

# Can't We All Be More Like Scandinavians?\*

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## Abstract

In an interdependent world, could all countries adopt the same egalitarianism reward structures and institutions? To provide theoretical answers to this question, we develop a simple model of economic growth in a world in which all countries benefit and potentially contribute to advances in the world technology frontier. A greater gap of incomes between successful and unsuccessful entrepreneurs (thus greater inequality) increases entrepreneurial effort and hence a country's contributions to the world technology frontier. We show that, under plausible assumptions, the world equilibrium is necessarily asymmetric: some countries will opt for a type of “cutthroat” capitalism that generates greater inequality and more innovation and will become the technology leaders, while others will free-ride on the cutthroat incentives of the leaders and choose a more “cuddly” form of capitalism. Paradoxically, those with cuddly reward structures, though poorer, may have higher welfare than cutthroat capitalists—but in the world equilibrium, it is not a best response for the cutthroat capitalists to switch to a more cuddly form of capitalism. We also show that domestic constraints from social democratic parties or unions may be beneficial for a country because they prevent cutthroat capitalism domestically, instead inducing other countries to play this role.

**JEL Classification:** O40, O43, O33, P10, P16.

**Keywords:** cutthroat capitalism, economic growth, inequality, innovation, interdependences, technological change.

Preliminary. Comments Welcome.

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# 1 Introduction

Against the background of the huge inequalities across countries, the United States, Finland, Norway, Sweden and Switzerland are all prosperous, with per capita incomes more than 40 times those of the poorest countries around the world today. Over the last 60 years, all four countries have had similar growth rates.<sup>1</sup> But there are also notable differences between them. The United States is richer than Finland, Sweden and Switzerland, with an income per capita (in purchasing power parity, 2005 dollars) of about \$43,000 in 2008. Finland's is about \$33,700, Sweden's stands at \$34,300, and Switzerland's at \$37,800 (OECD, 2011).<sup>2</sup> The United States is also widely viewed as a more innovative economy, providing greater incentives to its entrepreneurs and workers alike, who tend to respond to these by working longer hours, taking more risks and playing the leading role in many of the transformative technologies of the last several decades ranging from software and hardware to pharmaceuticals and biomedical innovations. Figure 1 shows annual average hours of work in the United States, Finland, Norway, Sweden and Switzerland since 1980, and shows the significant gap between the United States and the rest.<sup>3</sup>

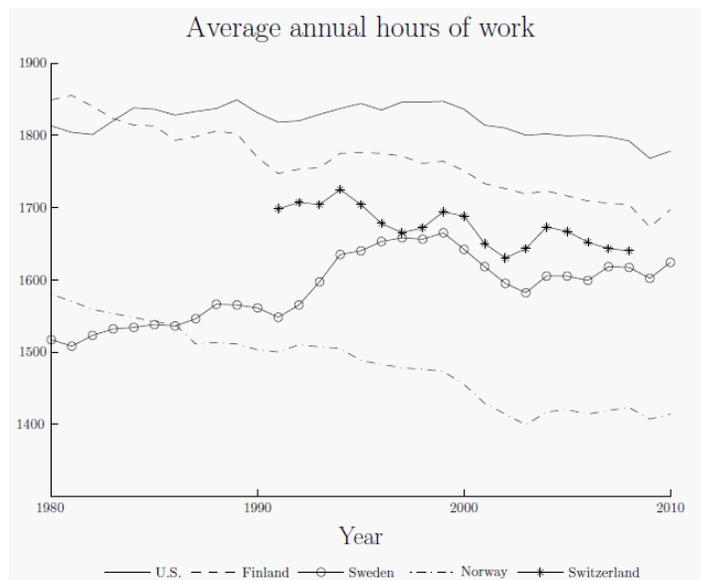


Figure 1: Annual average hours worked. Source: OECD (2010)

<sup>1</sup>In particular, the average growth rates in the United States, Denmark, Finland, Norway, Sweden and Switzerland between 1980 and 2009 are 1.59%, 1.50%, 1.94%, 2.33%, 1.56% and 1.10%.

<sup>2</sup>Norway, on the other hand, has higher income per capita (\$48,600) than the United States, but this comparison would be somewhat misleading since these higher Norwegian incomes are in large part due to oil revenues.

<sup>3</sup>Average annual hours are obtained by dividing total work hours by total employment. Data from the OECD Labor market statistics (OECD, 2010).

To illustrate the differences in innovation behavior, Figure 2 plots domestic patents per one million residents in these five countries since 1995, and shows an increasing gap between the United States and the rest.<sup>4</sup> These differences may partly reflect difficulties in obtaining patents in different patent offices, and may be driven by “less important” patents that contribute little to productive knowledge and will receive few cites (meaning that few others will build on them). To control for this difference, we adopt another strategy.<sup>5</sup> We presume that important—highly-cited—innovations are more likely to be targeted to the world market and thus patented in the US patent office (USPTO). USPTO data enable us to use citation information. Figure 3 plots the numbers of patents granted per one million residents for Finland, Norway, Sweden and Switzerland relative to the United States between 1980 and 1999. Each number corresponds to the relevant ratio once we restrict the sample to patents that obtain at least the number of citations (adjusted for year of grant) specified in the horizontal axis.<sup>6</sup> If a country is more innovative (per resident) than the United States, we would expect the gap to close as we consider higher and higher thresholds for the number of citations. The figure shows that, on the contrary, the gap widens, confirming the pattern indicated by Figure 2 that the United States is more innovative (per resident) than these countries.

But there are other important differences. The United States does not have the type of welfare state that many European countries, including Finland, Norway, Sweden and Switzerland, have developed, and despite recent health-care reforms, many Americans do not have the type of high-quality health care that their counterparts in these other countries do. They also receive much shorter vacations and more limited maternity leave, and do not have access to a variety of other public services that are more broadly provided in many continental European countries. Perhaps more importantly, poverty and inequality are much higher in the United States and

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<sup>4</sup>These data are from the World Intellectual Property Organization Statistics Database (WIPO 2011). The WIPO construct these series by counting the total number of patent filings by residents in their own country patent office. For instance, the U.S. number of 783 patent filings per million residents in 2010 is obtained by dividing the total number of patent filings by U.S. citizens at the U.S. patent office (USPTO), by million residents. Patents are likely to be filed at different offices, so adding numbers from different offices may count many times the same patent. Filings at own country office has the advantage that it avoids multiple filings and first time filings are more likely to occur at the inventor’s home country office.

<sup>5</sup>Another plausible strategy would have been to look at patent grants in some “neutral” patent office or total number of world patterns. However, because US innovators appear less likely to patent abroad than Europeans, perhaps reflecting the fact that they have access to a larger domestic market, this seems to create an artificial advantage for European countries, and we do not report these results.

<sup>6</sup>Patents granted by the USPTO and the number of citations are taken from the NBER U.S. Patent Citations Data File. Number of citations are adjusted to reflect future citations not counted using the adjustment factor created by Hall, Jaffe and Trajtenberg (2001). This factor is calculated by estimating an obsolescence-diffusion model in which citations are explained by technology field, grant year and citation lags. The model is then used to predict citations after the year 2006 since the data is truncated at this date. We do not include patents granted after 1999 so as not to excessively rely on this adjustment. For details on these data and issues, see, e.g., Hall, Jaffe and Trajtenberg (2001) or Kerr (2008).

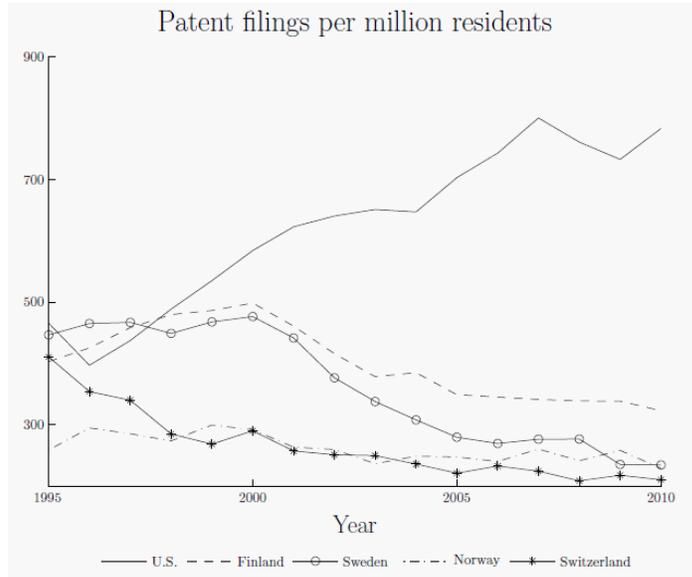


Figure 2: Patent filings per million residents at domestic office. Source: World Intellectual Property Organization.

have been increasing over the last three decades. Figure 4 depicts the evolution of the ratio of 90th and the 10th percentiles of the income distribution in these countries, and shows that the United States is both more unequal than Finland, Norway, Sweden and Switzerland, and that this gap has been increasing since the 1980s.<sup>7</sup> Income inequality at the top of the distribution has also been exploding in the United States, with the top 1% of earners capturing over 20% of total national income, while the same number is around 5% in Finland and Sweden (Atkinson, Piketty and Saez, 2011).

The economic and social performance of Finland, Sweden and Switzerland, as well as several other European countries, raise the possibility that the US path to economic growth is not the only one, and nations can achieve prosperity within the context of much stronger safety net, more elaborate welfare states, and more egalitarian income distributions. Many may prefer to sacrifice 10 or 20% of GDP per capita to have better public services, a safety net, and a more equal society, not to mention to avoid the higher pressure that the US system may be creating.<sup>8</sup> So can't we all—meaning all nations of the relatively developed world—be more like Scandinavians? Or can we?

<sup>7</sup>Data from the Luxembourg Income Study (2011). The percentiles refer to the distribution of household disposable income, defined as total income from labor, capital and transfers minus income taxes and social security contributions. See, for example, Smeeding (2002).

<sup>8</sup>Schor (1993) was among the first to point out the comparatively much greater hours that American workers work. Blanchard (2007) has more recently argued that Americans may be working more than Europeans because they value leisure less.

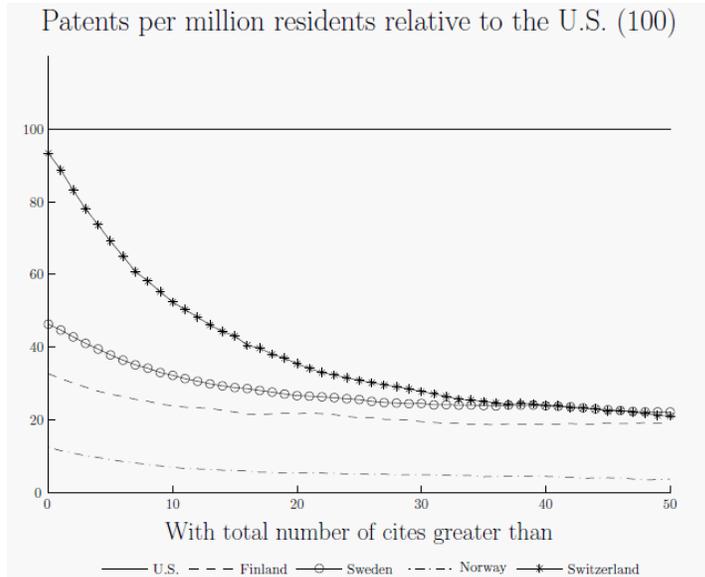


Figure 3: Patents granted between 1980-1999 per million residents to each country relative to the U.S. by number of citations. Source: NBER patent data from the USPTO.

The literature on “varieties of capitalism,” pioneered by Hall and Soskice (2001), suggests that the answer is yes. They argue that According A successful capitalist economy need not give up on social insurance to achieve rapid growth. They draw a distinction between a Coordinated Market Economy (CME) and a Liberal Market Economy (LME), and suggest that both have high incomes and similar growth rates, but CMEs have more social insurance and less inequality. Though different societies develop these different models for historical reasons and once set up institutional complementarities make it very difficult to switch from one model to another, Hall and Soskice suggest that an LME could turn itself into a CME with little loss in terms of income and growth—and with significant gains in terms of welfare.

In this paper, we suggest that in an interconnected world, the answer may be quite different. In particular, it may be precisely the more “cutthroat” American society that makes possible the more “cuddly” Scandinavian societies based on a comprehensive social safety net, the welfare state and much more limited poverty. The basic idea we propose is simple and is developed in the context of a canonical model of endogenous technological change at the world level. The main building block of our model is technological interdependence across countries: technological innovations, particularly by the most technologically advanced countries, contribute to the world technology frontier, and other countries can build on the world technology frontier.<sup>9</sup> We combine this with the idea that technological innovations require incentives

<sup>9</sup>Such knowledge spillovers are consistent with broad patterns in the data and are often incorporated into

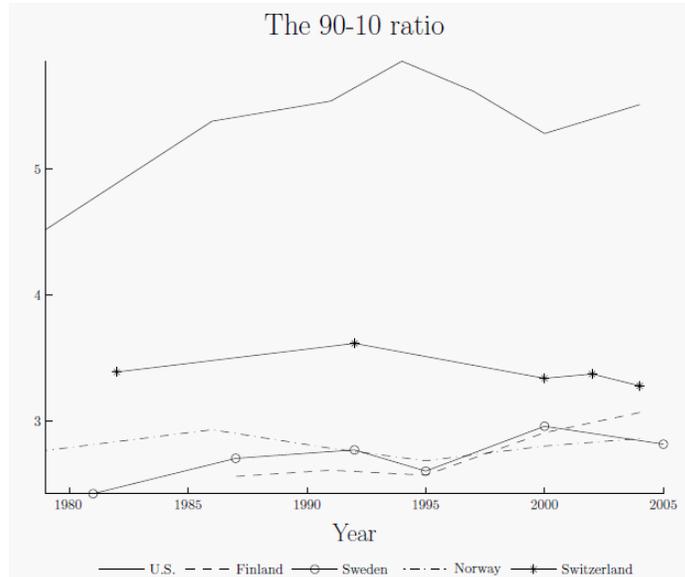


Figure 4: Evolution of the ratio of the 90th to the 10th percentile of the income distribution. Source: Luxembourg Income Study.

for workers and entrepreneurs. From the well-known incentive-insurance trade-off captured by the standard moral hazard models (e.g., Holmstrom, 1979), this implies greater inequality and greater poverty (and a weaker safety net) for a society encouraging innovation. Crucially, however, in a world with technological interdependences, when one (or a small subset) of societies is at the technological frontier and are rapidly advancing it, the incentives for others to do so will be weaker. In particular, innovation incentives by economies at the world technology frontier will create higher incomes today and higher incomes in the future by advancing the frontier, while strong innovation incentives by followers will only increase their incomes today since the frontier is already being advanced by the frontier economies. This logic implies that the world equilibrium—with endogenous technology transfer—may be *asymmetric*, and some countries will have greater incentives to innovate than others. Since innovation is associated with more high-powered incentives, these countries will have to sacrifice insurance and equality. The followers, on the other hand, can best respond to the technology leader’s advancement of the world technology frontier by ensuring better insurance to their population—a better safety net, a welfare state and greater equality.

The bulk of our paper formalizes these ideas using a simple (canonical) model of world equilib-

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models of world equilibrium growth. See, Coe and Helpman (1995) and Keller (2001), Botazzi and Peri (2003), and Griffith, Redding and Van Reenen (2005) for some of the cross-industry evidence, and see, among others, Nelson and Phelps (1966), Howitt (2000), and Acemoglu, Aghion and Zilibotti (2006) for models incorporating international spillovers.

rium with technology transfer. Our model is a version of Romer’s (1990) endogenous technological change model with multiple countries (as in Acemoglu, 2009, Chapter 18). R&D investments within each economy advance that economy’s technology, but these build on the knowledge stock of the world—the world technology frontier. Incorporating Gerschenkron (1962)’s famous insight, countries that are further behind the world technology frontier have an “advantage of backwardness” in that there is more unused knowledge at the frontier for them to build upon (see also Nelson and Phelps, 1966). We depart from this framework only in one dimension: by assuming, plausibly, that there is a moral hazard problem for workers (entrepreneurs) and for successful innovation they need to be given incentives, which comes at the cost of consumption insurance.<sup>10</sup> A fully forward-looking (country-level) social planner chooses the extent of “safety net,” which in our model corresponds to the level of consumption for unsuccessful economic outcomes for workers (or entrepreneurs). The safety net then fully determines a country-level *reward structure* shaping work and innovation incentives.

The main economic forces are simpler to see under two simplifying assumptions, which we adopt in our benchmark model. First, we focus on the case in which the world technology frontier is advanced only by the most advanced country’s technology. Second, we assume that social planners (for each country) choose a time-invariant reward structure. Under these assumptions, and some simple parameter restrictions, we show that the world equilibrium is necessarily asymmetric, meaning that one country (the frontier economy) adopts a “cutthroat” reward structure, with high-powered incentives for success, while other countries free-ride on this frontier economy and choose a more egalitarian, “cuddly,” reward structure. In the long-run, all countries grow at the same rate, but those with cuddly reward structures are strictly poorer. Notably, however, these countries may have higher welfare than the cutthroat leader. In fact, we prove that if the initial gap between the frontier economy and the followers is small enough, the cuddly followers will necessarily have higher welfare. Thus, our model confirms the casual intuition that all countries may want to be like the “Scandinavians” with a more extensive safety net and a more egalitarian structure. Yet the main implication of our theoretical analysis is that, under the assumptions of our model which we view as a fairly natural approximation to reality, we *cannot* all be like the Scandinavians. That is, it is not an equilibrium for the cutthroat leader, “the United States,” to also adopt such a reward structure. This is because if, given the strategies of other countries, the cutthroat leader did so, this would reduce the growth rate of the entire world economy. Because this would make future generations in all countries sufficiently worse

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<sup>10</sup>To do this in the most transparent fashion, we assume that the world consists of a sequence of one-period lived agents. We allow the social planner to have infinite horizon.

off, the social planner of the frontier country would be discouraged from adopting this more egalitarian reward structure. Put differently, the egalitarian reward structure in this world is made possible by the positive externalities created by the cutthroat frontier economy. So interpreting the empirical patterns in light of our theoretical framework, one may claim (with all the usual caveats of course) that the more harmonious and egalitarian Scandinavian societies are made possible because they are able to benefit from and free-ride on the knowledge externalities created by the cutthroat American equilibrium.

The rest of our paper shows that our simplifying assumptions are not crucial for these main insights, and also investigates the impact of other (domestic) institutional arrangements on the nature of the world equilibrium. First, we fully characterize the equilibrium of the dynamic game between (country-level) social planners that choose time-varying reward structures that are best responses to the current state of the world economy and the strategies of others (more formally, we look for the Markov perfect equilibrium of the game between the country social planners). In this case, the equilibrium generally is time varying, but the major insights are similar. An important difference is that in this case, we show that countries that start sufficiently far from the frontier will first adopt a cutthroat reward structure, and then switch to a cuddly, more egalitarian reward structure only once they approach the frontier. The reason for this is instructive. The advantages of being backward, which are at the root of the long-run equilibrium leading to a stable world income distribution, also imply that the return to greater innovativeness is higher when a country is far from the world technology frontier. This encourages these relatively backward countries to also adopt a cutthroat reward structure. Nevertheless, once an economy is sufficiently close to the world technology frontier, the same forces as in our time-invariant analysis kick in and encourage these follower economies to change their reward structures in a more egalitarian, cuddly direction. Thus, under some parameter restrictions, the time path of an economy has the flavor of the predictions of the “modernization theory,” starting with a cutthroat reward structure and then changing this in a more egalitarian direction to take advantage of better insurance for their citizens. Nevertheless, the intuition is very different from that of the approaches based on modernization theory, and the driving force is again the positive externalities created by the frontier economy. It is also worth noting that the broad pattern implied by this analysis is in line with the fact that the more egalitarian reward structures and elements of the welfare state did not arise in follower countries integrated into the world economy such as South Korea and Taiwan until they became somewhat more prosperous.

Second, we relax the assumption that the world technology frontier is affected only by innovation in the most technologically advanced country. We show that our main results extend to

this case, provided that the function aggregating the innovation decisions of all countries into the world technology frontier is sufficiently convex. In particular, such convexity ensures that innovations by the more advanced countries are more important for world technological progress, and creates the economic forces towards an asymmetric equilibrium, which is at the root of our main result leading to an endogenous separation between cutthroat and cuddly countries.

Finally, we consider an extension in which we introduce domestic politics as a constraint on the behavior of the social planner. We do this in a simple, reduced-form, assuming that in some countries there is a trade union (or a strong social democratic party) ruling out reward structures that are very unequal. We show that if two countries start at the same level initially, an effective labor movement or social democratic party in country 1 may prevent cutthroat capitalism in that country, inducing a unique equilibrium in which country 2 is the one adopting the cutthroat reward structure. In this case, however, this is a significant advantage, because if the two countries start at the same level, the cutthroat country always has lower welfare. Therefore, a tradition of strong a social democratic party or labor movement, by constraining the actions of the social planner, can act as a commitment device to egalitarianism, inducing an equilibrium in which the country in question becomes the beneficiary from the asymmetric world equilibrium. This result highlights that even if we cannot all be like Scandinavians, there are benefits from having the political institutions of Scandinavian nations—albeit at the cost of some other country in the world equilibrium adopting the cutthroat reward structure. This result thus also has the flavor of the domestic political conflicts in one country being “exported” to another, as the strength of the unions or the social democratic party in country 1 makes the poor in country 2 suffer more—as country 2 in response adopts a more cutthroat reward structure (a result with the same flavor of Davis, 1998, though he took institutions as exogenous and emphasized very different mechanisms).

Our paper is related to several different literatures. First, the issues we discuss are at the core of the “varieties of capitalism” literature in political science, e.g., Hall and Soskice (2001) which itself builds on earlier intellectual traditions offering taxonomies of different types of capitalism (Cusack, 2009) or welfare states (Esping-Anderson, 1990). A similar argument has also been developed by Rodrik (2008). As mentioned above, Hall and Soskice (2001) argue that while both CME and LMEs are innovative, they innovate in different ways and in different sectors. LMEs are good at “radical innovation” characteristic of particular sectors, like software development, biotechnology and semiconductors, while CMEs are good at “incremental innovation” in sectors such as machine tools, consumer durables and specialized transport equipment (see Taylor, 2004, and Akkermans, Castaldi, and Los, 2009, for assessments of the empirical evidence on these

issues). This literature has not considered that growth in an CME might critically depend on innovation in the LMEs and on how the institutions CMEs are influenced by this dependence. Most importantly, to the best of our knowledge, the point that the world equilibrium may be asymmetric, and different types of capitalism are chosen as best responses to each other, is new and does not feature in this literature. Moreover, we conduct our analysis within the context of a standard dynamic model of endogenous technological change and derive the world equilibrium from the interaction between multiple countries, which is different from the more qualitative approach of this literature.

Second, the idea that institutional differences may emerge endogenously depending on the distance to the world technology frontier has been emphasized in past work, for example, in Acemoglu, Aghion and Zilibotti (2006) (see also Krueger and Kumar, 2004). Nevertheless, this paper and others in this literature obtain this result from the domestic costs and benefits of different types of institutions (e.g., more or less competition in the product market), and the idea that activities leading to innovation are more important close to the world technology frontier is imposed as an assumption. In our model, this latter feature is endogenized in a world equilibrium, and the different institutions emerge as best responses to each other. Put differently, the distinguishing feature of our model is that the different institutions emerge as an asymmetric equilibrium of the world economy—while a symmetric equilibrium does not exist.

Third, our results also have the flavor of “symmetry breaking” as in several papers with endogenous location of economic activity (e.g., Krugman and Venables, 1996, Matsuyama, 2002, 2005) or with endogenous credit market frictions (Matsuyama, 2007). These papers share with ours the result that similar or identical countries may end up with different choices and welfare levels in equilibrium, but the underlying mechanism and the focus are very different.

Fourth, our work relates to the large literature which has tried to explain why the US lacks a European style welfare state and why Europeans work less. The preponderance of this literature relates these differences to different fundamentals. For example, the proportional representation electoral systems characteristic of continental Europe may lead to greater redistribution (Alesina, Glaeser and Sacerdote, 2001, Milesi-Ferretti, Perotti and Rostagno, 2002, Persson and Tabellini, 2003, Alesina and Glaeser, 2004), or the federal nature of the US may lower redistribution (Cameron, 1978, Alesina, Glaeser and Sacerdote, 2001), or the greater ethnic heterogeneity of the US may reduce the demand for redistribution (Alesina, Alberto, Glaeser and Sacerdote, 2001, Alesina and Glaeser, 2004), or greater social mobility in the US may mute the desire for redistributive taxation (Piketty, 1995, Bénabou and Ok, 2001, Alesina and La Ferrara, 2005), finally redistribution may be greater in Northern Europe because of higher levels of

social capital and trust (Algan, Cahuc and Sangnier, 2011). Greater work in the US can be explained by European labor market institutions (Alesina, Glaeser and Sacerdote, 2005, Other papers argue, perhaps more in the spirit of Hall and Soskice (2001) that there can be multiple equilibria. Piketty (1995) developed a model with multiple equilibria driven by self-fulfilling beliefs about social mobility, and Bénabou and Tirole (2006) developed one with self-fulfilling beliefs about justice, finally Bénabou’s (2000) model can simultaneously have one equilibria with high inequality and low redistribution and another with low inequality and high redistribution.<sup>11</sup> In none of these papers is the core idea of this paper developed that the institutions of one country interact with those of another and that even with identical fundamentals asymmetric equilibria are the norm not an exception to explain.

Finally, there is also a connection between our work and the literature on “dependency theory” in sociology, developed, among others, by Cardoso and Faletto (1979) and Wallerstein (1974-2011).<sup>12</sup> This theory argues that economic development in “core” economies, such as Western European and American ones, takes place at the expense of underdevelopment in the “periphery,” and that these two patterns are self-reinforcing. In this theory, countries such as the United States that grow faster are the winners from this asymmetric equilibrium. In our theory, there is also an asymmetric outcome, though the mechanisms are very different and indeed the model is more one of “reverse dependency theory” since it is the periphery which, via free-riding, is in a sense exploiting the core.

The rest of the paper is organized as follows. Section 2 introduces the economic environment. Section 3 presents the main results of the paper under two simplifying assumptions; first, focusing on a specification where progress in the world technology frontier is determined only by innovation in the technologically most advanced economy, and second, supposing that countries have to choose time-invariant reward structures. Under these assumptions and some plausible parameter restrictions, we show that there does not exist a symmetric world equilibrium, and instead, one country plays the role of the technology leader and adopts a cutthroat reward structure, while the rest choose more egalitarian reward structures. Section 4 establishes that relaxing these assumptions does not affect our main results. Section 5 shows how domestic political economy constraints can be advantageous for a country because they prevent it from adopting a cutthroat reward structure. Section 6 concludes, and proofs omitted from the text are contained in the Appendix.

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<sup>11</sup>Key to his model is that, contrary to the model we develop, redistribution can spur growth because of capital market imperfections a feature common to other papers such as Saint-Paul and Verdier (1993) and Moene and Wallerstein (1997). Such mechanisms could be added to our model without destroying the channels we emphasize. Which is more important is an empirical issue.

<sup>12</sup>We thank Leopoldo Fergusson for pointing out this connection.

## 2 Model

In this section, we first describe the economic environment. This environment combines two components: the first is a standard model of endogenous technological change with knowledge spillovers across  $J$  countries—and in fact closely follows Chapter 18 of Acemoglu (2009). The second component introduces moral hazard on the part of entrepreneurs, thus linking entrepreneurial innovative activity of an economy to its reward structure. We then introduce “country social planners” who choose to reward structures within their country in order to maximize discounted welfare.

### 2.1 Economic Environment

Consider an infinite-horizon economy consisting of  $J$  countries, indexed by  $j = 1, 2, \dots, J$ . Each country is inhabited by non-overlapping generations of agents who live for a period of length  $\Delta t$ , work, produce, consume and then die. A continuum of agents, with measure normalized to 1, is alive at any point in time in each country, and each generation is replaced by the next generation of the same size. We will consider the limit economy in which  $\Delta t \rightarrow 0$ , represented as a continuous time model.

The aggregate production function at time  $t$  in country  $j$  is

$$Y_j(t) = \frac{1}{1-\beta} \left( \int_0^{N_j(t)} x_j(\nu, t)^{1-\beta} d\nu \right) L_j^\beta, \quad (1)$$

where  $L_j$  is labor input,  $N_j(t)$  denotes the number of machine varieties (or blueprints for machine varieties) available to country  $j$  at time  $t$ . In our model,  $N_j(t)$  will be the key state variable and will represent the “technological know-how” of country  $j$  at time  $t$ . We assume that technology diffuses slowly and endogenously across countries as will be specified below. Finally,  $x_j(\nu, t)$  is the total amount of machine variety  $\nu$  used in country  $j$  at time  $t$ . To simplify the analysis, we suppose that  $x$  depreciates fully after use, so that the  $x$ ’s are not additional state variables. Though the machines depreciate fully after use, the blueprints for producing these machines, captured by  $N_j(t)$ , lives on, and the increase in the range of these blueprints will be the source of economic growth.

Each machine variety in economy  $j$  is owned by a technology monopolist, “entrepreneur,” who sells machines embodying this technology at the profit-maximizing (rental) price  $p_j^x(\nu, t)$  within the country (there is no international trade). This monopolist can produce each unit of the machine at a marginal cost of  $\psi$  in terms of the final good, and without any loss of generality, we normalize  $\psi \equiv 1 - \beta$ .

Suppose that each worker/entrepreneur exerts some effort  $e_{j,i}(t) \in \{0, 1\}$  to invent a new machine. Effort  $e_{j,i}(t) = 1$  costs  $\gamma > 0$  units of time, while  $e_{j,i}(t) = 0$  has no time cost. Thus, entrepreneurs who exert effort consume less leisure, which is costly. We also assume that entrepreneurial success is risky. When the entrepreneur exerts effort  $e_{j,i}(t) = 1$ , he is “successful” with probability  $q_1$  and unsuccessful with the complementary probability. If he exerts effort  $e_{j,i}(t) = 0$ , he is successful with the lower probability  $q_0 < q_1$ . Throughout we assume that effort choices are private information.

To ensure balanced growth, we assume that the utility function of entrepreneur/worker  $i$  takes the form

$$U(C_{j,i}(t), e_{j,i}(t)) = \frac{[C_{j,i}(t)(1 - \gamma e_{j,i}(t))]^{1-\theta} - 1}{1 - \theta}, \quad (2)$$

where  $\theta \geq 1$  is the coefficient of relative risk aversion (and the inverse of the intertemporal elasticity of substitution).<sup>13</sup>

We assume that workers can simultaneously work as entrepreneurs (so that there is no occupational choice). This implies that each individual receives wage income as well as income from entrepreneurship, and also implies that  $L_j = 1$  for  $j = 1, \dots, J$ .

An unsuccessful entrepreneur does not generate any new ideas (blueprints), while a successful entrepreneur in country  $j$  generates

$$\dot{N}_j(t) = \eta N(t)^\phi N_j(t)^{1-\phi},$$

new ideas for machines, where  $N(t)$  is an index of the world technology frontier, to be endogenized below, and  $\eta > 0$  and  $\phi > 0$  are assumed to be common across the  $J$  countries. This form of the innovation possibilities frontier implies that the technological know-how of country  $j$  advances as a result of the R&D and other technology-related investments of entrepreneurs in the country, but the effectiveness of these efforts also depends on how advanced the world technology frontier is relative to this country’s technological know-how. When it is more advanced, then the same sort of successful innovation will lead to more rapid advances, and the parameter  $\phi$  measures the extent of this.

Given the likelihood of success by entrepreneurs as a function of their effort choices and defining  $e_j(t) = \int e_{j,i}(t) di$ , technological advance in this country can be written as:

$$\dot{N}_j(t) = (q_1 e_j(t) + q_0(1 - e_j(t))) \eta N(t)^\phi N_j(t)^{1-\phi}, \quad (3)$$

We also assume that monopoly rights over the initial set of ideas about machines in the

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<sup>13</sup>When  $\theta = 1$ , the utility function in (2) converges to  $\ln C_{j,i}(t) + \ln(1 - \gamma e_{j,i}(t))$ . All of our results apply to this case also, but in what follows we often do not treat this case separately to save space.

country are randomly allocated to some of the current entrepreneurs, so that they are also produced monopolistically.<sup>14</sup>

Throughout, we maintain the following assumption:<sup>15</sup>

**Assumption 1:**

$$\min \left\{ q_1(1 - \gamma)^{1-\theta} - q_0, (1 - q_0) - (1 - q_1)(1 - \gamma)^{1-\theta} \right\} > 0$$

Finally, the world technology frontier is assumed to be given by

$$N(t) = G(N_1(t), \dots, N_J(t)), \tag{4}$$

where  $G$  is a linearly homogeneous function. We will examine two special cases of this function. The first is

$$G(N_1(t), \dots, N_J(t)) = \max \{N_1(t), \dots, N_J(t)\}. \tag{5}$$

which implies that the world technology frontier is given by the technology level of the most advanced country, the technology leader, and all other countries benefit from the advances of this technological leader. The second is a more general convex aggregator

$$G(N_1(t), \dots, N_J(t)) = \frac{1}{J} \left[ \sum_{j=1}^J N_j(t)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{6}$$

with  $\sigma < 0$ . As  $\sigma \uparrow 0$  (6) converges to (5). For much of the analysis, we focus on the simpler specification (5), though at the end of Section 4 we show that our general results are robust when we use (6) with  $\sigma$  sufficiently small.

## 2.2 Reward Structures

As noted above, entrepreneurial effort levels will depend on the *reward structure* in each country, which determines the relative rewards to successful entrepreneurship. In particular, suppressing the reference to country  $j$  to simplify notation, let  $\tilde{R}_s(t)$  denote the time  $t$  entrepreneurial income for successful entrepreneurs and  $\tilde{R}_u(t)$  for unsuccessful entrepreneurs. Thus the total income of a worker/entrepreneur is

$$R_i(t) = \tilde{R}_i(t) + w(t),$$

---

<sup>14</sup>The alternative is to assume that existing machines are produced competitively. This has no impact on any of the results in the paper, and would just change the value of  $B$  in (8) below.

<sup>15</sup>This assumption ensures that, both when  $\theta < 1$  and when  $\theta > 1$ , effort will only be forthcoming if entrepreneurs are given incentives. That is, it is sufficient to guarantee that with the same consumption conditional on success and failure, no entrepreneur would choose to exert effort. Why Assumption 1 ensures this can be seen from equation (7).

where  $w(t)$  is the equilibrium wage at time  $t$ .<sup>16</sup> In what follows, it is sufficient to look at the total income  $R_i$  rather than just the entrepreneurial component  $\tilde{R}_i$ . The reward structure can then be summarized by the ratio  $r(t) \equiv R_s(t)/R_u(t)$ . When  $r(t) = 1$ , there is perfect consumption insurance at time  $t$ , but this generates effort  $e = 0$ . Instead, to encourage  $e = 1$ , the summary index of the reward structure  $r(t)$  needs to be above a certain threshold, which we characterize in the next section.

This description makes it clear that countries will have a choice between two styles of capitalism: “cutthroat capitalism” in which  $r(t)$  is chosen above a certain threshold, so that entrepreneurial success is rewarded while failure is at least partly punished, and “cuddly capitalism” in which  $r(t) = 1$ , so that there is perfect equality and consumption insurance, but this comes at the expense of lower entrepreneurial effort and innovation.

Throughout we assume that the sequence of reward structures in country  $j$ ,  $[r_j(t)]_{t=0}^{\infty}$  is chosen by country-level social planner who maximizes the discounted welfare of the citizens in that country, given by

$$\int_0^{\infty} e^{-\rho t} \left( \int U(C_{j,i}(t), e_{j,i}(t)) di \right) dt,$$

where  $\rho$  is the discount rate that the social planner applies to future generations and  $U(C_{j,i}(t), e_{j,i}(t))$  denotes the utility of agent  $i$  in country  $j$  alive at time  $t$  (and thus the inner integral averages across all individuals of that generation). This assumption enables us to construct a simple game across countries and their choices of reward structures, taking into account how the reward structures of other countries will affect the evolution of the world technology frontier (in particular, it enables us to abstract from within-country political economy issues until later). Limiting the social planner to only choose the sequence of reward structures is for simplicity and without any consequence.<sup>17</sup>

### 3 Equilibrium with Time-Invariant Reward Structures

In this section, we simplify the analysis by assuming that the reward structure for each country  $j$  is time-invariant, i.e.,  $r_j(t) = r_j$ , and is chosen at time  $t = 0$ . This assumption implies that each country chooses between “cuddly” and “cutthroat” capitalism once and for all, and enables us to characterize the structure of the world equilibrium in a transparent manner, showing how this equilibrium often involves different choices of reward structures across countries—in particular, one country choosing cutthroat capitalism while the rest choose cuddly capitalism.

<sup>16</sup>Thus both  $\tilde{R}_u(t)$  and  $\tilde{R}_s(t)$  include the rents that entrepreneurs make in expectation because of existing ideas being randomly allocated to them.

<sup>17</sup>If we allow the social planner to set prices that prevent the monopoly markup, nothing in our analysis below, except that the value of  $B$  in (8), would change.

We show in the next section that these insights generalize to the case in which countries can change their reward structures dynamically. In addition, for most of this section, we focus on the “max” specification of the world technology frontier given by (5).

### 3.1 World Equilibrium Given Reward Structures

We first characterize the dynamics of growth for given (time-invariant) reward structures. The following proposition shows that a well-defined world equilibrium exists and involves all countries growing at the same rate, set by the rate of growth of the world technology frontier. This growth rate is determined by the innovation rates (and thus reward structures) of either all countries (with (6)) or the leading country (with (5)). In addition, differences in reward structures determine the relative income of each country.

**Proposition 1** *Suppose that the reward structure for each country is constant over time (i.e., for each  $j$ ,  $R_s^j(t)/R_u^j(t) = r_j$ ). Then starting from any initial conditions  $(N_1(0), \dots, N_J(0))$ , the world economy converges to a unique stationary distribution  $(n_1^*, \dots, n_J^*)$ , where  $n_j(t) \equiv N_j(t)/N(t)$  and  $\dot{N}(t)/N(t) = g^*$ , and  $(n_1^*, \dots, n_J^*)$  and  $g^*$  are functions of  $(r_1, \dots, r_J)$ . Moreover, with the max specification of the world technology frontier, (5),  $g^*$  is only a function of the most innovative country’s reward structure,  $r_\ell$ .*

**Proof.** The proof of this proposition follows from the material in Chapter 18 of Acemoglu (2009) with minor modifications and is omitted to save space. ■

The process of technology diffusion ensures that all countries grow at the same rate, even though they may choose different reward structures. In particular, countries that do not encourage innovation will first fall behind, but given the form of technology diffusion in equation (3), the advances in the world technology frontier will also pull them to the same growth rate as those that reward innovation. The proposition also shows that in the special case where (5) applies, it will be only innovation and the reward structure in the technologically most advanced country that determines the world growth rate,  $g^*$ .

### 3.2 Cutthroat and Cuddly Reward Structures

We now define the cutthroat and cuddly reward structures. First suppose that a country would like to set the reward structure so as to ensure effort  $e = 1$  at time  $t$ . This will require that the incentive compatibility constraint for entrepreneurs be satisfied at  $t$ , or in other words, expected utility from exerting effort  $e = 1$  should be greater than expected utility from  $e = 0$ . Using (2),

this requires

$$\frac{1}{1-\theta} \left( q_1 R_s(t)^{1-\theta} + (1-q_1) R_u(t)^{1-\theta} \right) (1-\gamma)^{1-\theta} \geq \frac{1}{1-\theta} \left( q_0 R_s(t)^{1-\theta} + (1-q_0) R_u(t)^{1-\theta} \right),$$

where recall that  $R_s(t)$  is the income and thus the consumption of an entrepreneur/worker conditional on successful innovation, and  $R_u(t)$  is the income level when unsuccessful, and this expression takes into account that high effort leads to success with probability  $q_1$  and low effort with probability  $q_0$ , but with high effort the total amount of leisure is only  $1-\gamma$ . Rearranging this expression, we obtain

$$\begin{aligned} r(t) \equiv \frac{R_s(t)}{R_u(t)} &\geq \left( \frac{(1-q_0) - (1-q_1)(1-\gamma)^{1-\theta}}{q_1(1-\gamma)^{1-\theta} - q_0} \right)^{\frac{1}{1-\theta}} \\ &= \left( 1 + \frac{1 - (1-\gamma)^{1-\theta}}{q_1(1-\gamma)^{1-\theta} - q_0} \right)^{\frac{1}{1-\theta}} \equiv A. \end{aligned} \quad (7)$$

Clearly, the expression  $A$  defined in (7) measures how “high-powered” the reward structure needs to be in order to induce effort, and will thus play an important role in what follows. Assumption 1 is sufficient to ensure that  $A > 1$ .<sup>18</sup>

Since the social planner maximizes average utility, she would like to achieve as much consumption insurance as possible subject to the incentive compatibility constraint (7), which implies that she will satisfy this constraint as equality. In addition,  $R_s(t)$  and  $R_u(t)$  must be satisfy the resource constraint at time  $t$ . Using the expression for total output and expenditure on machines provided in the Appendix, this implies

$$q_1 R_s(t) + (1-q_1) R_u(t) = B N_j(t)$$

where

$$B \equiv \frac{\beta(2-\beta)}{1-\beta}, \quad (8)$$

and we are using the fact that in this case, all entrepreneurs will exert high effort, so a fraction  $q_1$  of them will be successful. Combining this expression with (7), we obtain

$$R_s(t) = \frac{BA}{q_1 A + (1-q_1)} N_j(t) \quad \text{and} \quad R_u(t) = \frac{B}{q_1 A + (1-q_1)} N_j(t). \quad (9)$$

The alternative to a reward structure that encourages effort is one that forgoes effort and provides full consumption insurance—i.e., the same level of income to all entrepreneur/workers of  $R_0(t)$ , regardless of whether they are successful or not. In this case, the same resource constraint implies

$$R_0(t) = B N_j(t). \quad (10)$$

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<sup>18</sup>In particular, when  $\theta < 1$ ,  $1 + \frac{1-(1-\gamma)^{1-\theta}}{q_1(1-\gamma)^{1-\theta}-q_0}$  is greater than one and is raised to a positive power, while when  $\theta > 1$ , it is less than one and it is raised to a negative power.

Given these expressions, the expected utility of entrepreneurs/workers under the “cutthroat” and “cuddly” capitalist systems, denoted respectively by  $s = c$  and  $s = o$ , can be rewritten as

$$W_j^c(t) \equiv \mathbb{E} [U (C_j^c(t), e_j^c(t))] = \frac{\left( q_1 R_s(t)^{1-\theta} + (1 - q_1) R_u(t)^{1-\theta} \right) (1 - \gamma)^{1-\theta} - 1}{1 - \theta},$$

$$W_j^o(t) \equiv \mathbb{E} [U (C_j^o(t), e_j^o(t))] = \frac{R_0(t)^{1-\theta} - 1}{1 - \theta}.$$

Now using (9) and (10), we can express these expected utilities as:<sup>19</sup>

$$W_j^c(t) = \omega_c N_j(t)^{1-\theta} - \frac{1}{1-\theta} \text{ and } W_j^o(t) = \omega_o N_j(t)^{1-\theta} - \frac{1}{1-\theta},$$

where

$$\omega_c \equiv \frac{(q_1 A^{1-\theta} + (1 - q_1)) (1 - \gamma)^{1-\theta} B^{1-\theta}}{(q_1 A + (1 - q_1))^{1-\theta}} \frac{1}{1 - \theta} \text{ and } \omega_o \equiv \frac{B^{1-\theta}}{1 - \theta}. \quad (11)$$

It can be verified that  $\omega_c < \omega_o$ , though when  $\theta > 1$ , it is important to observe that we have  $\omega_c < \omega_o < 0$ . It can also be established straightforwardly that  $\omega_c$ , and thus the ratio  $\omega_c/\omega_o$ , is decreasing in  $A$  (defined in (7)) since a higher  $A$  translates into greater consumption variability. It can also be verified that  $A$  (and thus  $\omega_c/\omega_o$ ) is increasing in  $\gamma$  (to compensate for the higher cost of effort), but  $A$  is non-monotone in  $\theta$  (because a higher coefficient of relative risk aversion also reduces the disutility of effort).

From (3), the growth rate of technology of country  $j$  adopting reward structure  $s_j \in \{c, o\}$  can be derived as

$$\dot{N}_j(t) = g_{s_j} N(t)^\phi N_j(t)^{1-\phi}$$

where the growth rates  $g_{s_j} \in \{g_c, g_o\}$  are given by

$$g_o \equiv q_0 \eta, \text{ and } g_c \equiv q_1 \eta.$$

This reiterates that at any point in time, country choosing a cutthroat reward structure will have a faster growth of its technology stock.

### 3.3 Equilibrium Reward Structures

We now characterize the equilibrium of the game between the country social planners. Since reward structures are chosen once and for all at time  $t = 0$ , the interactions between the country social planners can be represented as a static game with the payoffs given as the discounted payoffs implied by the reward structures of all countries (given initial conditions  $\{N_1(0), \dots, N_J(0)\}$ ).

<sup>19</sup>In what follows, we will also drop the constant  $-1/(1 - \theta)$  in  $W_j^c(t)$  and  $W_j^o(t)$  when this causes no confusion.

We will characterize the Nash equilibria of this static game. We also restrict attention to the situation in which the same country, denoted  $\ell$ , remains the technology leader throughout. Given our focus on the world technology frontier specification in (5), the fact that this country is the leader implies at each  $t$  implies that  $N_\ell(t) = \max\{N_1(t), \dots, N_J(t)\}$  for all  $t$ . This assumption simplifies the exposition in this section.<sup>20</sup>

We introduce a second assumption, which will also be maintained throughout:

**Assumption 2:**

$$\frac{\omega_c}{\rho - (1 - \theta)g_c} > \frac{\omega_o}{\rho - (1 - \theta)g_o}.$$

This assumption ensures that the technology leader, country  $\ell$ , prefers a cutthroat reward structure. This can be seen straightforwardly by noting that when the growth rate of the world technology frontier is determined by innovation in country  $\ell$ ,  $\frac{\omega_c}{\rho - (1 - \theta)g_c}$  is the discounted value from such a cutthroat reward structure, while the discounted value of a cuddly reward structure is  $\frac{\omega_o}{\rho - (1 - \theta)g_o}$  given that all other countries are choosing a cuddly strategy.<sup>21</sup>

Now recalling that  $n_j(t) \equiv N_j(t)/N(t) = N_j(t)/N_\ell(t)$ , for  $j \neq \ell$  we have

$$\frac{\dot{n}_j(t)}{n_j(t)} = \left(\frac{N_\ell(t)}{N_j(t)}\right)^\phi g_{s_j} - g_\ell = n_j(t)^{-\phi} g_{s_j} - g_\ell.$$

where  $g_\ell = g_c$ , and we have imposed that the leader is choosing a cutthroat reward structure. This differential equation's solution is

$$N_j(t) = \left(N_j(0)^\phi + \frac{g_{s_j}}{g_c} \left(e^{\phi g_c t} - 1\right) (N_\ell(0))^\phi\right)^{\frac{1}{\phi}}, \quad (12)$$

enabling us to evaluate the welfare of the country  $j$  the social planner choosing reward structure  $s_j \in \{c, o\}$  as

$$\begin{aligned} \mathcal{W}_j(s_j) &= \int_0^\infty e^{-\rho t} W_j^{s_j}(t) dt = \int_0^\infty e^{-\rho t} \omega_{s_j} N_\ell(0)^{1-\theta} \left(n_j(0)^\phi + \frac{g_{s_j}}{g_c} \left(e^{\phi g_c t} - 1\right)\right)^{\frac{1-\theta}{\phi}} dt \quad (13) \\ &= \omega_{s_j} N_\ell(0)^{1-\theta} \left(\frac{g_{s_j}}{g_c}\right)^{\frac{1-\theta}{\phi}} \int_0^\infty e^{-(\rho - (1-\theta)g_c)t} \left(1 + \left(\frac{g_c}{g_{s_j}} n_j(0)^\phi - 1\right) e^{-\phi g_c t}\right)^{\frac{1-\theta}{\phi}} dt, \end{aligned}$$

where recall that  $n_j(0) \equiv N_j(0)/N_\ell(0)$ .

The second line of (13) highlights that, under Assumption 2, the long-run growth rate of all countries will be  $g_c$ , and thus ensure that these welfare levels are well defined, we impose the following assumption:

<sup>20</sup>Essentially, it enables us to pick a unique equilibrium among asymmetric equilibria. A byproduct of the analysis in Section 5 is to show how this assumption can be relaxed without affecting any of our results.

<sup>21</sup>If the country in question chose a cuddly reward structure while some other country chose the cutthroat structure, then this other country would necessarily become the leader at some point. Here we are restricting attention to the case in which this other country would be the leader from the beginning, which is without much loss of generality.

**Assumption 3**

$$\rho - (1 - \theta) g_c > 0.$$

Under Assumptions 2 and 3, country  $j$  will adopt a cuddly reward structure when  $\mathcal{W}_j(o) > \mathcal{W}_j(c)$ . This implies the following straightforward result:

**Proposition 2** *Suppose that each country chooses a time-invariant reward structure at time  $t = 0$ . Suppose also that the world technology frontier is given by (5), Assumptions 1-3 hold, and*

$$\left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}} < \left(\frac{g_o}{g_c}\right)^{\frac{1}{\phi}} \left( \frac{\int_0^\infty e^{-(\rho-(1-\theta)g_c)t} \left(1 + \left(\frac{g_c}{g_o} n_j(0)^\phi - 1\right) e^{-\phi g_c t}\right)^{\frac{1-\theta}{\phi}} dt}{\int_0^\infty e^{-(\rho-(1-\theta)g_c)t} \left(1 + \left(n_j(0)^\phi - 1\right) e^{-\phi g_c t}\right)^{\frac{1-\theta}{\phi}} dt} \right)^{\frac{1}{1-\theta}} \quad \text{for each } j \neq \ell. \quad (14)$$

*Then there exists no symmetric equilibrium. Moreover, there exists a unique world equilibrium in which the initial technology leader, country  $\ell$  remains so throughout, and this equilibrium involves country  $\ell$  choosing a cutthroat reward structure, while all other countries choose a cuddly reward structure. In this world equilibrium, country  $\ell$  grows at the rate  $g_c$  throughout, while all other countries asymptotically grow also at this rate, and converge to a level of income equal to a fraction  $g_o/g_c$  of the level of income of country  $\ell$ .*

**Proof.** Suppose first that country  $\ell$  chooses a cutthroat reward structures throughout. Then the result that country  $j$  strictly prefers to choose a cuddly reward structure follows immediately from comparing  $\mathcal{W}_j(c)$  and  $\mathcal{W}_j(o)$  given by (13) (remembering that when  $\theta > 1$ , we have  $\omega_c < \omega_o < 0$  and thus the direction of inequality is reversed twice, first when we divide by  $\omega_o$  and second when we raise the left-hand side to the power  $1/(1 - \theta)$ ).

The result that there exists no symmetric equilibrium in which all countries choose the same reward structure follows from this observation: when (14) holds, all  $j \neq \ell$  will choose a cuddly reward structure when  $\ell$  chooses a cutthroat reward structure; and Assumption 2 implies that when  $j \neq \ell$  choose a cuddly reward structure, country  $\ell$  strictly prefers to choose a cutthroat reward structure. This also characterizes the unique equilibrium in which  $\ell$  remains the technology leader throughout.

Finally, convergence to a unique stationary distribution of income with the same asymptotic growth rate follows from Proposition 1, and the ratio of income between the leader and followers in this stationary distribution is given from the limit of equation (12). ■

The important implication is that, under the hypotheses of the proposition, the world equilibrium is necessarily asymmetric—i.e., a symmetric equilibrium does not exist. Rather, it

involves one country choosing a cutthroat reward structure, while all others choose cuddly reward structures. The intuition for this result comes from the differential impacts of the leader, country  $\ell$ , and non-leader countries on the world growth rate. Because country  $\ell$ 's innovations and reward structure determine the pace of change of the world technology frontier, if it were to switch from a cutthroat to a cuddly reward structure, this would have a *growth effect* on the world economy (and thus on itself). The prospect of permanently lower growth discourages country  $\ell$  from choosing a cuddly reward structure. In contrast, any other country deviating from the asymmetric equilibrium and choosing a cutthroat reward structure would only enjoy a beneficial *level effect*: such a country would increase its position relative to country  $\ell$ , but would not change its long-run growth rate (because its growth rate is already high thanks to the spillovers from the cutthroat incentives that country  $\ell$  provides to its entrepreneurs). The contrast between the growth effect of the reward structure of the leader and the level effect of the reward structure of followers is at the root of the asymmetric equilibrium (and the non-existence of asymmetric equilibrium).<sup>22</sup>

Condition (14), which ensures that the world equilibrium is asymmetric, is in terms of the ratio of two integrals which do not in general have closed-form solutions. Nevertheless, the special case where  $\phi = 1 - \theta$  admits a closed-form solution and is useful to illustrate the main insights. In particular, in this case (14) simplifies to :

$$\left(\frac{\omega_c}{\omega_o}\right) < \left(\frac{g_o}{g_c}\right) \left(\frac{\int_0^\infty e^{-(\rho-\phi g_c)t} \left(1 + \left(\frac{g_c}{g_o} n_j(0)^\phi - 1\right) e^{-\phi g_c t}\right) dt}{\int_0^\infty e^{-(\rho-\phi g_c)t} \left(1 + \left(n_j(0)^\phi - 1\right) e^{-\phi g_c t}\right) dt}\right) = \frac{n_j(0)^\phi (\rho - \phi g_c) + \phi g_o}{n_j(0)^\phi (\rho - \phi g_c) + \phi g_c} \quad (15)$$

Inspection of (15) shows that an asymmetric equilibrium is more likely to emerge when  $n_j(0)$  is close to 1 for all followers—since the last expression is strictly increasing in  $n_j(0)$ . This implies that, bearing in mind that country  $\ell$  is the technology leader initially, the asymmetric equilibrium is more likely to emerge when all countries are relatively equal to start with. Intuitively, the innovation possibilities frontier (3) implies that a country that is further behind the world technology frontier (i.e., low  $n_j(0)$ ) has a greater growth potential—and in fact will grow faster for a given level of innovative activity. This also implies that the additional gain in growth from choosing a cutthroat reward structure is greater the lower is  $n_j(0)$ . Consequently, for countries that are significantly behind the world technology frontier (or behind country  $\ell$ ), the incentives

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<sup>22</sup>Naturally, with any asymmetric equilibrium of this type, there are in principle several equilibria, with one country playing the role of the leader and choosing a cutthroat reward structure, while others choose cuddly reward structures. Uniqueness here results from the fact that we have imposed that the same country remains the leader throughout, which picks the initial technology leader as the country choosing the cutthroat reward structure.

to also adopt a cutthroat reward structure are stronger.<sup>23</sup>

Proposition 2 is stated under condition (14), which ensures that the world equilibrium is asymmetric. This condition is in terms of the ratio of two integrals which do not have closed-form solutions. We next provide a simpler sufficient condition that enables us to reach the same conclusion.

**Corollary 1** 1. *The condition*

$$\left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}} < \left(\frac{g_o}{g_c}\right)^{\frac{1}{\phi}} \quad (16)$$

*is sufficient for (14) to hold, so under this condition and the remaining hypotheses of Proposition 1, the conclusions in Proposition 1 hold.*

2. *In addition, there exists  $\bar{n}$  such that for  $n_j(0) < \bar{n}$ , the condition*

$$\left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}} < \left(\frac{g_o}{g_c}\right)^{\frac{1}{\phi}} \left[1 + \frac{n_j(0)^\phi}{\phi} (\rho - (1-\theta)g_c) \left(\frac{1}{g_o} - \frac{1}{g_c}\right)\right]^{\frac{1}{1-\theta}} \quad (17)$$

*is sufficient for (14) to hold, so under this condition and the remaining hypotheses of Proposition 1, the conclusions in Proposition 1 hold.*

**Proof.** See the Appendix, where we also prove that the sufficient condition (16) is satisfied for a non-empty set of parameter values. ■

We next provide a simple result characterizing when Assumption 2 (which ensures that the leader prefers a cutthroat reward structure) and (16) (which ensures that followers choose a cuddly reward structure) are simultaneously satisfied. This result illustrates the role of risk aversion in the asymmetric equilibria described above.<sup>24</sup>

**Corollary 2** 1. *Condition (16) is satisfied for  $\gamma \in (0, \bar{\gamma})$  and  $\theta \geq \theta^*(\phi, \gamma)$  where  $\bar{\gamma} > 0$  and  $0 < \theta^*(\phi, \gamma) < \infty$ . Moreover  $\theta^*(\phi, \gamma)$  is decreasing in  $\phi$  and  $\gamma$ .*

2. *Assumption 2 is satisfied for  $\theta \in [0, \bar{\theta}]$  and  $\rho \in (\bar{\rho}(\theta, \gamma), (1-\theta)g_c)$ , where  $\bar{\theta} > 0$ . Moreover  $\bar{\rho}(\theta, \gamma)$  is decreasing in  $\theta$  and in  $\gamma$ .*

Therefore, this corollary implies that the asymmetric equilibrium will arise (or more accurately, the sufficient conditions for an asymmetric equilibria will be satisfied) when  $\theta \geq \theta^*(\phi, \gamma)$ , i.e., when the coefficient of relative risk aversion is sufficiently high. But to ensure Assumption

<sup>23</sup>We will see in the next section that this economic force will sometimes lead to a time-varying reward structure.

<sup>24</sup>Recall, however, that (16) is a sufficient condition—not the exact condition—for such a symmetric equilibria to exist.

3 also holds, this coefficient needs to be less than some threshold  $\bar{\theta} > 1$ . Note, however, that as  $\phi$  increases (so that there are greater technology spillovers from the leader to followers),  $\theta^*(\phi, \gamma)$  decreases, making these conditions more likely to be satisfied. Naturally, as the second part of the corollary specifies, we also need  $\rho$  not to be too small, otherwise it would not be a best response for the technology leader to choose a cutthroat reward structure.

**Remark 1** In this section, we have restricted countries to choose either cutthroat or cuddly reward structures for all of their entrepreneurs. In the next section, we allow for mixed reward structures whereby some entrepreneurs are given incentives to exert high effort, while others are not. It is straightforward to see that in this case, (14) continues to be sufficient, together with Assumptions 1-3, for there not to exist a symmetric equilibrium, but is no longer necessary. Sufficiency follows simply from the following observation: condition (14) implies that for followers a cuddly reward structure is preferred to a cutthroat one, so even when intermediate reward structures are possible, the equilibrium will not involve a cutthroat reward structure, hence will not be symmetric. The reason why (14) is not necessary is that when  $\phi > 1 - \theta$ , welfare is concave in the fraction of agents receiving cutthroat incentives (as we show in the next section), and thus even if a cuddly reward structure is not preferred to a cutthroat one, an intermediate one may be. In particular, denoting the fraction of entrepreneurs receiving cutthroat incentives by  $u$ , the necessary condition is

$$\begin{aligned} & \frac{\partial \mathcal{W}_j(u=1)}{\partial u} \\ = & (\omega_c - \omega_o) \int_0^\infty e^{-\rho t} \left( n_j(0)^\phi + e^{\phi g_c t} - 1 \right)^{\frac{1-\theta}{\phi}} dt + \frac{(1-\theta)\omega_c(g_c - g_o)}{\phi g_c} \int_0^\infty e^{-\rho t} \left( n_j(0)^\phi + \left( e^{\phi g_c t} - 1 \right) \right)^{\frac{1-\theta}{\phi} - 1} \left( e^{\phi g_c t} - 1 \right) dt \end{aligned}$$

We can also note that under Assumption 1-3, there cannot be a fully mixed reward structure equilibrium where all countries choose a fraction  $u^*$  of entrepreneurs receiving cutthroat incentives. Suppose that all countries, except the technology leader, choose a mixed reward structure with the fraction  $u^*$  of entrepreneurs receiving cutthroat incentives. If the leader also chose  $u^*$ , it would remain the technology leader forever, with discounted utility of

$$\mathcal{W}_\ell(u^*) = \frac{\omega_c u^* + \omega_o(1 - u^*)}{\rho - (1 - \theta)[g_c u^* + g_o(1 - u^*)]}.$$

But it can be verified that this is strictly increasing in  $u^*$ , so that the leader would in fact prefer a fully cutthroat reward structure.

### 3.4 Welfare

The most interesting result concerning welfare is that, even though the technological leader, country  $\ell$ , starts out ahead of others and chooses a “growth-maximizing” strategy, average

welfare (using the social planner’s discount rate) may be lower in that country than in the followers choosing a cuddly reward structure. This result is contained in the next proposition and its intuition captures the central economic force of our model: followers are both able to choose an egalitarian reward structure providing perfect insurance to their entrepreneur/workers and benefit from the rapid growth of technology driven by the technology leader, country  $\ell$ , because they are able to free-ride on the cutthroat reward structure in country  $\ell$ , which is advancing the world technology frontier. In contrast, country  $\ell$ , as the technology leader, must bear the cost of high risk for its entrepreneur/workers. The fact that followers prefer to choose the cuddly reward structure implies that, all else equal, the leader, country  $\ell$ , would have also liked to but cannot do so, because it realizes that if it did, the growth rate of world technology frontier would slow down—while followers know that the world technology frontier is being advanced by country  $\ell$  and can thus free-ride on that country’s cutthroat reward structure.

**Proposition 3** *Suppose that countries are restricted to time-invariant reward structures, and Assumptions 1-3 and (14) hold, so that country  $\ell$  adopts the cutthroat strategy and country  $j$  adopts the cuddly strategy. Then there exists  $\delta > 0$  such that for all  $n_j(0) > 1 - \delta$ , welfare in country  $j$  is higher than welfare in country  $\ell$ .*

**Proof.** Consider the case where  $n_\ell(0) = n_j(0)$ . Then the result follows immediately from (14), since, given this condition, country  $j$  strictly prefers to choose a cuddly rather than a cutthroat reward structure. If it were to choose a cutthroat structure, it would have exactly the same welfare as country  $\ell$ . Next by continuity, this is also true for  $n_j(0) > 1 - \delta$  for  $\delta$  sufficiently small and positive. ■

## 4 Equilibrium with Time-Varying Rewards Structures

In this section, we relax the assumption that reward structures are time-invariant, and thus assume that each country chooses  $s_j(t) \in \{c, o\}$  at time  $t$ , given the strategies of other countries, thus defining a differential game among the  $J$  countries. We focus on the Markov perfect equilibria of this differential game, where strategies at time  $t$  are only conditioned on payoff relevant variables, given by the vector of technology levels. To start with, we focus on the world technology frontier given by (5), and at the end, we will show that the most important insights generalize to the case with general aggregators of the form (6) provided that these aggregators are sufficiently “convex,” i.e., putting more weight on technologically more advanced countries.

## 4.1 Main Result

In this subsection, we focus on the world technology frontier given by (5), and also assume that at the initial date, there exists a single country  $\ell$  that is the technology leader, i.e., a single  $\ell$  for which  $N_\ell(0) = \max\{N_1(0), \dots, N_J(0)\}$ . We also allow follower countries to provide cutthroat reward structures to some of their entrepreneurs while choosing a cuddly reward structure for the rest. Hence, we define  $u_j(t)$  as the fraction of entrepreneurs receiving a cutthroat reward structure,<sup>25</sup> and thus

$$\begin{aligned}\omega(u_j(t)) &= \omega_o(1 - u_j(t)) + \omega_c u_j(t) \\ g(u_j(t)) &= g_o(1 - u_j(t)) + g_c u_j(t),\end{aligned}$$

with  $u_j(t) \in [0, 1]$ , and naturally  $u_j(t) = 0$  at all points in time corresponds to a cuddly reward structure and  $u_j(t) = 1$  for all time is cutthroat throughout, like those analyzed in the previous section.

The problem of the country  $j$  social planner can then be written as

$$\begin{aligned}\mathcal{W}_j(N_j(t), N_\ell(t)) &= \max_{u_j(\cdot) \in [0, 1]} \int_t^\infty e^{-\rho(\tau-t)} \omega(u_j(\tau)) N_j(\tau)^{1-\theta} d\tau & (18) \\ \text{such that } \dot{N}_j(\tau) &= g(u_j(\tau)) N_\ell(\tau)^\phi N_j(\tau)^{1-\phi}, \\ \text{with } N_\ell(\tau) &= N(t) e^{g_c(\tau-t)} \text{ (for } \tau \geq t).\end{aligned}$$

Depending on what the country  $j$  social planner can condition on for the choice of time  $t$  reward structure, this would correspond to either a “closed loop” or “open loop” problem—i.e., one in which the strategies are chosen at the beginning or are updated as time goes by. In the Appendix, we show that the two problems have the same solution, so the distinction is not central in this case.

The main result in this section is as follows.

**Proposition 4** *Suppose the world technology frontier is given by (5), Assumptions 1-3 hold, and technology spillovers are large in the sense that  $\phi > 1 - \theta$ . Let*

$$\tilde{m} \equiv (1 - \theta) \frac{(\omega_o - \omega_c) g_c + (g_c - g_o) \omega_c}{(\omega_o - \omega_c) (\rho + \phi g_c)}. \quad (19)$$

*Then the world equilibrium is characterized as follows:*

1. *If*

$$\tilde{m} < \frac{g_o}{g_c}, \quad (20)$$

---

<sup>25</sup>It is straightforward to see that it is never optimal to give any entrepreneur any other reward structures than perfect insurance or the cutthroat reward structure that satisfies the incentive compatibility constraint as equality

there exist  $\bar{m} < g_o/g_c$  and  $0 < T < \infty$  such that for  $n_j(0) < \bar{m}^{1/\phi}$ , the reward structure of country  $j$  is cutthroat (i.e.,  $s_j(t) = c$  or  $u_j(t) = 1$ ) for all  $t \leq T$ , and cuddly (i.e.,  $s_j(t) = o$  or  $u_j(t) = 0$ ) for all  $t > T$ ; for  $n_j(0) \geq \bar{m}^{1/\phi}$ , the reward structure of country  $j$  is cuddly (i.e.,  $s_j(t) = o$  or  $u_j(t) = 0$ ) for all  $t$ . Moreover,  $\bar{m} > 0$  if  $\theta < 1$ , and  $\bar{m} < 0$  if  $\theta$  is sufficiently large (in which case the cuddly reward structure applies with any initial condition). Regardless of the initial condition (and the exact value of  $\bar{m}$ ), in this case,  $n_j(t) \rightarrow (g_o/g_c)^{1/\phi}$ .

2. If

$$\frac{g_o}{g_c} < \tilde{m} < 1, \quad (21)$$

there exists  $0 < T < \infty$  such that for  $n_j(0) < \tilde{m}^{1/\phi}$ , the reward structure of country  $j$  is cutthroat (i.e.,  $s_j(t) = c$  or  $u_j(t) = 1$ ) for all  $t \leq T$ , and then at  $t = T$  when  $n_j(T) = \tilde{m}^{1/\phi}$ , the country adopts a “mixed” reward structure and stays at  $n_j(t) = \tilde{m}^{1/\phi}$  (i.e.,  $u_j(t) = u_j^* \in (0,1)$ ) for all  $t > T$ ; for  $n_j(0) > \tilde{m}^{1/\phi}$ , the reward structure of country  $j$  is cuddly (i.e.,  $s_j(t) = o$  or  $u_j(t) = 0$ ) for all  $t \leq T$ , and then at  $t = T$  when  $n_j(T) = \tilde{m}^{1/\phi}$ , the country adopts a mixed reward structure and stays at  $n_j(t) = \tilde{m}^{1/\phi}$  (i.e.,  $u_j(t) = u_j^* \in (0,1)$ ) for all  $t > T$ .

3. If

$$\tilde{m} > 1, \quad (22)$$

then the reward structure of country  $j$  is cutthroat for all  $t$  (i.e.,  $s_j(t) = c$  or  $u_j(t) = 1$  for all  $t$ ).

**Proof.** See the Appendix. ■

This proposition has several important implications. First, the equilibrium of the previous section emerges as a special case, in particular when condition (20) holds and the initial gap between the leader and the followers is not too large (i.e.,  $n_j(0)$  is greater than the threshold specified in the proposition), or when  $\bar{m} < 0$ . In this case, the restriction to time-invariant reward structures is not binding, and exactly the same insights as in the previous section obtain.

Secondly, however, the rest of the proposition shows that the restriction to time-invariant reward structures is generally binding, and the equilibrium involves countries changing their reward structures over time. In fact, part 1 of the proposition shows that, in line with the discussion following Proposition 2, the growth benefits of cutthroat reward structures are greater when the initial gap between the leader and the country in question is larger, because this creates a period during which this country can converge rapidly to the level of income of the technological

leader, and a cutthroat reward structure can significantly increase this convergence growth rate. In consequence, for a range of parameters, the equilibrium involves countries that are sufficiently behind the technological leader choosing cutthroat reward structures, and then after a certain amount of convergence takes place, switching to cuddly capitalism. This pattern, at least from a bird’s eye perspective, captures the sort of growth and social trajectory followed by countries such as South Korea and Taiwan, which adopted fairly high-powered incentives with little safety net during their early phases of convergence, but then started building a welfare state.

Thirdly, part 2 shows that without the restriction to time-invariant reward structures, some countries may adopt mixed reward structures when they are close to the income level of the leader. With such reward structures some entrepreneurs are made to bear risk, while others are given perfect insurance—and thus are less innovative. This enables them to reach a growth rate between that implied by a fully cuddly reward structure and the higher growth rate of the cutthroat reward structure.

Finally, for another range of parameters (part 3 of the proposition), there is “institutional convergence” in that followers also adopt cutthroat reward structures. When this is the case, technology spillovers ensure not only the same long-run growth rate across all countries but convergence in income and technology levels. In contrast, in other cases, countries maintain their different institutions (reward structures), and as a result, they reach the same growth rate, but their income levels do not converge.

The growth dynamics implied by this proposition are also interesting. These are shown in Figures 5-7. Figure 5 corresponds to the part 1 of Proposition 4, and shows the pattern where, starting with a low enough initial condition, i.e.,  $n_j(0) < \bar{m}^{1/\phi}$ , cutthroat capitalism is followed by cuddly capitalism. As the figure shows, when  $n_j(t)$  reaches  $\bar{m}^{1/\phi}$ , the rate of convergence changes because there is a switch from cutthroat to cuddly capitalism. This figure also illustrates another important aspect of Proposition 4: there is institutional divergence as a country converges to the technological leader—and as a consequence of this, this convergence is incomplete, i.e.,  $n_j(t)$  converges to  $(g_o/g_c)^{1/\phi}$ . The figure also shows that countries that start out with  $n_j(0) > \bar{m}^{1/\phi}$  will choose cuddly capitalism throughout.

Figure 6 shows the somewhat different pattern of convergence implied by part 2 of the proposition, where followers reach the growth rate of the leader in finite time and at a higher level of relative income—because they choose a mixed reward structure in the limit. Nevertheless, institutional differences and level differences between the leader and followers remain. In Figure 7 corresponding to part 3, leaders and followers to the same institutions and there is complete convergence.

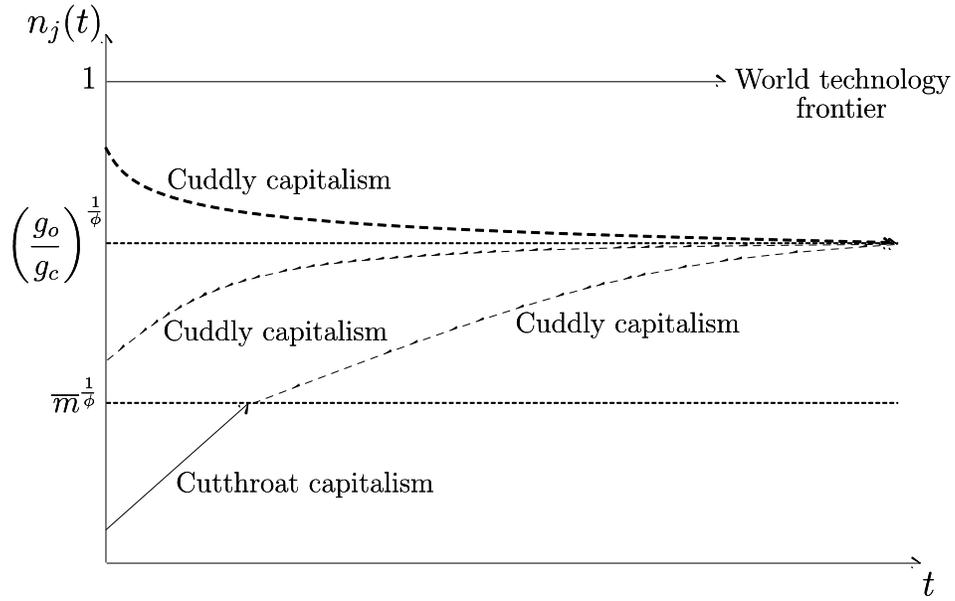


Figure 5: Growth dynamics: part 1 of Proposition 4

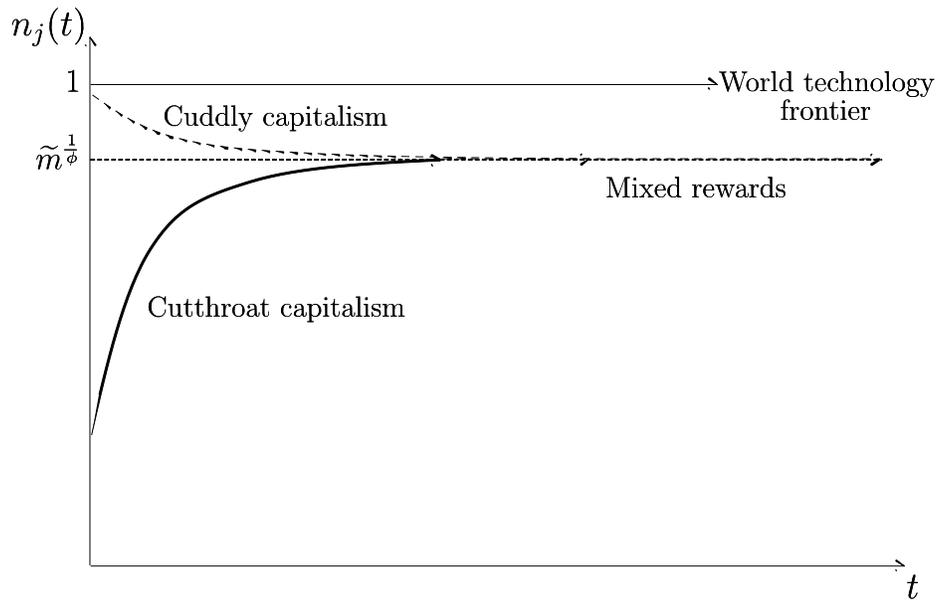


Figure 6: Growth dynamics: part 2 of Proposition 4

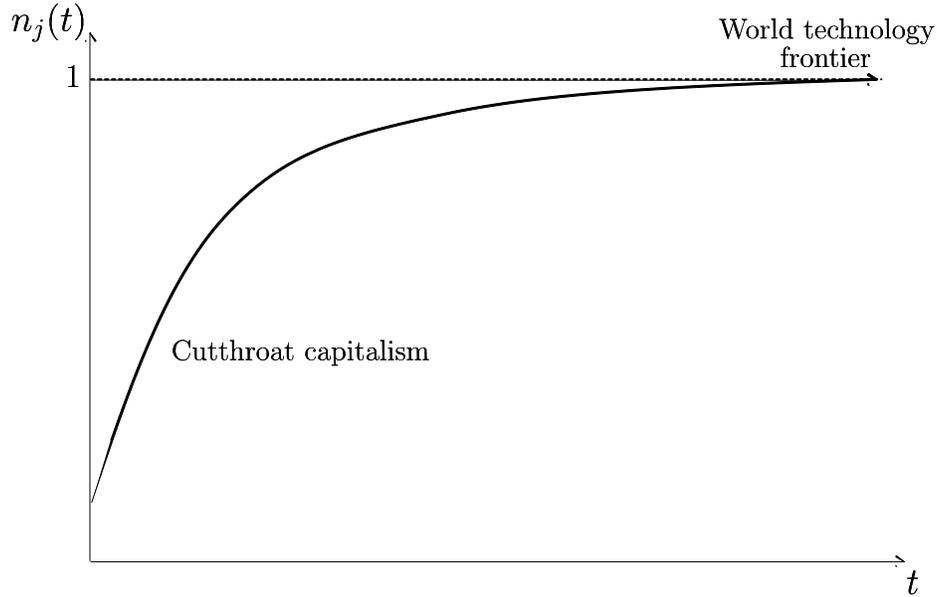


Figure 7: Growth dynamics: part 3 of Proposition 4

## 4.2 General Convex Aggregators for World Technology Frontier

We next show that the main result of this section holds with general aggregators of the form (6) provided that these aggregators are sufficiently “convex,” i.e., putting more weight on technologically more advanced countries. The main difference from the rest of our analysis is that with such convex aggregators, the world growth rate is no longer determined by the reward structure (and innovative activities) of a single technology leader, but by a weighted average of all economies. Nevertheless, the same economic forces exhibit themselves because the convexity of these aggregators implies that the impact on the world growth rate of a change in the reward structure of a technologically advanced country would be much larger than that of a backward economy, and this induces the relatively advanced economies to choose cutthroat reward structures, while relatively backward countries can free-ride and choose cuddly reward structures safe in the knowledge that their impact on the long-run growth rate of the world economy (and thus their own growth rate) will be small.

**Proposition 5** *Suppose that the world technology frontier is given by (6). Then there exist  $\bar{\sigma} < 0$ ,  $\bar{\rho} > 0$  and  $\bar{\gamma} < 1$  such that when  $\sigma \in (\bar{\sigma}, 0)$ ,  $\rho \leq \bar{\rho}$  and  $\bar{\gamma} > \gamma$  there is no symmetric world equilibrium with all countries choosing the same reward structure. Instead, there exists  $T < \infty$*

such that for all  $t > T$ , a subset of countries will choose a cutthroat reward structure while the remainder will choose a cuddly or mixed reward structure.

**Proof.** See the Appendix. ■

## 5 Equilibrium under Domestic Political Constraints

In this section, we focus on the world economy with two countries,  $j$  and  $j'$ , and also simplify the discussion by assuming that  $n_{j'}(0) = n_j(0)$ , by focusing on time-invariant reward structures as in Section 3, and also by assuming that the world technology frontier is given by (5) again as in Section 3. This implies that there are two asymmetric equilibria, one in which country  $j$  is the technology leader and  $j'$  the follower, and vice versa. We also suppose that the social planner in country  $j$  is subject to domestic political constraints imposed by unions or a social democratic party, which prevent the ratio of rewards when successful and unsuccessful to be less than some amount  $\zeta$ . There are no domestic constraints in country  $j'$ . If  $\zeta \geq A$ , then domestic constraints have no impact on the choice of country  $j$ , and there continue to be two asymmetric equilibria.

Suppose instead that  $\zeta < A$ . This implies that because of domestic political constraints, it is impossible for country  $j$  to adopt a cutthroat strategy regardless of the strategy of country  $j'$ . This implies that of the two asymmetric equilibria, the one in which country  $j$  adopts a cutthroat reward structure disappears, and the unique equilibrium (with time-invariant strategies) becomes the one in which country  $j'$  adopts the cutthroat strategy and country  $j$  chooses an egalitarian structure. However, from Proposition 4 above, this implies that country  $j$  will now have higher welfare than in the other asymmetric equilibrium (which has now disappeared). This simple example thus illustrates how domestic political constraints, particularly coming from the left and restricting the amount of inequality in society, can create an advantage in the world economy.

We next show that this result generalizes to the case in which the two countries do not start with the same initial level of technology. To do this, we relax our focus on equilibria in which the leader at time  $t = 0$  always remains the leader. Let us also suppose, without loss of any generality, that country  $j'$  is technologically more advanced at  $t = 0$ , so  $n_j(0) \leq 1$ . Finally, note that when condition (14) holds for  $n_j(0)$ , it also holds for  $n_{j'}(0) > 1$ , taking country  $j$  as the country always choosing a cutthroat reward structure. Then we have the following proposition.

**Proposition 6** *1. Suppose that there are two countries  $j$  and  $j'$  with initial technology levels  $N_{j'}(0) \geq N_j(0)$  (which is without loss of any generality), they are restricted to time-invariant reward structures, Assumptions 1-3 and condition (14) hold. Then there exists  $\delta > 0$  such that for all  $n_j(0) > 1 - \delta$ , there are two asymmetric time-invariant equilibria,*

*one in which country  $j$  adopts a cutthroat reward structure and country  $j'$  adopts a cuddly reward structure, and vice versa.*

- 2. If domestic constraints imply that country  $j$  cannot adopt a cutthroat reward structure, then the unique time-invariant equilibrium is the one in which country  $j'$  adopts a cutthroat reward structure and country  $j$  adopts a cuddly reward structure. The equilibrium welfare of country  $j$  is greater than that of country  $j'$ .*

**Proof.** The first part follows by noting that when Assumption 2 holds and the gap between the two countries is small, then it also ensures that the follower country would like to choose the cutthroat reward structure when it will determine the rate of change of the world technology frontier in the near future (i.e., for  $n_j(0) > 1 - \delta$ , there exists  $T$  such that the follower determines the world growth rate for  $t > T$ ). Part 2 then immediately follows from Proposition 4. ■

An interesting implication of this result is that country  $j$ , which has a stronger social democratic party or labor movement, benefits in welfare terms by having both equality and rapid growth, but in some sense exports its potential labor conflict to country  $j'$ , which now has to choose a reward structure with significantly greater inequality.

(Note: we may want to have a discussion of the strength of the labor movement in Sweden at the turn-of-the-century to complement this result).

## 6 Conclusion

In this paper, we have taken a first step towards a systematic investigation of institutional choices in an interdependent world—where countries trade or create knowledge spillovers on each other. Focusing on a model in which all countries benefit and potentially contribute to advances in the world technology frontier, we have suggested that the world equilibrium may necessarily be asymmetric. In our model economy, because effort by entrepreneurs is private information, a greater gap of incomes between successful and unsuccessful entrepreneurs—thus greater inequality—increases innovative effort and a country’s contributions to the world technology frontier. Under plausible assumptions, in particular with sufficient risk aversion and a sufficient return to entrepreneurial effort, some countries will opt for a type of “cutthroat” capitalism that generates greater inequality and more innovation and will become the technology leaders, while others will free-ride on the cutthroat incentives of the leaders and choose a more “cuddly” form of capitalism. We have also shown that, paradoxically, starting with similar initial conditions, those that choose cuddly capitalism, though poorer, will be better off than those opting for cutthroat capitalism. Nevertheless, this configuration is an equilibrium because

cutthroat capitalists cannot switch to cuddly capitalism without having a large impact on world growth, which would ultimately reduce their own welfare. This perspective therefore suggests that the diversity of institutions we observe among relatively advanced countries, ranging from greater inequality and risk taking in the United States to the more egalitarian societies supported by a strong safety net in Scandinavia, rather than reflecting differences in fundamentals between the citizens of these societies, may emerge as a mutually self-reinforcing equilibrium. If so, in this equilibrium, we cannot all be like the Scandinavians, because Scandinavian capitalism depends in part on the knowledge spillovers created by the more cutthroat American capitalism.

Clearly, the ideas developed in this paper are speculative. We have theoretically shown that a specific type of asymmetric equilibrium emerges in the context of a canonical model of growth—with knowledge spillovers combined with moral hazard on the part of entrepreneurs. Whether these ideas contribute to the actual divergent institutional choices among relatively advanced nations is largely an empirical question. We hope that our paper will be an impetus for a detailed empirical study of these issues.

In addition, there are other interesting theoretical questions raised by our investigation. Similar institutional feedbacks may also emerge when countries interact via international trade rather than knowledge spillovers. For example, if different stages of production require different types of incentives, specialization in production resulting in a Ricardian equilibrium may also lead to “institutional specialization”. In addition, while we have focused on a specific and simple aspect of institutions, the reward structure for entrepreneurs, our results already hint that there may be clusters of institutional characteristics that co-vary—for example, strong social democratic parties and labor movements leading to cuddly capitalism domestically and to cutthroat capitalism abroad. Institutional choices concerning educational systems, labor mobility, and training investments may also interact with those related to reward structures for entrepreneurs and workers. We believe that these are interesting topics for future study.

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## Appendix

**Derivation of Equation (10)** . To derive (10), we need to characterize the equilibrium prices and quantities in country  $j$  as a function of current technology  $N_j(t)$ . This follows directly from Chapter 18 of Acemoglu (2009). Here it suffices to note that the final good production function (1) implies iso-elastic demand for machines with elasticity  $1/\beta$ , and thus each monopolist will charge a constant monopoly price of  $\psi/(1-\beta)$ , where recall that  $\psi$  is the marginal cost in terms of the final good of producing any of the machines given its blueprint (invented or adapted from the world technology frontier). Our normalization that  $\psi \equiv 1-\beta$  then implies that monopoly prices and equilibrium quantities are given by  $p_j^x(\nu, t) = 1$  and  $x_j(\nu, t) = L_j = 1$  for all  $j, \nu$  and  $t$ . This gives that total expenditure on machines in country  $j$  at time  $t$  will be  $X_j(t) = (1-\beta)N_j(t)$ , while total gross output is

$$Y_j(t) = \frac{1}{1-\beta}N_j(t).$$

Therefore, total net output, left over for distributing across all workers/entrepreneurs is  $NY_j(t) \equiv Y_j(t) - X_j(t) = BN_j(t)$ , where

$$B \equiv \frac{\beta(2-\beta)}{1-\beta},$$

which gives us (10). ■

**Proof of Corollary 1.** We first proved the second part of the corollary. By integration by parts,

$$\begin{aligned} \int_0^\infty e^{-\rho t} \left( e^{\phi g_c t} - 1 \right)^{\frac{1-\theta}{\phi}} dt &= \left[ -\frac{e^{-\rho t}}{\rho} \left( e^{\phi g_c t} - 1 \right)^{\frac{1-\theta}{\phi}} \right]_0^\infty + \int_0^\infty \frac{e^{-\rho t}}{\rho} (1-\theta) e^{\phi g_c t} g_c \left( e^{\phi g_c t} - 1 \right)^{\frac{1-\theta}{\phi}-1} dt \\ &= \frac{(1-\theta)g_c}{\rho} \int_0^\infty e^{-\rho t} \left( e^{\phi g_c t} - 1 \right)^{\frac{1-\theta}{\phi}} dt + \frac{(1-\theta)g_c}{\rho} \int_0^\infty e^{-\rho t} e^{\phi g_c t} \left( e^{\phi g_c t} - 1 \right)^{\frac{1-\theta}{\phi}-1} dt \\ &= \frac{\int_0^\infty e^{-\rho t} \left( e^{\phi g_c t} - 1 \right)^{\frac{1-\theta}{\phi}-1} dt}{\frac{\rho-(1-\theta)g_c}{(1-\theta)g_c}}. \end{aligned}$$

Then, a first-order Taylor approximation of (13) for  $n_j(0) \equiv N_j(0)/N_l(0)$  small gives

$$\begin{aligned} \mathcal{W}_j(s_j) &= \int_0^\infty e^{-\rho t} \omega_{s_j} N_\ell(0)^{1-\theta} \left[ \left( \frac{g_{s_j}}{g_c} \left( e^{\phi g_c t} - 1 \right) \right)^{\frac{1-\theta}{\phi}} + \frac{1-\theta}{\phi} n_j(0)^\phi \left( \frac{g_{s_j}}{g_c} \left( e^{\phi g_c t} - 1 \right) \right)^{\frac{1-\theta}{\phi}-1} \right] dt + \mathcal{R}(n_j(0)) \\ &= \omega_{s_j} (N_\ell(0))^{1-\theta} \left( \frac{g_{s_j}}{g_c} \right)^{\frac{1-\theta}{\phi}} \left( 1 + \frac{n_j(0)^\phi}{\phi} \frac{\rho - (1-\theta)g_c}{g_{s_j}} \right) \int_0^\infty e^{-\rho t} \left( e^{\phi g_c t} - 1 \right)^{\frac{1-\theta}{\phi}} dt + \mathcal{R}(n_j(0)), \end{aligned}$$

where  $\mathcal{R}(n_j(0))$  is the residual which goes to zero as  $n_j(0) \rightarrow 0$ . Thus there exists  $\bar{n} > 0$  such that for  $n_j(0) < \bar{n}$ ,  $\mathcal{W}_j(c) < \mathcal{W}_j(o)$  if

$$\left( \frac{\omega_c}{\omega_o} \right)^{\frac{1}{1-\theta}} < \left( \frac{g_o}{g_c} \right)^{\frac{1}{\phi}} \left( \frac{1 + \frac{n_j(0)^\phi}{\phi} \frac{\rho - (1-\theta)g_c}{g_o}}{1 + \frac{n_j(0)^\phi}{\phi} \frac{\rho - (1-\theta)g_c}{g_c}} \right)^{\frac{1}{1-\theta}}.$$

Next another first-order Taylor approximation of the right-hand side of this expression gives (16), and with the same reasoning implies that there exists some  $0 < \tilde{n} \leq \bar{n}$  such that for  $n_j(0) < \tilde{n}$ ,  $\mathcal{W}_j(c) < \mathcal{W}_j(o)$  if (16) holds.

The second part now follows by setting  $n_j(0) = 0$ , and noting that, as observed in the text, (14) becomes easier to satisfy when  $n_j(0)$  increases. Thus  $\left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}} < \left(\frac{g_o}{g_c}\right)^{\frac{1}{\phi}}$  is a sufficient condition for all  $n_j(0)$ .

**Proof of Corollary 2.**

**Part 1:** It is straightforward to verify that  $\left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}}$  is decreasing in  $A$  (defined in (7)) and  $\gamma$ . Its dependence on  $\theta$  is more complicated. As noted in the text, it is decreasing in  $A$ . Differentiation and algebra then establishes  $A$  decreases in  $\theta$  when  $\gamma \leq \bar{\gamma} \equiv 1 - \sqrt{\frac{g_0(1-g_0)}{q_1(1-q_1)}}$  (and  $\left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}}$  is also decreasing in  $\theta$  for fixed  $A$ ). Moreover, defining  $\theta_{\max} \equiv 1 - \frac{\log(\frac{1-g_0}{1-q_1})}{\log(1-\gamma)} > 1$ , we also have  $\lim_{\theta \rightarrow \theta_{\max}} \left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}} = 0$ . Thus there exists  $\theta^*(\phi, \gamma) \in (0, \theta_{\max}(\gamma))$  such that when  $\theta \geq \theta^*(\phi, \gamma)$ ,  $\left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}} < \left(\frac{g_o}{g_c}\right)^{\frac{1}{\phi}}$ , and moreover  $\theta \geq \theta^*(\phi, \gamma)$  is decreasing in  $\gamma$  and  $\phi$  (the latter from the fact that the right-hand side of inequality is increasing in  $\phi$ ). ■

**Part 2:** When  $\theta < 1$ , Assumption 2 requires that

$$\frac{\omega_c}{\omega_o} > \frac{\rho - (1 - \theta)g_c}{\rho - (1 - \theta)g_o}.$$

Since  $\frac{\omega_c}{\omega_o} < 1$  and  $(1 - \theta)g_c > (1 - \theta)g_o$ , there exists a unique  $\bar{\rho}(\theta, \gamma) \in [(1 - \theta)g_c, \infty)$  such that is inequality satisfied if and only if  $\rho < \bar{\rho}(\theta, \gamma)$ . When  $\theta > 1$ ,  $\omega_c < \omega_o < 0$ , and Assumption 2 requires

$$\frac{\omega_c}{\omega_o} < \frac{\rho - (1 - \theta)g_c}{\rho - (1 - \theta)g_o}.$$

In this case, some algebra establishes that the same conclusion follows provided that  $\gamma \leq \bar{\gamma} \equiv 1 - \sqrt{\frac{g_0(1-g_0)}{q_1(1-q_1)}}$  and  $\theta \in [1, \bar{\theta}(\gamma)]$  where  $\bar{\theta}(\gamma) > 1$ . Moreover, in both cases  $\bar{\rho}(\theta, \gamma)$  is decreasing in  $\theta$  and  $\gamma$ . ■

**Proof of Proposition 4.** We rewrite (18) with a change of variable for  $m_j \equiv (N_j/N_\ell)^\phi \leq 1$  as:

$$\begin{aligned} \mathcal{W}_j(m_j(t)) &= N_\ell(t) \max_{u(\cdot) \in [0,1]} \int_t^\infty e^{-(\rho - (1-\theta)g_c)(\tau-t)} \omega(u(\tau)) m_j(\tau)^{\frac{1-\theta}{\phi}} d\tau \\ \dot{m}_j(\tau) &= \phi [g(u(\tau)) - g_c m_j(\tau)]. \end{aligned} \quad (23)$$

The solution to this problem would be the “closed loop” best response of follower  $j$  to the evolution of the world technology frontier driven by the technology leader,  $\ell$ . The Markov perfect equilibrium corresponds to the situation in which all countries use “open loop” strategies.

However, given our focus on equilibria in which the same country,  $\ell$ , remains the leader and adopts a cutthroat reward structure (under Assumption 2), the open loop and the closed loop solutions coincide, because under this scenario, country  $\ell$  always adopts a cutthroat reward structure, regardless of the strategies of other countries. Hence we can characterize the equilibria by deriving the solution to (23).

We now proceed by defining the current-value Hamiltonian, suppressing the country index  $j$  to simplify notation,

$$H(m(t), u(t), \mu(t)) = \omega(u(t))m(t)^{\frac{1-\theta}{\phi}} + \mu(t)\phi[g(u(t)) - g_c m(t)],$$

where  $\mu(t)$  is the current-value co-state variable. We next apply the Maximum Principle to obtain a candidate solution. This implies for the control variable (reward structure)  $u(t)$  the following bang-bang form:

$$u(t) \begin{cases} = 1 & \Psi(t) < 0 \\ \in [0, 1] & \text{if } \Psi(t) = 0 \\ = 0 & \Psi(t) > 0 \end{cases} \quad (24)$$

where  $\Psi(t)$  is the switching function:

$$\Psi(t) \equiv (\omega_o - \omega_c)m(t)^{\frac{1-\theta}{\phi}} - \mu(t)\phi[g_c - g_o]. \quad (25)$$

In addition,

$$\begin{aligned} \dot{m}(t) &= \phi[g(u(t)) - g_c m(t)] \quad \text{with } m(0) > 0 \text{ given} \\ \dot{\mu}(t) &= (\rho - (1-\theta)g_c + \phi g_c)\mu(t) - \frac{1-\theta}{\phi}m(t)^{\frac{1-\theta}{\phi}-1}\omega(u(t)), \end{aligned} \quad (26)$$

and the transversality condition,

$$\lim_{t \rightarrow \infty} e^{-(\rho - (1-\theta)g_c)t}\mu(t) = 0. \quad (27)$$

Now combining (25) with (26), we have

$$\dot{\Psi}(t) = (\rho - (1-\theta)g_c + \phi g_c)\Psi(t) + (\omega_o - \omega_c)(\rho + \phi g_c)m(t)^{\frac{1-\theta}{\phi}-1}(\tilde{m} - m(t)), \quad (28)$$

where  $\tilde{m}$  is given by (19) in the statement of Proposition 4. Integrating (28), we obtain

$$\Psi(t) = (\omega_o - \omega_c)(\rho + \phi g_c) \int_t^\infty e^{-((\rho - (1-\theta)g_c + \phi g_c)(\tau - t))} m(\tau)^{\frac{1-\theta}{\phi}-1} (m(\tau) - \tilde{m}) d\tau. \quad (29)$$

Moreover, (24) implies that in the candidate solution, cutthroat (cuddly) reward structures will be adopted at time  $t$  when  $\Psi(t) < 0$  ( $> 0$ ). Notice first that (26) implies that

$$\dot{m}(t) \geq \phi[g_o - g_c m(t)]$$

Thus,

$$m(t) \geq \frac{g_o}{g_c} + (m(0) - \frac{g_o}{g_c})e^{-\phi g_c t} \quad (30)$$

Next observe the following about the candidate solution.

1. Suppose  $\tilde{m} < g_o/g_c$  (corresponding to part 1 of Proposition 4). One can first notice that the control variable  $u(t)$  can only take the extreme values 0 or 1. To see this, suppose to obtain a contradiction that in some interval  $t \in [t_1, t_2]$ ,  $u(t) \in (0, 1)$ . Then also  $\Psi(t) = 0$  on that same interval  $[t_1, t_2]$ . Therefore for  $t \in [t_1, t_2]$ ,  $\dot{\Psi}(t) = 0$ , but then (28) implies that  $m(t)$  is a constant equal to  $\tilde{m}$ . Thus  $\dot{m}(t) = 0$  and  $u(t) = \tilde{u} = (g_c \tilde{m} - g_o)/(g_c - g_o)$ , which together with  $\tilde{m} < g_o/g_c$  implies that  $\tilde{u} < 0$ , yielding a contradiction.

Next consider the following cases:

- If  $m(0) > g_o/g_c$ , Then (30) implies that  $m(t) \geq g_o/g_c > \tilde{m}$  for all  $t$ . Hence (29) implies that  $\Psi(t) > 0$  for all  $t$ , and thus  $u(t) = 0$  for all  $t$  (which also implies from (26) that  $m(t)$  is monotonically decreasing towards  $g_o/g_c$ ).
- If  $m(0) < g_o/g_c$ , then (30) implies that  $\liminf m(t) \geq g_o/g_c > \tilde{m}$ , and thus  $\liminf \Psi(t) > 0$ . Hence there exists  $T'$  such that for  $t > T'$ ,  $\Psi(t) > 0$ , and thus  $u(t) = 0$ . Two cases need to be considered:
  - Case i) For all  $t \in [0, T']$ ,  $\Psi(t) > 0$  and therefore for all  $t \geq 0$ ,  $u(t) = 0$  (and  $m(t)$  is monotonically increasing towards  $g_o/g_c$ ).
  - Case ii) There exists  $t' \in [0, T']$  such that  $\Psi(t') = 0$ . Let  $t_o < T$  be the maximum of such dates  $t'$ . We have  $\Psi(t_o) = 0$ . By definition of  $t_o$ , for all  $t > t_o$   $\Psi(t) > 0$ . Hence we also have  $\Psi'(t_o) > 0$ . Equation (28) implies that  $m(t_o) < \tilde{m}$ . Suppose now that there is another date  $t'' < t_o$  such that  $\Psi(t'') = 0$  and take the largest of such dates  $t_1 < t_o$ . By construction,  $\Psi'(t_1) < 0$ . Also given that for all  $t \geq t_o$   $\Psi(t) \geq 0$ , and the continuity of  $\Psi(t)$ ,  $\Psi(t) < 0$  on the interval  $t \in (t_1, t_o)$  and  $\Psi(t_o) = \Psi(t_1) = 0$ . Hence for  $t \in (t_1, t_o)$ , we also have  $u(t) = 1$  and  $m(t)$  increasing in  $t$  (from (26)). It follows that  $m(t_1) < m(t_o) < \tilde{m}$ . However, (28),  $\Psi'(t_1) < 0$  and  $\Psi(t_1) = 0$  jointly imply that  $m(t_1) > \tilde{m}$ , yielding a contradiction. Hence there cannot exist another date  $t'' < t_o$  such that  $\Psi(t'') = 0$ . Hence the function  $\Psi(t)$  cannot change sign on  $[0, t_o)$ . Given that at  $t_o$   $\Psi(t_o) = 0$ , one should have  $\Psi(t) < 0$  on  $[0, t_o)$ .
  - From the previous discussion, it follows that there exists *at most* one date  $T \geq 0$  at which the function  $\Psi(t)$  changes sign. When such a date  $T$  exists, it must be that  $\Psi(t) < 0$  and  $u(t) = 1$  for  $t \in [0, T)$  and  $\Psi(t) > 0$  and  $u(t) = 0$  for  $t \in (T, \infty)$ . The

existence of such time  $T$  depends on the sign of  $\Psi(0)$ . When  $\Psi(0) < 0$ , there exists such switching date  $T$  at which  $\Psi(t)$  changes signs ( $< 0$  to  $> 0$ ). When conversely  $\Psi(0) > 0$  the switching function is positive for all  $t$ . Note that  $m(t)$  is increasing in  $m(0)$ . From (29) and the condition  $\phi > 1 - \theta$  one gets

$$\frac{\partial \Psi(0)}{\partial m(0)} = (\omega_o - \omega_c)(\rho + \phi g_c) \int_t^\infty e^{-((\rho - (1 - \theta)g_c + \phi g_c)(\tau - t))} \left[ \frac{\partial m(\tau)}{\partial m(0)} \right] \left[ \frac{1 - \theta}{\phi} m(\tau) - \left( \frac{1 - \theta}{\phi} - 1 \right) \tilde{m} \right] m(\tau)^{\frac{1 - \theta}{\phi}}$$

Hence  $\Psi(0)$  is increasing in  $m(0)$ , and thus there exists  $\bar{m}$  such that  $\Psi(0) \geq 0$  if  $m(0) \geq \bar{m}$  (i.e.,  $n(0) \geq \bar{m}^{1/\phi}$ ).

2. Suppose  $1 > \tilde{m} > g_o/g_c$  (corresponding to part 2 of Proposition 4). Then the following choice of rewards structure satisfies (24):

$$u(t) = \begin{cases} 0 & \text{if } m(t) > \tilde{m} \\ u^* & \text{if } m(t) = \tilde{m} \\ 1 & \text{if } m(t) < \tilde{m} \end{cases}$$

where  $u^*$  is such that  $\tilde{m} = g(u^*)/g_c$ , and when  $m(t) = \tilde{m}$ , we have  $\dot{m}(t) = 0$  and  $\Psi(t) = 0$ , ensuring that this choice of reward structure does indeed satisfy (24). Note also that in this case whenever  $m(t) > \tilde{m}$  ( $m(t) < \tilde{m}$ )  $m(t)$  declines (increases) to  $\tilde{m}$  monotonically, and at  $m(t) = \tilde{m}$ , it remains constant.

3. Suppose  $\tilde{m} > 1$  (corresponding to part 3 of Proposition 4). In this case,  $\Psi(t) < 0$  for all  $t$  (regardless of initial conditions), and thus  $u(t) = 1$  for all  $t$ . Given this reward structure, in this case  $m(t)$  monotonically converges to 1.

Finally, in each case, the candidate solution satisfies the transversality condition (27), and the assumption that  $1 - \theta < \phi$  ensures that Mangasarian's sufficiency condition is satisfied (e.g., Acemoglu, 2009, Chapter 7). Thus the candidate solution characterized above is indeed a solution and is unique. This completes the proof of Proposition 4. ■

**Proof of Proposition 5.** We will prove that under the hypotheses of the proposition, there does not exist a symmetric equilibrium. Suppose first that all countries choose a cuddly reward structure for all  $t \geq 0$ . Then the world economy converges to a Balanced Growth Path (BGP) where every country has the same level of income,  $N_j(t)/(1 - \beta) = N(t)/(1 - \beta)$ , and grows at the same rate, which from (6) is equal to  $\dot{N}(t)/N(t) = g_o$ . The time  $t$  welfare of country  $j$  in this equilibrium can be written as

$$\mathcal{W}_j^o(t) = \int_t^\infty e^{-\delta(\tau - t)} \omega_o \left( \frac{N_j(\tau)}{N(\tau)} \right)^{1 - \theta} N(\tau)^{1 - \theta} d\tau,$$

which implies that for any  $\epsilon > 0$ , there exists  $T_1$  such that for all  $t > T_1$ , we are close enough to the steady state equilibrium in the sense that  $1 - \epsilon < \frac{N_j(t)}{N(t)} < 1 + \epsilon$ ,  $\dot{N}/N < g_o + \epsilon$ , and

$$\mathcal{W}_j^o(t) < \frac{\omega_o N(t)^{1-\theta} (1 + \epsilon)^{1-\theta}}{\rho - (1 - \theta)(g_o + \epsilon)}$$

Consider now a deviation of one country  $k$  to a cutthroat reward structure at all times  $t > T_1$ . Denote by  $\hat{N}_j(t)$ , the new growth path of country  $j$  and by  $\hat{N}(t)$  the growth path to the world technology frontier. The world economy converges again to a new BGP with growth rate  $\hat{g}$ . This BGP growth rate can be written as

$$\hat{g} = \frac{1}{J^{\frac{\phi}{1+\phi}}} \left[ (J-1)g_o^{\frac{1}{\phi} \frac{\sigma-1}{\sigma}} + g_c^{\frac{1}{\phi} \frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1} \frac{\phi}{1+\phi}} > g_o.$$

After this deviation, we have  $\hat{N}_k(t) > N_k(t)$  and  $\hat{N}_k(t) > N(t)$  for all  $t > T_1$ . Then for  $\epsilon_1 > 0$ , there exists  $T'_1 > T_1$  and  $\epsilon'_1$  such that for all  $t > T'_1$ ,  $\hat{N}_k/\hat{N}_k \geq \hat{g} - \epsilon_1$ , and welfare of country  $k$  satisfies

$$\begin{aligned} \mathcal{W}_k^c(T_1) &= \int_{T_1}^{\infty} e^{-\rho(t-T_1)} \omega_c \hat{N}_k(t)^{1-\theta} dt \\ &= \int_{T_1}^{T'_1} e^{-\rho(t-T_1)} \omega_c \hat{N}_k(t)^{1-\theta} dt + e^{-\rho(T'_1-T_1)} \int_{T'_1}^{\infty} e^{-\rho(t-T'_1)} \omega_c \hat{N}_k(t)^{1-\theta} dt \\ &> e^{-\rho(T'_1-T_1)} \omega_c \frac{\hat{N}_k(T'_1)^{1-\theta}}{\rho - (1 - \theta)(\hat{g} - \epsilon'_1)}. \end{aligned}$$

Now using the fact that  $\hat{N}_k(T'_1) \geq N_k(T'_1) \geq e^{g_o(T'_1-T_1)} N_k(T_1)$ , a sufficient condition for the deviation for country  $k$  to be profitable is

$$\begin{aligned} e^{-(\rho-(1-\theta)g_o)(T'_1-T_1)} \omega_c \frac{N_k(T_1)^{1-\theta}}{\rho - (1 - \theta)(\hat{g} - \epsilon_1)} &> \omega_o \frac{N_k(T_1)^{1-\theta} (1 + \epsilon)^{1-\theta}}{\rho - (1 - \theta)(g_o + \epsilon)} \\ &> \mathcal{W}_k^o(T_1) = \int_{T_1}^{\infty} e^{-(\rho-(1-\theta)g_o)(t-T_1)} \omega_o N_k(t)^{1-\theta} dt. \end{aligned}$$

Rearranging terms, this can be written as

$$\left( \frac{\omega_c}{\omega_o} \right)^{\frac{1}{1-\theta}} > (1 + \epsilon) e^{\frac{\rho-(1-\theta)g_o}{1-\theta}(T'_1-T_1)} \left( \frac{\rho - (1 - \theta)(\hat{g} - \epsilon_1)}{\rho - (1 - \theta)(g_o + \epsilon)} \right)^{\frac{1}{1-\theta}}. \quad (31)$$

Next suppose that all countries adopt a cutthroat reward structure for all  $t \geq 0$ . In this case, the world economy converges to a BGP where every country has the same level of income and grows at the same rate, which from (6) is equal to  $\dot{N}(t)/N_j(t) = g_c$ . With a similar reasoning, for  $\epsilon > 0$ , there exists  $T_2$  such that for all  $j$  and  $t > T_2$ ,  $1 - \epsilon < N_j(t)/N(t) < 1 + \epsilon$  and  $\dot{N}/N < g_c + \epsilon$ . Thus

$$\mathcal{W}_j^c(t) < \frac{\omega_c N(t)^{1-\theta} (1 + \epsilon)^{1-\theta}}{\rho - (1 - \theta)(g_c + \epsilon)}$$

Consider now a deviation of one country  $k$  to a cuddly reward structure at all time  $t > T_2$  while all other countries  $j \neq k$  stay with cutthroat reward structures throughout. Denote the path of technology of country  $j$  after this deviation by  $\tilde{N}_j(t)$ , and the path of world technology frontier by  $\tilde{N}(t)$ . Clearly,  $\tilde{N}(t)/\tilde{N}_j(t) = \tilde{g} < g_c$ , and moreover  $\tilde{N}_k(t) \leq N_k(t)$  for all  $t > T_2$ . Let us also note that

$$\tilde{g} = \frac{\dot{\tilde{N}}_j(t)}{\tilde{N}(t)} = \frac{1}{J} \left[ (J-1)g_c \frac{\sigma-1}{\sigma} + g_o \frac{\sigma-1}{\sigma} \right]^{\frac{\sigma}{\sigma-1}} > g_o.$$

Now, again fixing  $\epsilon_2 > 0$ , there exists  $T'_2 > T_2$  such that for all  $t > T'_2$ ,  $\tilde{N}_k/\tilde{N}_k \geq \tilde{g} - \epsilon_2$ , and the welfare of country  $k$  satisfies

$$\begin{aligned} \mathcal{W}_k^o(T_2) &= \int_{T_2}^{\infty} e^{-\rho(t-T)} \omega_o \tilde{N}_k(t)^{1-\theta} dt \\ &= \int_{T_2}^{T'_2} e^{-\rho(t-T_2)} \omega_o \tilde{N}_k(t)^{1-\theta} dt + e^{-\rho(T'_2-T_2)} \int_{T'_2}^{\infty} e^{-\rho(t-T'_2)} \omega_o \tilde{N}_k(t)^{1-\theta} dt \\ &> \omega_o N_k(T_2)^{1-\theta} \int_{T_2}^{T'_2} e^{-\rho(t-T)} e^{(1-\theta)g_o(t-T)} dt + e^{-\rho(T'_2-T_2)} \omega_o \frac{N_k(T_2)^{1-\theta} e^{(1-\theta)g_o(T'_2-T_2)}}{\rho - (1-\theta)(\tilde{g} - \epsilon_2)} \\ &> \omega_o N_k(T_2)^{1-\theta} \frac{1 - e^{-(\rho-(1-\theta)g_o)(T'_2-T_2)}}{\rho - (1-\theta)g_o} + e^{-(\rho-(1-\theta)g_o)(T'_2-T_2)} \omega_o \frac{N_k(T_2)^{1-\theta}}{\rho - (1-\theta)(\tilde{g} - \epsilon_2)}, \end{aligned}$$

where the second line uses the fact  $\tilde{N}_k(t) > N_k(T_2)e^{g_o(t-T_2)}$ . Then a sufficient condition for the deviation to the cuddly reward structure for country  $k$  to be profitable is

$$e^{-(\rho-(1-\theta)g_o)(T'_2-T_2)} \omega_o \frac{N_k(T_2)^{1-\theta}}{\rho - (1-\theta)(\tilde{g} - \epsilon_2)} > \omega_c \frac{N(T_2)^{1-\theta} (1+\epsilon)^{1-\theta}}{\rho - (1-\theta)(g_c + \epsilon)}.$$

Since  $N_k(T_2) > N(T_2)(1-\epsilon)$ , this sufficient condition can be rewritten as

$$\frac{1-\epsilon}{1+\epsilon} \left( \frac{\rho - (1-\theta)(g_c + \epsilon)}{\rho - (1-\theta)(\tilde{g} - \epsilon_2)} \right)^{\frac{1}{1-\theta}} e^{-\frac{\rho-(1-\theta)g_o}{1-\theta}(T'_2-T_2)} > \left( \frac{\omega_c}{\omega_o} \right)^{\frac{1}{1-\theta}}. \quad (32)$$

Thus combining (31) and (32), we obtain that the following is a sufficient condition for an asymmetric equilibrium not to exist after some time  $T = \max\{T_1, T_2\}$ :

$$\frac{1-\epsilon}{1+\epsilon} \left( \frac{\rho - (1-\theta)(g_c + \epsilon)}{\rho - (1-\theta)(\tilde{g} - \epsilon_2)} \right)^{\frac{1}{1-\theta}} e^{-\frac{\rho-(1-\theta)g_o}{1-\theta}(T'_2-T_2)} > \left( \frac{\omega_c}{\omega_o} \right)^{\frac{1}{1-\theta}} > \frac{1-\epsilon}{1+\epsilon} e^{\frac{\rho}{1-\theta}(T'_1-T_1)} \left( \frac{\rho - (1-\theta)(\hat{g} - \epsilon_1)}{\rho - (1-\theta)(g_o + \epsilon)} \right)^{\frac{1}{1-\theta}}. \quad (33)$$

Now note that as  $\sigma \uparrow 0$  in (6),  $\hat{g} \rightarrow g_c$  and  $\tilde{g} \rightarrow g_c$ . Therefore, for  $\epsilon' > 0$ , there exists  $\bar{\sigma} < 0$  such that for  $\sigma > \bar{\sigma}$ ,  $\hat{g} - \epsilon' < g_o$  and  $\tilde{g} - \epsilon' < g_o$ . Thus choosing  $\epsilon, \epsilon_1, \epsilon_2$ , and  $\epsilon'$  sufficiently small, the following is also a sufficient condition:

$$e^{-\frac{\rho-(1-\theta)g_o}{1-\theta}(T'_2-T_2)} > \left( \frac{\omega_c}{\omega_o} \right)^{\frac{1}{1-\theta}} > e^{\frac{\rho-(1-\theta)g_o(T'_1-T_1)}{1-\theta}} \left( \frac{\rho - (1-\theta)g_c}{\rho - (1-\theta)g_o} \right)^{\frac{1}{1-\theta}}. \quad (34)$$

Finally, choosing  $\rho$  sufficiently close to  $(1 - \theta)g_c$  and defining  $\bar{T} \equiv \{T'_1 - T_1, T'_2 - T_2\}$ , a further sufficient condition is obtained as

$$e^{-(g_c - g_o)\bar{T}} > \left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}} > e^{(g_c - g_o)\bar{T}} \left(\frac{\rho - (1 - \theta)g_c}{\rho - (1 - \theta)g_o}\right)^{\frac{1}{1-\theta}}. \quad (35)$$

For given choices of  $\epsilon$  and  $\epsilon_1$ ,  $\bar{T}$  is fixed. Hence there exists  $\bar{\rho} > (1 - \theta)g_c$  such that for  $(1 - \theta)g_c < \rho < \bar{\rho}$ , the right-hand side term inequality is close to zero and the left-hand term is given by some positive number. Next recall that

$$\left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}} = \frac{(q_1 A + (1 - q_1))(1 - \gamma)}{q_1 A^{\frac{1}{1-\theta}} + (1 - q_1)}.$$

When  $\theta < 1$ , this tends to 0 as  $\gamma \rightarrow 1 - \left(\frac{g_o}{q_1}\right)^{1/(1-\theta)}$ . When  $\theta > 1$ , this tends to 0 as  $\gamma \rightarrow 1 - \left(\frac{1 - g_o}{1 - q_1}\right)^{1/(1-\theta)}$ . Thus in both cases (for a fixed value of  $\theta$ ) there exists  $\bar{\gamma} < 1$  such that for  $\gamma > \bar{\gamma}$ ,  $\left(\frac{\omega_c}{\omega_o}\right)^{\frac{1}{1-\theta}}$  is sandwiched between these two terms, ensuring that (35) is satisfied and a symmetric equilibrium does not exist.

Finally, when these conditions are satisfied, a similar analysis to that in the proof of Proposition 4 implies that the equilibrium will take the form where after some  $T$ , subset of countries choose a cuddly reward structure and the remainder choose a cutthroat reward structure. ■