, because "'Human knowledge' is just human, not Japanese or Chinese or Korean."

nonexcludable. Romer (1990) and almost all other work on economic growth address nonexcludability by assuming perfectly-enforceable IPRs. In the tacit-knowledge approach, nonexcludability is handled without an IPR system but instead by individual-specific costs of learning and adaptation. This paper addresses nonexcludability in yet a third way.

2.5 Arrow-Jefferson coalitions

The model in this paper is one that adopts the Arrow-Jefferson view on knowledge and technology, i.e., a priori no physical barriers can stop the infinite spread of ideas. But the model assumes also no IPR regime.

Instead, what holds back complete idea dissemination are deliberate economic choices made in equilibrium. The modelling strategy is to construct Arrow-Jefferson type coalitions: By assumption, within coalitions ideas, blueprints, and designs are shared promiscuously. No sharing is possible across coalitions. The boundaries of those coalitions thus determines endogenously the extent to which technology is transferred. What is the structure of coalitions that emerges? Does only a single coalition form, so that nonexcludability indeed dominates? Or do nontrivial coalition structures arise in equilibrium, so that complete idea dissemination does not occur?

Keely (1999, Ch. 4) addresses similar questions on coalition emergence and distribution dynamics, with tools related to those I use below. She specifies a more detailed underlying economic model differing in structure from the minimalist one below, and thus is able to address a richer set of issues. The model in this paper, by contrast, is designed to concentrate on the strategic forces at work in such settings (forces that are, therefore, necessarily common to both her model and mine).

The model produces distribution dynamics in cross-economy incomes, where clustering can appear in equilibrium. Such polarization and stratification have previously been studied in Durlauf (1996) and Esteban and Ray (1994), and empirically in Quah (1997). Related analyses of cross-section distribution dynamics that result from exogenously-determined clusters appear in Durlauf and Quah (1999, Sec. 4.6) and Lucas (1993).

2.6 Empirical implications

In the model, cross-section dependence is pervasive in the comovements across economies. Thus, analyzing the dynamics of economies in isolation—as in an econometric cross section or panel, where the empirical procedure ends up averaging across economies—is not particularly revealing. Instead, techniques such as described in Chen and Conley (1999), Durlauf and Quah (1999), and Quah (1997) will be more appropriate for studying empirical implications of models like that below.

3 THE MODEL

Denote the fixed finite set of economies by J. A *coalition* of economies is a nonempty subset C of J. By convention, J is also called the *grand coalition*. For $C \subseteq J$ write $|C|$ for the number of its members. The complementary set of C in J is $J \setminus C$.

Index economies in the cross section by $j = 1, 2, \ldots |J|$.

A *coalition structure*

$$\mathbb{C} = \left\{C_1,\ C_2,\ \ldots,\ C_{|\mathbb{C}|}\right\}$$

is a partition of J, i.e.,

1. $C_j \subseteq J,\ j = 1,\ 2,\ \ldots,\ |\mathbb{C}|$,
2. $C_j \cap C_{j'} = \emptyset$, whenever $j \neq j'$,
3. $C_1 \cup C_2 \cup \cdots \cup C_{|\mathbb{C}|} = J$.

For $C \subset J$, write the collection of all C's partitions by $\mathbb{P}(C)$. For convenience, write simply $\mathbb{P}$ for $\mathbb{P}(J)$. A coalition structure is therefore an element of $\mathbb{P}$.

The concepts and terminology thus far are standard in the literature on coalitional games (e.g., Moldovanu and Winter, 1995; Ray and

Vohra, 1997, 1999). For the first part of the subsequent discussion we need a further definition.

Time begins at 0 and is continuous. A *time-t coalition scheme* is a mapping

$$\mathbb{C}^t : [t, \infty] \to \mathbb{P},$$

so that at each timepoint $t+s$ (with s positive), from the perspective at time t, the image $\mathbb{C}^t(t+s) \in \mathbb{P}$ is a well-defined coalition structure. A time-t coalition scheme is *consistent* if

$$\forall s > t: \quad \mathbb{C}^t(s) = \mathbb{C}^s(s), \tag{1}$$

i.e., the perception of a future coalition structure is confirmed as events unfold. A time-t coalition scheme is *constant* if

$$\forall s > t: \quad \mathbb{C}^t(t) = \mathbb{C}^t(s) = \mathbb{C}^s(s), \tag{2}$$

i.e., individual coalitions at t never change thereafter. By definition a constant coalition scheme is restricted to be consistent, but a consistent one need not be constant.[2]

3.1 The Economic Structure

Each economy j has a time profile of its stock of *human capital*:

$$\{h_j(t) \mid h_j(t) \geq 0, \ t \text{ in } [0, \infty]\}.$$

For a given time profile $h_j : [0, \infty] \to \mathbb{R}_+$ denote the time derivative (when it exists) by $\dot{h}_j$.

Each economy contains a constant population of homogenous representative agents. Population size is equal across economies and normalized to 1. Agents value consumption and discount the future at rate $\rho > 0$. Denote economy j's consumption time profile by

$$\{c_j(t) \mid t \text{ in } [0, \infty]\}.$$

[2] Omitting the middle term in (2) would permit constant schemes that are not consistent. But this only introduces an unnecessary complication in the discussion, so I have strengthened (2) to its current form.

The representative agent in economy j is forward-looking and at time t enjoys utilty

$$\int_{s=0}^{\infty} e^{-s\rho} U(c_j(t+s))\, ds, \tag{3}$$

with U increasing and concave.

Time profiles in c will be related to those in h, but to describe them fully, the rest of the economic structure needs to be made explicit.

Write $h(t)$ to denote the function $h(t) : J \to \mathbb{R}_+$ taking the value $h_j(t)$ at $j \in J$. For $C \subset J$ let $h_C(t)$ denote the restriction of $h(t)$ to C. It will be unambiguous and convenient to call $h(t)$ the *distribution* of human capital at t, and similarly $h_C(t)$ the distribution of human capital at t across coalition C.

Human capital has two nonrival uses in the model. It is a factor input for current production, and it is a capacity for ongoing development. I assume that its function as one does not detract from its role as the other, and that coalitions matter for both as follows. First, assume that joint production occurs in coalitions. Coalition C at time t produces total current output by the production function

$$Y_C = Y(h_C(t)) = \left[\sum_{j \text{ in } C} h_j(t)^{\gamma} \right]^{1/\gamma}, \quad 0 < \gamma < 1. \tag{4}$$

For fixed C, this technology is constant returns to scale in h_C. Restricting the substitution coefficient γ to $[0, 1]$ constrains the isoquants of (4) to lie between those of linear and Cobb-Douglas technologies.

In (4) the exclusion of any member j of a coalition C to form a smaller coalition $C' \overset{\text{def}}{=} C \setminus \{j\}$ always reduces total output for the (remaining) coalition C'. This remains true regardless of how low h_j might be relative to the distribution $h_{C'}$. Indeed, a stronger statement is possible. From $\gamma \in (0, 1)$, the production technology (4), taken as a characteristic function mapping coalitions to real numbers, is superadditive (Myerson, 1991, Ch. 9):

$$\forall\ \{C_1,\ C_2\} \in \mathbb{P}(C) : \quad Y_{C_1} + Y_{C_2} \le Y_C.$$

As we will see below, the natural way to describe equilibrium is in a game of coalition formation. Then, if either individual payoffs (related, ultimately, to (3)) for members of a coalition are increasing in the coalition's total output or if the game is specified to have transferable utility, the superadditive technology (4) represents a force for coalitions to merge or *consolidate* until only the grand coalition remains.

Why then might an equilibrium exist where, by contrast, J breaks up into distinct coalitions? For this, we turn to the second function of human capital, namely its role in growth. Assume that if j is in C at time t, then h_j evolves

$$\dot{h}_j(t) = \xi \times h_j(t)^{1-\alpha} \left(\mathcal{D}(h_C(t))\right)^{\alpha}, \quad \text{with } 0 < \alpha < 1 \text{ and } 0 < \xi < \rho. \tag{5}$$

Equation (5) says human capital grows both from the capacity already extant domestically and from some aggregation $\mathcal{D}$ of the distribution of capacities in the coalition to which the economy belongs. Spillovers matter, but they are controlled in that what happens outside the coalition is irrelevant.

For equilibrium below to be well-defined, we require in (5) that ξ be dominated by agents' discount rate ρ from (3). We return below to the specification of $\mathcal{D}$, but for now we require only that $\mathcal{D}$ take values in $\mathbb{R}_+$ and that if $h_l(t) = h_j(t)$ for all l in C, then $\mathcal{D}(h_C(t)) = h_j(t)$. This implies that for a singleton coalition $\mathcal{D}(h_j(t)) = h_j(t)$. This property would hold if $\mathcal{D}$ were, say, a weighted average or a mean-variance transformation.

Rewriting (5) as

$$\dot{h}_j/h_j = \xi \times \left(\mathcal{D}(h_C)/h_j\right)^{\alpha},$$

we see that an economy grows at rate ξ in isolation, or whenever it is in a coalition with only exact copies of itself. Thus, ξ is an underlying natural growth rate, and whether an economy grows faster or slower than ξ varies with who else is in its coalition. Since α is positive, the higher relative to h_j is $\mathcal{D}$ on the coalition, the higher is the growth rate for j.

Whatever distributional characteristic leads to a lower $\mathcal{D}$ is then a force for excluding certain members of C from a coalition, or for *fragmenting* a coalition. In equilibrium the force for consolidation, given by joint production (4), is balanced against the force for fragmentation in (5). Section **3.3** below will consider specifications for $\mathcal{D}$ in greater detail.

3.2 The Game in (NTU) Coalitional Form

To describe payoff outcomes, we need to consider the entire range of coalitional possibilities.

At time t fix a coalition scheme $\mathbb{C}^t$ and a distribution of human capital $h(t)$. Define the *state vector*

$$\sigma(t) \stackrel{\text{def}}{=} (\mathbb{C}^t, h(t), t).$$

Let the instantaneous consumption payoff for j in $C \in \mathbb{C}^t(t)$ be

$$c_j(t) = w_j(\sigma(t)) \text{ with } \sum_{j \text{ in } C} w_j(\sigma(t)) = Y(h_C(t)).$$

The second equality specifies that allocation within the coalition exactly exhausts total coalition output. From consumer preferences (3), the time-t expected value for j in state $\sigma(t)$ is

$$V_j(\sigma(t)) = \int_{s=0}^{\infty} e^{-(s-t)\rho} U(w_j(\sigma(s)))\, ds. \tag{6}$$

Define the payoff for coalition $C \in \mathbb{C}^t(t)$ to be the sum of (6) across coalition C's members:

$$V_C(\sigma(t)) = \sum_{j \text{ in } C} V_j(\sigma(t)). \tag{7}$$

If the coalition scheme $\mathbb{C}^t$ is not consistent, then neither (6) nor (7) sensibly describes the objectives of the different agents. If the coalition scheme $\mathbb{C}^t$ is consistent but not constant, then (6) will, in general, involve somewhere on $(t, \infty]$ switches in the coalition to which j belongs. The coalition payoff (7) can, nevertheless, be defined without ambiguity. Over time the members of $C \in \mathbb{C}^t(t)$ might no longer be in a single coalition—an event foreseen ahead of time through knowledge of the given coalition scheme $\mathbb{C}^t$. At the given time t, however, the coalition C and thus the payoff (7) are unambiguous.

These considerations suggest the following.[3]

Definition *Assume $\mathbb{C}^0$ is consistent. Let V in* (7) *define a characteristic function over coalitions $C \in \mathbb{C}^0(0)$. The TU (transferable utility) game in coalition form at time* 0 *is $\Gamma = (J, V, h(0))$. Similarly, let $V_j(0)$ in* (6) *define a vector V of individual payoffs. The NTU (nontransferable utility) game in coalition form at time* 0 *is $\Gamma = (J, V, h(0))$.*

[[**INCOMPLETE**]]

3.3 Distributional characteristics

We consider some alternative specifications of the aggregator $\mathcal{D}$. The examples here carry a distinct "reduced-form" feel to them—it would be interesting to study more explicitly how each might arise—but they are intended here to do no more than illustrate a range of possibilities.

Suppose

$$\mathcal{D}(h_C(t)) = |C|^{-1} \sum_{j \text{ in } C} h_j(t), \tag{8}$$

The aggregator here is just the mean of the distribution. In (8) the low part of the cross section in h_C draws down $\mathcal{D}$. Coalition members with high h_j's can therefore increase growth by casting off those

[3] Requiring in (5) that no spillovers occur across coalitions matters importantly for these definitions. Should that not hold, we would need the *partition function* approach used in Ray and Vohra (1999).

members with h at the low end of the distribution h_C. If not for the consolidation tendency in (4), a reasonable conjecture would be that a specification like (8) leads to complete shattering of the cross section J, as no economy would agree to be in a coalition with any ranked below it in human capital.

If, on the other hand,

$$\begin{aligned} \mathcal{D}^*(h_C(t)) &\stackrel{\text{def}}{=} |C|^{-1} \sum_{j \text{ in } C} h_j(t), \quad \text{and} \\ \mathcal{D}(h_C(t)) &= \mathcal{D}^*(h_C(t)) \\ &\quad - \left(|C|^{-1} \sum_{j \text{ in } C} |h_j(t) - \mathcal{D}^*(h_C(t))|^2 \right)^{1/2}, \end{aligned} \tag{9}$$

the aggregator $\mathcal{D}$ is a mean-standard deviation transformation, where, conditional on the mean, greater variation is penalized. This might be sensible when high variation—differing levels of development—necessitates costly translation and adaptation. Here, too, the tendency for shattering of the cross section is apparent.

Alternatively, $\mathcal{D}$ in equation (9) might be specified with a plus rather than minus after $\mathcal{D}^*$: This would capture a “love of diversity”, where differences in a coalition are valued, perhaps because a more varied mixture might lead to more innovative ideas. The “complete shattering” outcome, described following (8), would now be less reasonable.

Finally, we might extend the definition of $\mathcal{D}$ to take into account unobservable characteristics x_j that are valued in growth:

$$\mathcal{D}(h_C(t), x_C(t)) \in \mathbb{R}_+. \tag{10}$$

If $x(t)$ is either constant or independently and identically distributed in time, it will not add to the state vector (to be introduced below) and thus to the dimensionality of the dynamic system. Candidates for x might include geographical location or “sociological” variables. A rich range of possibilities can be permitted in (10); we return to this after describing equilibrium.

Equations (5) and (8)–(10) have the following economic interpretation. Producing useful new ideas—making new h_j—comes from pooling the different capacities across a coalition. More traditional R&D-type models specify an explicit cost to the activity of generating ideas; here, there is none, but that is inessential to the concerns in the current paper. Instead, what we focus on here is the following. In (8), listening to crazy ideas, i.e., getting input from low h_l's, is costly and holds back the growth of useful new ideas. Provided the standard deviation term in either version of (9) does not overwhelm,

[[**INCOMPLETE**]]

4 CONCLUSION

This paper has.

[[**INCOMPLETE**]]

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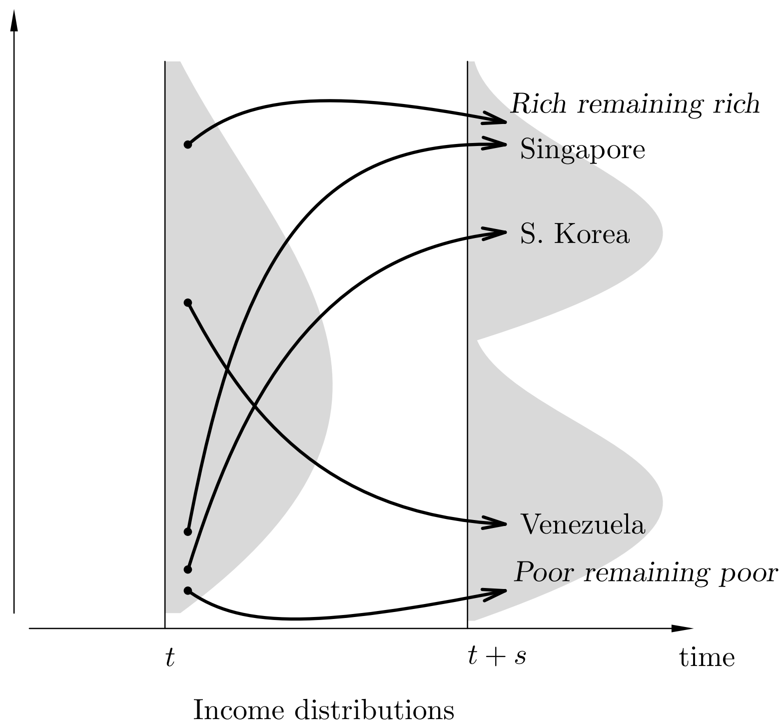

Fig. 1: Emerging twin peaks The earlier cross-section income distribution is nondescript. Over time, two modes appear and (potentially) persist. Some elements of the cross section succeed; some fail; yet others either languish or preserve their relative success. Post-1960 experiences projected over 40 years for named countries are drawn to scale, relative to historical cross-country distributions.

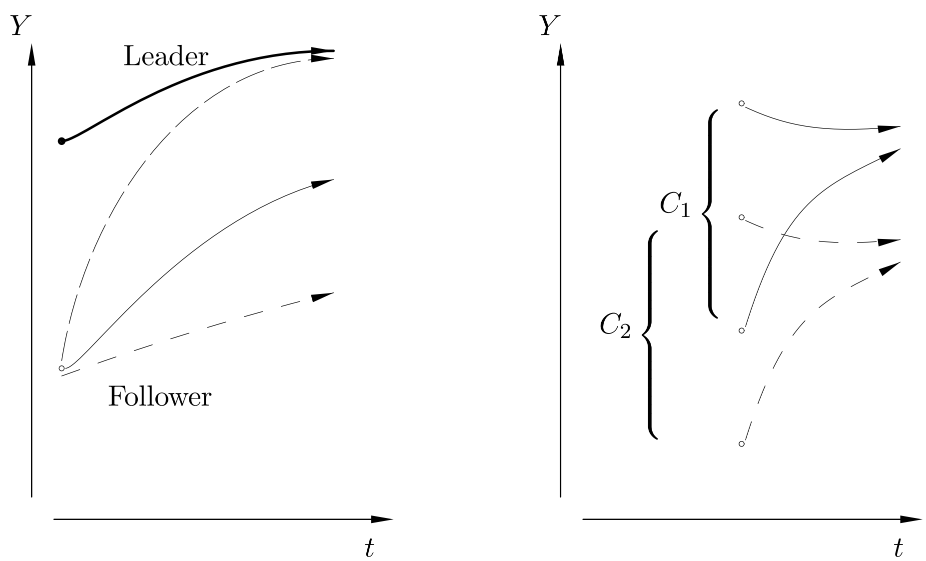

Fig. 2: Duality The two panels show time series of economies' development. In the left panel, Follower and Leader identities are taken as given. What is investigated is the rate of Follower catchup to the Leader: Is it fast or slow? The different lines emanating from the Follower economy denote alternative possible outcomes. By contrast, in the right panel, it is the identities of leaders and followers that are to be determined. One possible outcome, as drawn, has the initially first and third ranked economies—grouped in C_1—converge towards each other; similarly, the initially second and fourth—grouped in C_2. The relation across the two groups is unspecified, but none need exist.