Endogenous Strength of Intellectual Property Rights:

Implications for Economic Development and Growth*

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Abstract: The key institution that determines sustained growth in R&D-based growth models is the strength of intellectual property rights, which are usually assumed to be exogenous. In this paper we endogenize the strength of the intellectual property rights and show how private incentives to protect these rights affect economic development and growth. Our model explains endogenous differences in intellectual property rights across countries as private incentives to invest in property rights generate multiple equilibria. We show that the resulting institutional threshold offers an explanation for why the effect of a transfer of institutions from one country to another depends on the quality of the institutions that were imported.

Key words: R&D, Institutional Change; Intellectual Property Rights; Technological Change

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"The patent system added the fuel of interest to the fire of genius."
Abraham Lincoln - the only U.S. President to be issued a patent
(Dobyns 1994).

1. Introduction

The protection of property rights and the appropriation of rents are central aspects of R&D-based growth models whose engine of growth is the return to innovation. As a consequence, a voluminous literature has examined the costs and benefits of intellectual property right (IPR) protection and their effects on innovation and growth. The existing analyses all share an emphasis on the government's choice of the degree of IPR protection.[1] Yet, both public and private choices about enforcement are important in determining the *de facto* strength of IPR protection. In contrast to the previous literature, this paper examines the role of private investments in the (endogenous) degree of IPR protection and their impact on economic growth.

We focus on the private incentives to invest in IPR protection, taking formal institutions, such as the existence of a patent office, as given.[2] Our interest in private investment is motivated by the evidence that private patent infringement suits are often necessary steps to establishing patent value. Khan (2003), in her description of the early British patent system, argues that "potential patentees were well advised to obtain the help of a patent agent to aid in negotiating the numerous steps [...] required for pursuit of the application in London", and that even after the patent had been awarded "patent rights could not be regarded as settled unless the patent had been contested in court with a favorable outcome".

Little is known about exact costs of patent enforcement, yet there is general agreement that firm level enforcement costs are substantial; see Lanjouw et al. (1998) and Lanjouw and Schankerman (2001). These costs include litigation expenses, monitoring for possible infringement, and the costs of establishing new case law to ensure legal

[1] See Helpman (1993), Horowitz and Lai (199), Kwan and Lai (2003), and Grossman and Lai (2004)

[2] Although we do not model them in this paper, private incentives to establish property rights can have positive spillovers on a) the future costs of protection through reputation, b) the cost of IPR protection of other firms who may free ride, and c) the cost of protection for all future firms. These and other reasons cited in Grossman and Lai (2004) have long been employed to justify the public provision of intellectual property protection.

protection for new innovations (see the discussion of patent rights in the "New Economy" in Jaffe and Learner, 2004). All this indicates that the private cost of strengthening IPR protection is an important determinant of the returns to innovation.

In this paper we integrate endogenous strength of intellectual property rights into an R&D-based growth model to understand agents' private incentives to engage in institutional improvements, and thus endogenise the degree of rent appropriation. We use the Romer (1990) model in which firms engage in R&D in order to invent new varieties of intermediate goods, and suppose that research firms can invest resources in order to establish their patent rights. When the patent is enforced, the innovation is produced by the inventor under monopolistic conditions; if the patent is not enforced, the commodity can be imitated and produced by a competitive fringe. In this case the innovator receives no profits.[3]

The possibility of spending resources on IPR protection creates an interdependence between research investments and expenditures in IPR protection: a lower degree of protection reduces the returns from research and hence the incentives to do R&D; similarly, a low level of R&D will reduce the return to investment in IPR protection. As a result, multiple equilibria emerge. There is a high-growth equilibrium characterized by high-quality institutions, extensive R&D, and comparatively small but productive manufacturing employment. Rapid productivity growth is driven by fast technological change, which in turn is profitable because of high enforcement. There is also a poverty trap, in which all research activity ceases in the absence of IPR protection.

Examining the stability of the equilibria, we uncover an institutional threshold among countries that invest in R&D. A policy of adopting best practice institutions from other countries in order to reduce private enforcement costs can only move a country onto a high-growth equilibrium if the adopted level of IPR protection is sufficiently strong to warrant subsequent, strong investment in IPR institutional quality. Otherwise, weak investment in IPR quality eventually leads to large-scale misappropriation of the returns

[3] Using the Romer (1990) model has the basis for our model must be kept in mind when we discuss policy implications below. As a referee pointed out, the model addresses a specific set of counties (those that innovate) and does hold specifically implications for countries whose growth is (mainly) driven by imitation of technology from abroad (and capital deepening). This implies that the policy implications derived below are not specific to countries that not rely on their own R&D and IPR.

to innovation and a fall in R&D activity as the economy reverts to the no-growth equilibrium. These results shed light on the evidence provided by Acemoglu et al (2001) on the very long term effects of the *type* of colonial influence. Their work highlights that colonizers who transferred strong institutions to settlement colonies eventually had a positive impact on long-run economic performance, while extractionary colonies received institutions of low quality from the colonizer and experienced low subsequent growth. Our model can explain this in the context of settlement colonies and colonizers that could eventually be characterized by the R&D based growth model[4]

Our results are broadly consistent with the empirical literature on intellectual property rights. In a study of over 120 countries, Ginarte and Park (1997) find threshold effects in the relationship between IPR strength and innovation. Only if the research sector surpasses a threshold level, do they find that better property rights associated with improved economic performance. This is exactly the institutional threshold level we find in our model. Falvey, Foster and Greenaway (2004), using a panel of 80 countries, also find threshold effects, where the effect of stronger IPRs on growth depends on the level of development (see also Gould and Gruben, 1996). Note that in contrast to the extensive theoretical literature on IPRs and welfare, the empirical evidence mainly relates IPRs not to welfare, but to growth, as is the case in our model. Kwan and Lai (2003) examine the effects of IPRs on welfare and find that welfare losses due to excessively strict IPRs are small compared to those associated with under-protection.

The relationship between IPR protection and growth has been extensively studied. Helpman (1993) first analyzed the effect of different IPR regimes, and Kwan and Lai (2003) extended his model to highlight the importance of transitional dynamics.[5] Grossman and Lai (2004) examine the incentives of a government to implement a welfare maximizing level of IPR protection. Their approach follows an important branch of the

[4] There also exists evidence that institutions can be "imported" (with mixed success), however, and that participatory regimes (i.e., democracy) are conducive to institution-building (e.g., Rodrik 2000). Another branch of the literature examines endogenous formal institutions such as political institutions and constitutions to optimize tension between the state, the rulers/enforcers and economic agents (Aghion, Alesina and Trebbi 2004, and Barzel 2002).

[5] Other related literatures examine effects of IPRs on product cycles (Lai 1998), and standard harmonization (Lai and Qui, 2003). In North-South models, Horowitz and Lai (1996) find that stronger IPRs may slow innovation; a similar result is obtained by Glass and Saggi (2001) for the case of North-South foreign direct investment.

literature that examines the impact of differing IPR regimes on growth, trade and the product cycle. However, this literature has focused on the public aspect of IPR protection. Indubitably governments play an important role in IPR enforcement, but, as we have argued, firms bear part of the cost of enforcement. It is precisely this aspect, previously ignored in the growth literature that we examine in this paper.

Our analysis contributes to the recent literature on the relationship between the quality of institutions and growth, pioneered by Hall and Jones (1999) and Acemoglu et al (2001, 2002). Their empirical work has shown that institutions possess a surprising ability to explain large variations in cross-country income level.[6] The data used to measure institutional quality is generally a composite of several indices that represent proxies for formal and informal economic and political institutions. Theoretical analyses have, however, focused on the public-good aspect of institutions, and the role that governments (whether a benevolent government or a self-interested elite) play in choosing different types of institutions; see Tornell (1997), Aghion, Alesina and Trebbi (2004), Acemoglu, Aghion and Zilibotti (2006), Acemoglu and Robinson (2000, 2001), Cervellati, Fortunato, and Sunde (2006). In contrast, we model the idea that private investments also play a role in determining the *de facto* quality of institutions.

The paper is organized as follows. Section 2 presents the basic structure of the model. In Section 3 we examine an economy with exogenous institutional quality, in order to identify the effects of imperfect intellectual property rights on growth. We then consider the endogenous determination of the strength of IPR protection in Section 4, using the insights derived in Section 3 to understand the incentives that motivate agents to invest in maintaining and improving IPRs. Section 5 concludes.

2. A model of Intellectual Property Rights Protection and Growth

We introduce into Romer's (1990) R&D-based growth model the possibility that intellectual property rights are imperfectly protected. We interpret the strength of IPR

[6] Hall and Jones (1999) document that cross-country differences in output per worker are driven not only by differences in government policies, but also by institutions, as measured by openness, risk of expropriation, corruption, and rule of law, bureaucratic quality, and risk of government repudiation of contracts. Similar studies have been conducted for transition economies with similar results (e.g., Grigorian and Martinez, 2002). Stiglitz (2000) highlights how weak institutions contributed to the Asian crisis.

protection as a measure of institutional quality. It is hence it is the *quality* of institutions, and not their existence that is captured by our model.

2.1. Consumers

Consider an economy that is populated by a continuum of identical individuals of mass L. At each instant in time, each individual supplies one unit of labor inelastically.[7] Individuals face two choices. First, they decide in which sector to work, where the sectors will be specified below. Second, they choose how much to consume and save, so as to maximize intertemporal utility, which is given by

$$U = \int_0^\infty \frac{C_t^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} dt \qquad (1)$$

where C is individual consumption, σ the inverse of the elasticity of intertemporal substitution, and ρ the discount rate.[8] Utility maximization implies the familiar Ramsey rule of optimal saving that depends on the interest rate, r,

$$\frac{\dot{C}}{C} = \frac{r-\rho}{\sigma}. \qquad (2)$$

2.2. The Final Good Sector

There are two types of goods produced in the economy: a single final good, which is the numeraire, and a continuum of intermediate capital goods, indexed by i. Final output, Y, is produced in a competitive sector with a technology that exhibits constant returns to scale at each point in time, according to

$$Y = L_Y^{1-\alpha} \int_0^A x_i^{\alpha} di\,, \qquad (3)$$

where A is the number of different intermediate goods used in production, x_i represents the amount of intermediate good i used, and L_Y is the amount of labor employed in the manufacturing sector. Each intermediate good embodies a different technology, as in Romer (1990), and growth is due to increasing product variety. The final good is used for consumption and investment, implying

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[7] The simplified Romer (1990) production structure follows Jones (1995) and Arnold (2000) who abstract, without loss of generality, from different types of labor.
[8] Below we suppress time subscripts unless necessary to avoid confusion.

$$\dot{K} = Y - C\,, \tag{4}$$

where K is the capital stock, defined as $K = \int_0^A x_i di$. Note that the capital stock does not depreciate.[9]

2.3. The R&D Sector

The state of knowledge at any point in time is parameterized by the number of existing blueprints for intermediate goods, A. We suppose that there is a given number of symmetric research firms, N, which we normalize to N=1. Research firms are indexed by j. At each instant in time, firm j employs $L_{R,j}$ researchers who produce $\dot{A}_j = L_{R,j} A / a$ new designs, where $1/a$ denotes the productivity of researchers, and it is assumed that there is an intertemporal spillover of knowledge captured by the presence of the current stock of knowledge on the right-hand side of the equation. The aggregate R&D function is then

$$\dot{A} = \frac{L_R}{a} A\,, \tag{5}$$

where L_R is the aggregate number of workers employed in research, $L_R = \sum_j L_{R,j}$. Once a blueprint is invented, the innovator is awarded an infinitely-lived patent on it. Innovators then sell it to a single intermediate goods producer. The value of a protected patent is denoted P_A, and will be determined below.

The linearity of R&D with respect to the level of technology, A, is a simplification, widely used in the literature. Caballero and Jaffe (1993) attempt to estimate the exact functional form of R&D production functions without much success, although more recent evidence certainly suggests that there are diminishing returns (see, for example, Jones and Williams, 1998). With less than full spillovers, the model reverts to a non-scale model (Eicher and Turnovsky, 1999); the effects of better institutions would be muted but qualitatively unchanged.

[9] Introducing a constant depreciation rate would not alter our results. However, allowing for depreciation to vary with the growth rate would imply creative destruction as in Boucekkine, del Río, and Licandro (2005), and would have important implications.

2.4. Intellectual Property Rights

We introduce imperfect protection of intellectual property rights, which we assume is captured by the degree of IPR enforcement, denoted by $q \in [0,1]$. We interpret q as the probability that, after an innovation occurs, the inventor can enforce her patent in court and prevent imitation. With probability $1-q$ the innovator cannot enforce a patent in court, and the intermediate good will be imitated. From the point of view of researchers, this implies that the expected value of an innovation is qP_A.[10]

Although the effect of patent enforcement on the value of the innovation is akin to that in Grossman and Lai (2004), we differ in that they examine the optimal degree of public IPR enforcement, while we consider private incentives to engage in IPR protection. We take as given the existence of formal institutions such as a system of courts or patent offices, and suppose that effective protection requires private investments in the enforcement of the law. The *quality* or *strength* of the enforcement is determined endogenously by private expenditures, as research firms will hire *institution-building* agents (see Magee, 1992, and Olsen, 1992).

We thus suppose that there is a third type of activity which consists of enforcing IPR protection. We suppose that the degree of enforcement experienced by a research firm *j* over its innovations is a function of the number of institution-building agents, $L_{B,j}$, that it employs,

$$q_j = F\lfloor L_{B,j} \rfloor, \text{ with } F' > 0, F'' < 0. \qquad (6)$$

This is clearly a reduced form relationship that captures the idea that the quality of institutions depends positively on the number of institution-building agents, $L_{B,j}$, employed by the research firm.[11] Note also, that q is a flow, to represent the notion that such institutions must be constantly maintained. We also assume that in the absence of

[10] We could model this in an alternative way, by supposing that innovators sell the patent before it is known whether it is infringed upon or not. In this case, and with risk-neutral intermediate good producers, the probability of infringement lowers the patent price to its expected value, qP_A. Results are identical to the ones discussed below, since ultimately it is funding for research that is reduced by weak patent protection.

[11] One might suggest that institution builders are simply "mercenary enforcers," in the sense that any injured party can hire a lawyer or an enforcer to defend her rights. Mercenary/defense terminology is perhaps more applicable in the case of physical capital, see Grossman and Kim (1996).

institution-building agents there is no protection of IPRs whatsoever, $F(0)=0$.[12] Finally, just as in the case of production, the concavity of the enforcement function is necessary for the existence of a balanced growth path.

This simple functional form could be expanded to include externalities. It is plausible that the degree of enforcement depends on both own employment of institution-builders and the aggregate number of agents engaged in such activities, $L_B \equiv \sum_j L_{B,j}$, which is taken as given by the firm. We would then have $q_j = F\lfloor L_{B,j}, L_B \rfloor$. If this were the case, multiple equilibria would emerge naturally as a result of the externality, and there is an extensive literature on how similar externalities in, for example, education result in poverty traps.[13] In what follows we abstract from this externality, not because we think it is not present, but rather to show that even when it is absent (or weak) the presence of private enforcement can create multiplicity.[14]

Since R&D firms are symmetric, they all employ the same number of institution-builders, whose quantity will be determined below; therefore all will have the same degree of IPR enforcement. We can hence define an economy-wide level of institutional quality, $q = q_j \ \ \forall j$. That is, all firms will face the same expected value of an innovation, qP_A.

2.5. The Intermediate Good Sector

Intermediate goods are imperfect substitutes in the production of the final good, which gives rise to potential monopolistic competition in the intermediate goods sector. Each intermediate good producer *i* faces the standard downward-sloping demand function,

$$p_i = \alpha L_Y^{1-\alpha} x_i^{\alpha-1} \quad \forall i, \tag{7}$$

where greater manufacturing employment increases the demand for intermediaries.

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[12] This assumption is for simplicity only. Qualitatively results do not change if $F(0)=q_0>0$, except that the equilibrium with no intellectual property rights is replaced and the poverty trap features a level of q_0.

[13] See, for example, Azariadis and Drazen (1990), and Azariadis and Stachurski (2005) for a review.

[14] The introduction of externalities may therefore influence the results derived below as they affect the allocation of resources to R&D and IPR-protection causing private investment to be suboptimal. This would also complicate stability and the dynamics discussed below and there is no guarantee the same equilibria emerge. New equilibria, perhaps some that internalize the externality may well be superior.

Each intermediate good can be produced under either of two possible scenarios. If the technology is protected, there will be a single producer for each intermediate good, which purchases the blueprint and operates under monopolistic competition. The production of one unit of the intermediate good requires the use of one unit of capital. If no patent is awarded, or if enforcement of a patent right is lacking, the technology can be copied. We suppose that there is no cost of imitation; hence the unprotected intermediate good can be copied by a large number of firms and is hence produced by a competitive fringe. However, a copied technology comes without a blueprint, design specifications, or support from the R&D sector. We therefore suppose that imitated technologies have a cost differential of $b \leq 1$, so that such intermediate goods require $1/b$ units of capital.[15]

When a good is protected by a patent, and under the assumption that intermediate goods are infinitely-lived, we can express instantaneous profits as $\pi_i = p_i x_i - r x_i$, where the interest rate captures the cost of capital required for the production. Since the cost and demand functions of all protected intermediate goods are identical, Romer (1990) shows that all producers of such goods choose the same monopoly price, $p_{m,i} = p_m = r/\alpha$ and supply the same quantity, which from (7) is given by

$$x_{m,i} = x_m = \left(\frac{\alpha^2}{r}\right)^{1/(1-\alpha)} L_Y \,. \tag{8}$$

The resulting instantaneous profits obtained by each intermediate producer are

$$\pi = (1-\alpha)\, p_m x_m \,. \tag{9}$$

These profits determine the value of a patent. Intermediate goods producers are willing to pay the discounted flow of profits generated by the innovation. In steady state the price for a patent is then

[15] See Aghion and Howitt (2005) for a similar specification of the imitation process, which contrasts with the approach to imitation in a North-South trade context where fixed costs of imitation, and hence copied goods, are also produced under monopoly conditions, but where the imitator has a lower production cost due to lower wages in the South. See, for example, Helpman (1993). A referee pointed out that up-front costs reduce the incentives to imitate and could therefore also be seen substitutes for private IPR. These costs may then go a long way in explaining across industry differences in IPR-protection. We have abstracted from such industry dynamics below. If we parted ways with Aghion and Howitt (2005) and eliminated the cost differential between innovators and imitators, the ex ante private returns to R&D would be significantly reduced.

$$P_A = \frac{\pi}{r} = \frac{1-\alpha}{\alpha} x_m . \tag{10}$$

Thus far, the intermediate goods sector mirrors the standard setup in product-variety growth models.

When the good is not protected, it is produced by the competitive fringe. Imitators operate under perfect competition and charge a price equal to marginal cost, $p_{c,i} = p_c = r/b$. The quantity demanded at this price is

$$x_{c,i} = x_c = \left(\frac{\alpha b}{r} \right)^{1/(1-\alpha)} L_Y \tag{11}$$

Note that if b is less than α, imitation is too costly to drive out of the market the monopolist who purchased the patent. In that case, imperfect property rights have no effect on the incentives to do R&D. Hence we assume $\alpha \le b \le 1$, which implies that the price charged for copied intermediate goods is at most as large as the monopoly price, $p_c \le p_m$. It also implies that the quantity of each intermediate good produced under competition is greater than or equal to the quantity of patent-protected goods.

The relative supply of intermediate goods that have been produced with protected and stolen technology can be obtained from equations (8) and (11). The quantities produced are proportional, so that we can write $x_m = \varphi\, x_c$, where $\varphi \equiv (\alpha / b)^{1/(1-\alpha)} \le 1$. We interpret φ as the *relative supply factor* of the monopolistically produced good, which depends both on the cost differential and on the monopoly markup. For $b = \alpha$, the quantity produced is the same whether or not the patent is enforced.

We can now rewrite output as a function of monopolistically and competitively provided intermediate goods

$$Y_t = L_{Y,t}^{1-\alpha} A_t \left[\tilde{q}_t x_{m,t}^{\alpha} + (1-\tilde{q}_t) x_{c,t}^{\alpha} \right], \tag{12}$$

where $\tilde{q}_t = \int_0^t q_\tau A_\tau d\tau / A_t$ is the fraction of all intermediates that is produced under monopolistic competition at time *t*. This expression takes into account the fact that the strength of IPR protection may have varied over time. Lastly, the entire stock of capital must be used in the manufacturing of either copied or monopolistically competitive intermediate inputs, so that aggregate capital can be expressed as

$$K_t = A_t x_c \left[1 - \tilde{q}_t \left(1 - \varphi_t^{\alpha}\right)\right]. \tag{13}$$

3. Equilibrium with Exogenous Institutions

Before we examine how the endogeneity of IPR enforcement affects the equilibrium growth, we consider the effect of a given level of enforcement on growth and welfare. This has two advantages. First, it illustrates the various ways in which institutional quality affects growth, highlighting the benefits and costs of stricter property rights, and will help us to better understand the implications of indigenizing q in the next section. Second, it allows us to compare our setup with existing work on IPR in which enforcement is chosen by the government.

3.1. Output and IPR Protection

With exogenous institutions, $\tilde{q}_t = q$, the production function simplifies to

$$Y = AL_Y^{1-\alpha}\left[q x_m^{\alpha} + (1-q) x_c^{\alpha}\right]. \tag{12'}$$

Static output depends not only on the level of knowledge in the economy, A, but also on the quality of institutions, q, and on the different quantities of the monopolistically and competitively supplied intermediates. Better IPR protection (i.e. a higher level of q) increases the fraction of technologies that are produced under patent protection. Since the quantity of each monopolistically supplied intermediate good is smaller than the quantity of the competitively available product, the static implication is that aggregate output falls with stronger IPRs. Note that this supply effect depends crucially on the markup and the cost differential, which determine the relative supply factor, φ. We can rewrite (12') as

$$Y = AL_Y^{1-\alpha} x_c^{\alpha}\left[1 - q\left(1 - \varphi^{\alpha}\right)\right] \tag{12''}$$

Equation (12'') highlights that a greater cost differential (i.e. a lower value of b and hence a larger relative supply factor) reduces the static gain from weak IPR. Indeed, when $b = \alpha$, the supply factor is unity and the quantities of monopolistically and competitively produced goods are identical.[16] The production function simplifies to

[16] Steady state is robust to $b \neq \alpha$, but the dynamics would be too complex as we discuss in Section 4.3.3.

$Y = \left(AL_Y\right)^{1-\alpha} K^{\alpha}$, implying that, for a given level of technology, the level of output is independent of the strength of patent protection.

3.2. Equilibrium

The equilibrium of the model is determined by the allocation of labor across the research and the final good sectors. From the production function we obtain the manufacturing wage

$$w_Y = (1-\alpha) A L_Y^{-\alpha} x_c^{\alpha} \left[1 - q\left(1-\varphi^{\alpha}\right)\right]. \tag{14}$$

The wage in the R&D sector is simply the expected marginal value product of researchers. Since the value of a protected innovation is P_A and the innovation is protected with probability *q*, the research wage is a function of the strength of IPRs,

$$w_R = q P_A A / a \,. \tag{15}$$

Wage equalization across sectors, together with the labor market clearing condition $L_R + L_Y = L$, implies the following levels of manufacturing and research employment,

$$L_Y = \frac{ar\left(1-(1-\varphi^{\alpha})q\right)}{b\varphi\, q}\,, \tag{16a}$$

$$L_R = L - \frac{ar\left(1-(1-\varphi^{\alpha})q\right)}{b\varphi\, q}\,. \tag{16b}$$

The allocation of labor between research and manufacturing depends not only on the productivity of researchers and the interest rate, as in Romer (1990), but also on the level of institutional quality, and the relative supply factor of the two intermediate goods, φ. The closer the relative supply factor, φ, is to one (i.e. the larger the cost differential is), the lower is the quantity of competitively supplied intermediate goods, which reduces the demand for manufacturing labor and increases the number of researchers. Stronger IPRs thus tend to reduce manufacturing employment for two reasons. First, they reduce the number of competitively produced intermediate goods and hence the marginal product of labor in manufacturing. This reduces the demand for manufacturing workers. Second, a higher *q* implies a larger expected return to innovation, thus raising the demand for researchers.

In steady state, both the level of employment in manufacturing and the intermediate quantities are constant over time.[17] In this case the only source of growth is the increase in the number of varieties available. Denoting by g the rate of growth of output, we can then write

$$g = \dot{A}/A = L_R/a, \tag{17}$$

which is the rate of technological progress in the final goods sector. The balanced growth rate is obtained by substituting into this expression the level of R&D employment in (16b) and the interest rate obtained from utility maximization (2), which yields the balanced growth rate, $g*$,[18]

$$g^* = \frac{b\varphi L/a - \rho\left(1/q - (1-\varphi^{\alpha})\right)}{b\varphi + \sigma\left(1/q - (1-\varphi^{\alpha})\right)}. \tag{18}$$

As in Romer (1990), this expression implies that larger populations, or smaller discount rates, increase output. What is new is that weaker institutions reduce output growth, since $dg/dq > 0$. Two effects induce a lower growth rate: on the one hand, weaker IPRs reduce the expected value of an innovation, on the other, they raise the demand for manufacturing employment and hence the wage. Both effects reduce the incentives to invest in research.

3.3. Welfare Analysis

Our analysis above implies that institutional quality has dynamic and static effects on welfare, as it affects both the level of output and the rate of growth. To understand the various effects, we examine welfare by integrating the utility function (1) over time to express individual welfare as

$$W = \frac{1}{\rho(1-\sigma)} + \frac{K_0^{1-\sigma}}{1-\sigma}\frac{\chi^{1-\sigma}}{\left(\rho - (1-\sigma)g\right)}, \tag{19}$$

where $\chi = C/K$ is the consumption-capital ratio, and $\rho - (1-\sigma)g > 0$ from the transversality condition of the consumer's problem. Institutional quality then affects

[17] We abstract from dynamics in the exogenous institution case because it is a mirror of the Romer model's dynamics that have been discussed extensively in Arnold (2000).

[18] The corresponding equilibrium interest rate is $r^* = (\rho + \sigma L/a)/\left(b\varphi + \sigma\left(1/q - (1-\varphi^{\alpha})\right)\right)$.

welfare both through a dynamic effect on the growth rate and a level effect on the consumption-capital ratio. Differentiating (19) we find

$$sign\left[\frac{dW}{dq}\right] = sign\left[\frac{r}{\alpha b}\frac{d\Phi}{dq} + \frac{Y/K - r}{\rho - (1-\sigma)g}\frac{dg}{dq} + \frac{\sigma\Phi}{\alpha b}\frac{dg}{dq}\right] \tag{20}$$

where $\Phi \equiv \left(1 - q(1-\varphi^{\alpha})\right)/\left(1 - q(1-\varphi)\right)$ (see Appendix). A higher q affects welfare both through its effect on growth, where $dg/dq > 0$, and through a market power effect where output changes because the relative supplies of competitively and monopolistically produced intermediates change. The market power effect is captured by the term $d\Phi/dq \leq 0$.

Faster growth affects welfare in three ways. First, there is the positive direct effect of growth on welfare, which allows for greater future consumption (the g term in the denominator of (19)). Second, there is the negative effect of growth on welfare, as a faster rate of growth implies lower consumption for any given level of output. These two effects are standard in optimal growth models. The static effect is dominated by the dynamic one as long as the average product of capital is larger than the marginal product of capital, i.e. if $Y/K - r > 0$, which is the case with diminishing returns to capital. The third way in which a higher growth rate affects welfare is particular to the Romer model, and operates through the equilibrium interest rate. Faster growth implies a higher interest rate, which reduces the return to innovation and hence the level of research employment. As a result, employment in the final goods sector is higher, which raises consumption and welfare. This effect is captured by the last term in brackets in equation (20). These three effects together imply that since a higher q raises the growth rate it also tends to increase welfare.

The fourth effect is the market power effect, and is captured by the term $d\Phi/dq$. Stronger IPR protection implies that, for a given number of intermediate-good varieties, A, more varieties are produced under monopoly conditions. As a result the capital stock and hence output are lower, which reduces welfare. This static cost caused by the deadweight loss associated with the monopoly power of the innovator was first discussed by Schumpeter (1942). Better IPR protection hence results in a trade-off between greater incentives for innovation and the reduction in competition among firms that have previously innovated, which in turn limits the social surplus that can be realized from existing products. This trade-off was formalized by Grossman and Lai (2004), who show that the socially optimal degree of enforcement is not necessarily full enforcement.

In our framework, the deadweight loss can be parameterized by the cost disadvantage of the competitive fringe, *b*. If the cost disadvantage is small, the static output gain from weak property rights could in principle dominate, implying that weaker institutions are associated with higher welfare. The larger the cost disadvantage is (i.e. the lower *b* is), the more likely it is that the positive effect of institutions on welfare dominates. Indeed, for $b = \alpha$, the amount produced is the same for all intermediate goods, i.e. φ=1, and the negative effect of better institutions on welfare disappears $(d\Phi / dq = 0)$. Better IPR protection then generates unambiguously higher growth and welfare, implying that the socially optimal degree of enforcement is *q*=1. For higher values *b*, the socially optimal level of enforcement will, however, be less than full enforcement.

The other important parameter in the welfare analysis is the productivity of researchers, 1/*a*. It is possible to show that $d^2W / dadq < 0$, indicating that the more productive researchers are, the more likely it is that better institutions improve welfare. The reason for this is that if researchers are not very productive, the increase in the growth rate from strengthening IPR is small, and hence more likely to be offset by the welfare loss due to a lower quantity of intermediate goods.[19]

4. Endogenous Intellectual Property Rights Protection

We now allow institutional quality to be determined by economic incentives. Research firms, aware of the rents lost due to imperfect property rights, possess incentives to improve IPR protection. They will hence engage institution-builders in order to protect their innovations, according to the function specified in equation (6). The strength of these incentives depends on the magnitude of potential rents that are lost when intellectual property is not well protected, and hence is endogenous. As in the model with exogenous institutions, the growth rate will be driven by the allocation of labor across

[19] This is the effect discussed by the literature that argues that in less-developed open economies, with unproductive or nonexistent research sectors, weaker IPR enforcement may lead to higher welfare in these economies; see Grossman and Helpman (1991b), Grossman (1993) and Saint-Paul (2005).

sectors. The difference now is that labor is allocated to three activities: final good production, R&D, and the protection of intellectual property rights.

4.1. Labor market equilibrium

R&D firms hire both researchers and institution-building agents to protect their property rights over new technologies. Their expected net profits are given by

$$V_j = F\lfloor L_{B,j} \rfloor L_{R,j} P_A A / a - w_B L_{B,j} - w_R L_{R,j} . \qquad (21)$$

The expected output of the R&D firm, $F\lfloor L_{B,j} \rfloor L_{R,j} P_A A / a$, exhibits increasing returns to $L_{B,j}$ and $L_{R,j}$ together, and as a result, workers cannot be paid the value of their marginal product. We suppose that the two types of workers bargain over the surplus created.[20] Letting the bargaining power of institution-builders be β and that of researchers 1-β, and since the expected value of research in the absence of either type of worker (i.e. the outside option) is zero, the Nash bargaining problem is

$$\max_{\gamma} \left((1-\gamma) F\left[L_{B,j}\right] L_{R,j} P_A A / a\right)^{1-\beta} \left((\gamma F\left[L_{B,j}\right] L_{R,j} P_A A / a\right)^{\beta}, \qquad (22)$$

where γ and 1-γ are, respectively, the fractions of output devoted to rewarding institution-builders and researchers. The Nash bargaining solution to this problem implies that a fraction β of revenue will be paid to institution-builders and a fraction 1-β to researchers. The resulting wages are

$$w_B = \frac{\beta q L_{R,j} A P_A}{a L_{B,j}} \qquad (23)$$

$$w_R = \frac{(1-\beta) q A P_A}{a} \qquad (15')$$

implying that the wage of researchers is lower than in the case of exogenous institutions, since part of the value of the patent is used to reward institution-builders.

Labor market equilibrium requires that the two wages be the same. Using equations (23) and (15') this yields a relationship between the two levels of employment

[20] Our bargaining solution implies that, despite the presence of increasing returns in the sector, R&D firms make zero profits."

chosen by firm *j*, namely $L_{B,j} = \beta L_{R,j}/(1-\beta)$. Since R&D firms are symmetric, this implies that the aggregate employment of institution-builders is given by

$$L_B = \sum_j L_{B,j} = \frac{\beta}{1-\beta}\sum_j L_{R,j} = \frac{\beta}{1-\beta}L_R . \qquad (24)$$

Combining this expression with the labor market constraint $L = L_R + L_B + L_Y$, the aggregate levels of employment in institution-building and research are

$$L_B = \beta(L - L_Y), \qquad (25a)$$

$$L_R = (1-\beta)(L - L_Y). \qquad (25b)$$

An increase in the bargaining power of institution builders, β, tends to increase their number and to reduce the number of researchers, for a given level of manufacturing employment.

Since all *N* R&D firms are symmetric, they all employ the same number of institution-builders, $L_{B,j} = L_B / N$, and hence have the same degree of IPR enforcement. Equation (25a), together with the fact that we have normalized the number of R&D firms to 1,[21] implies that the economy-wide level of institutional quality, *q*, chosen by the research sector is

$$q_j = q = F\left[\beta(L - L_Y)\right]. \qquad (26)$$

Institutional quality declines in manufacturing employment because a higher level of L_Y reduces the amount of labor that the R&D sector can employ as either researchers or institution-builders.

In order to close the model we need to determine manufacturing employment. The wage in manufacturing is exactly as in the previous section, and given by (14). Equalizing the manufacturing and research wage we can again derive the level of manufacturing employment, which is now

[21] For $N \neq 1$ the institutional–quality function would also depend on the number of research firms in the economy. This in fact, takes care of possible scale effects, assuring that countries with larger populations do not necessarily have better institutions.

$$L_Y = \frac{ar\left(1-(1-\varphi^{\alpha})q\right)}{\varphi\ q(1-\beta)b} \quad . \tag{25c}$$

Equations (25a), (25b), and (25c) characterize the equilibrium allocation of labor across the three sectors for a given level of institutions. For the reasons discussed in section 3, stronger institutions shift labor away from manufacturing and toward the research sector.

4.2. Balanced growth

4.2.1. Characterization of the balanced growth equilibrium

Along the balanced growth path, the quality of institutions, *q*, is constant, hence the allocation of labor across sectors is also constant. The growth rate of the economy is, as before, given by $g = L_R / a$, implying

$$g = (1-\beta)(L - L_Y)/a\ , \tag{27}$$

which indicates that the rate of growth is a decreasing function of the equilibrium level of manufacturing employment.

The equilibrium level of institutional quality and manufacturing employment are jointly determined by the following equations

$$q = F\left[\beta(L - L_Y)\right], \tag{QQ}$$

$$q = \frac{a\rho + \sigma(1-\beta)(L-L_Y)}{(1-\beta)b\varphi L_Y + (1-\varphi^{\alpha})(a\rho + \sigma(1-\beta)(L-L_Y))} \ . \tag{LL}$$

Equation QQ is simply the institutional-quality function, which determines *q* as a function of manufacturing employment, and which holds at all points in time. Equation LL represents the labor market equilibrium, which determines manufacturing employment as a function of the quality of institutions. It is simply a rewriting of equation (25c), where we have substituted for the equilibrium interest rate and growth rate as given by (2) and (27). This expression is a steady state relationship. It holds as long as the labor market is in equilibrium, that is, as long as workers are not moving across sectors, i.e., $\dot{L}_Y = 0$.

Differentiating LL, we have $dq / dL_Y < 0$, since, as we saw in the previous section, better institutions tend to shift labor away from manufacturing. For a specific functional form for *F[.]*, the intersection of QQ and LL yields the equilibrium quality of institutions, q^*. The balanced growth rate is then given by

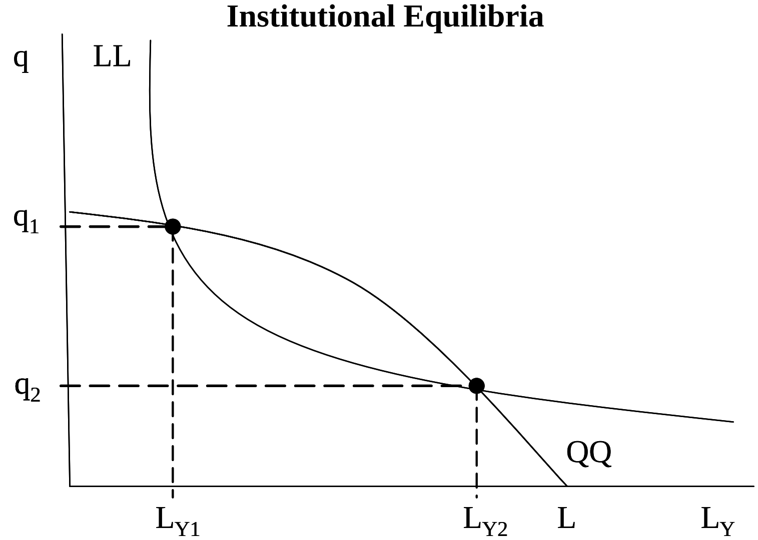
$$g^* = \frac{b\varphi(1-\beta)L/a - \rho\left(1/q^* - (1-\varphi^{\alpha})\right)}{b\varphi + \sigma\left(1/q^* - (1-\varphi^{\alpha})\right)} . \tag{28}$$

Just as in the case of exogenous institutions, the growth rate is increasing in institutional quality due to the positive effect of q on the demand for researchers.[22]

4.2.2. Multiplicity of equilibria

Explicit solutions to LL and QQ require a specific functional form for the institutions function. We can, however, characterize the equilibrium by examining the properties of the LL and QQ functions. Figure 1 represents the QQ and LL schedules that jointly determine the institutional quality and manufacturing employment. The QQ schedule is decreasing and concave, while the LL schedule is decreasing and will be convex for small values of *b*, but may be concave for higher ones (see Appendix). The $\dot{L}_Y = 0$ line can be shown to lie below the QQ schedule both at $L_Y = 0$ and $L_Y = L$; hence, there are either two intersections or none.[23]

Figure 1
Institutional Equilibria



[22] It is straightforward to show that the welfare analysis is identical to the case of exogenous institutions, implying that better institutions raise steady state welfare for high values of the relative supply factor φ and for the productivity of researcher 1/a, provided that the static loss due to monopoly is not too large.

[23] Given the labor market clearing condition, Figure 1 could have also been drawn for L_R so that all subsequent results regarding manufacturing employment can be directly translated to research employment.

The graph indicates that two internal equilibria are associated with positive growth. Equilibrium 1 exhibits strong IPRs and a low level of manufacturing employment, and from (28) a high growth rate. In contrast, equilibrium 2 features weak property rights, and large manufacturing employment, which leads to a small research sector and a low growth rate. The model's third equilibrium is at $L_Y = L,\ q = 0$. This is a poverty trap where innovation simply does not pay. The intuition that innovations cease in a country without property right enforcement is readily established: in the absence of institutions, all research outlays are fully misappropriated; research ceases. In this case, equation (25c) does not hold, and the economy degenerates to the Solow model without technical change.[24]

4.3.3. Stability of the equilibria

The stability analysis of the intertemporal general equilibrium requires the analysis of the evolution of manufacturing employment over time. Along the balanced growth path, all variables grow at a constant rate. We follow Arnold (2000) and normalize key variables to attain stationarity, using $\chi \equiv C/K, z \equiv Y/K$, and assume $b = \alpha$ to simplify the dynamics.

The dynamic system governing the evolution of the economy over time is then given by (see Appendix):

$$\frac{\dot{\chi}}{\chi} = \frac{\alpha^2 z - \rho}{\sigma} - z + \chi \tag{29}$$

$$\frac{\dot{L}_Y}{L_Y} = \frac{\dot{z}/z}{1-\alpha} - \frac{(1-\beta)(L-L_Y)}{a} + z - \chi \tag{30}$$

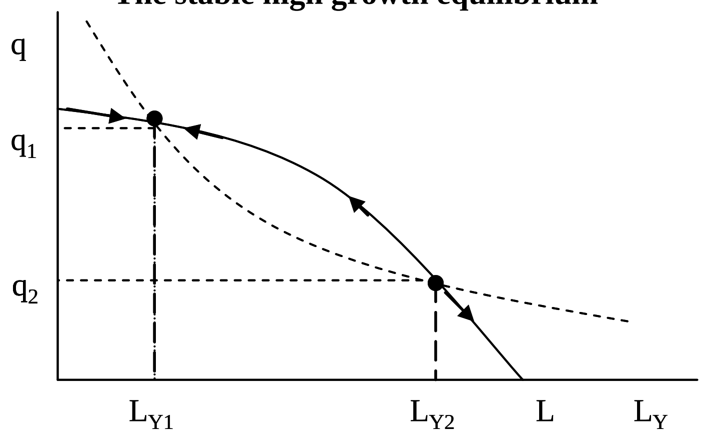
$$\frac{\dot{z}}{z} = (1-\alpha)\left((1-\beta)q\frac{L_Y}{a} - \alpha z - \frac{\dot{q}}{\alpha\ q}\right) \tag{31}$$

$$\frac{\dot{q}}{q} = -\beta \frac{\dot{L}_Y / L_Y}{(L/L_Y - 1)} \quad . \tag{32}$$

[24] The resulting equilibria are consistent with the evidence that although the majority of countries experienced positive growth during the second half of the 20th century, many of the poorest countries had growth rates equal to zero, or even negative; see Durlauf, Johnson, and Temple (2005). An extensive survey of poverty traps is provided by Azariadis and Stachurski (2005).

Equations (29)-(32) fully characterize the dynamics of the economy. Focusing the discussion of stability on the two dimensions in Figure 1, we analyze the autonomous differential equation system around the stationary state, $\dot{L}_Y = f\left(L_Y, q, \chi^*, z^*\right)$ and $\dot{q} = g\left(L_Y, q, \chi^*, z^*\right)$, where the stars denote steady state values. Arbitrage and labor mobility assure that the labor market equilibrium given by (25a) and (25b) is satisfied at each point in time. Since q is a jump variable, this implies that (23) also holds at each instance, and hence the economy is always on the solid QQ line of Figure 2. The dynamics around $\dot{L}_Y = 0$ represented by the LL line depend on the sign of $\partial\dot{L}_Y / \partial L_Y$. For $\partial\dot{L}_Y / \partial L_Y$ <0, the high-growth equilibrium is stable, as depicted in Figure 2, while $\partial\dot{L}_Y / \partial L_Y$ >0 would imply that the low-growth equilibrium is the stable one.[25]

Figure 2
The stable high growth equilibrium



For any initial manufacturing allocation $L_Y < L^*_{Y2}$, the economy converges along the QQ line to the high growth equilibrium. Along the transition, the evolution of manufacturing employment is such that IPRs are progressively better protected and high rates of innovation afford an ever greater investment in the stock of institution-builders to further protect property rights and increase growth. Alternatively one can describe the adjustment in terms of an initial institutional quality. As long as a country has an institutional quality that exceeds q_2^*, it will converge to the high-growth equilibrium. Note that this clearly outlines a development path were initially less developed economies start growing although they still have weak intellectual property rights

[25] The arrows in Figure 2 reverse for the case of $L_Y^* < \overline{L}_Y$, when the weak IPR equilibrium is stable.

enforcement, and then experience subsequent tightening (e.g., the cases of Japan and Korea).[26]

R&D based economies that start below an institutional threshold level of, q_2^*, would converge to a poverty trap since the return to research does not cover the cost of establishing sufficiently strong IPRs to provide adequate returns to innovators. The economy moves along a vicious cycle as innovators leave the research sector, which reduces institution-building funds further until the no-research, no-institutions equilibrium is attained. In this case, pure imitation of foreign technology might be preferred. The economy moves along a vicious cycle as innovators leave the research sector, which reduces institution-building funds further until the no-research, no-institutions equilibrium is attained.

The stability analysis provides insights as to why initial conditions, such as the type of colonial institutional influence, have been shown to be so influential in the empirical literature. In the endogenous institutional quality equilibrium, initial conditions are a crucial determinant of the long-run equilibrium. In the case of the stable high growth equilibrium, countries whose colonial experience imposed weak institutions (i.e., the institutional threshold, q_2^*) are shown to be unable to sustain such a level of institutional quality in the long run, and hence eventually revert to the poverty trap. For similar reasons, policy may not always be effective in generating strong institutions. Only policies that overcome the institutional threshold can generate fast growth in the long run.

5. Conclusions

We integrate endogenous strength of intellectual property rights into an R&D based growth model to analyze the effects of endogenous institutional quality on the performance of the economy. We argue that the enforcement of IPRs requires resources (in our case, labor), and that private agents have the incentives to invest such resources to protect their intellectual property. The model highlights two key relationships. On the one hand, stronger IPR protection raises the return to innovation and leads to greater research effort and lower manufacturing employment. On the other hand, better IPR

[26] Branstetter, Fisman and Foley (2005) report this pattern for a whole range of developing nations, providing empirical support for Argentina, Brazil, Chile, China, Colombia, Indonesia, Japan, Mexico, Philippines, Portugal, South Korea, Spain, Taiwan, Thailand, Turkey, and Venezuela.

protection increases labor productivity in manufacturing employment, lowers labor demand, and thus reduces the cost of subsequent IPR protection. Multiple equilibria emerge naturally, featuring high/low/no growth stationary states with strong/weak/no IPR protection, respectively.

Among countries that invest in R&D, the stability of the high growth equilibrium requires that institution building be sufficiently productive. In this case, the low-institutions equilibrium implies an institutional threshold such that those countries with initial institutions above this threshold converge to the high-growth/strong-institutions equilibrium, and those starting below the threshold will move to the no-growth/no-IPR protection equilibrium. In a world where technology was available from a technological leader, countries in such vicious cycles would presumably switch to pure imitation regime and do away with any intellectual property rights. Moving from the no-growth to the high-growth equilibrium with private R&D is shown to require the adoption of sufficiently strong institutions that overcome the institutional threshold defined by the low growth equilibrium. Further research is necessary to identify the possibility of growth (and rent appropriation) cycles. Given that Evans, Honkapohija and Romer (1998) show such cycles are possible within the basic Romer (1990) framework, they may also be a feature of the institution-augmented Romer model that we presented above. Most likely their existence depends upon the exact specification of the institution generating function.

A number of caveats are in order. First, our focus on countries for which innovation is driven by their own R&D implies that we have not examined the role of imitation across countries. The possibility of imitation being the source of growth has important implications for IPR protection. In countries that imitate products invented abroad, lax IPR protection can result in faster growth, as shown by Helpman (1993). Moreover, the innovation/imitation interaction between countries can generate interesting dynamics (see Horowitz and Lai, 1996) and even give rise to setups in which a country endogenously switches from imitation to directed R&D (see Eicher and García-Peñalosa, 2001). This implies that the policy implications derived here are not applicable to countries that do not rely on their own R&D and IPR.

The second aspect that qualifies our results is that we have not allowed for externalities stemming from private investments in R&D protection. Such externalities can occur across firms at a given point in time or intertemporally, implying that the amount of protection obtained by a firm from a given expenditure is greater the more other firms spend today or have spent in the past. Externalities of this type have two implications, as is well know from models with externalities in investments in human capital. First, they will reinforce the mechanism leading to multiple equilibria that we have examined in this paper. Second, the high-growth equilibrium that we have obtained may not be socially optimal, and a Pareto superior equilibrium can exist which would call for some form of public intervention. This is an important issue that is beyond the scope of this paper but which merits further investigation.

Appendix

A.1. Welfare with exogenous institutions

Integrating the utility function (1) over time we can express individual intertemporal utility as

$$W=\frac{1}{\rho(1-\sigma)}+\frac{K_0^{1-\sigma}}{1-\sigma}\frac{\chi^{1-\sigma}}{(\rho-(1-\sigma)g)}$$

where $\chi = C/K$ is the consumption-capital ratio and $\rho-(1-\sigma)g>0$ from the transversality condition of the consumer's problem. Differentiating we find

$$sign\left[\frac{dW}{dq}\right]=sign\left[\frac{d\chi}{dq}+\frac{\chi}{\rho-(1-\sigma)g}\frac{dg}{dq}\right]$$

From the individual's budget constraint we can express the consumption-capital ratio as $\chi = Y/K-g$, where $Y/K=r\Phi/\alpha b$ is the average product of capital and $\Phi\equiv\left(1-q(1-\varphi^{\alpha})\right)/\left(1-q(1-\varphi)\right)$. Using the fact that $r=\rho+\sigma g$, we can simplify the derivative to

$$sign\left[\frac{dW}{dq}\right]=sign\left[\frac{r}{\alpha b}\frac{d\Phi}{dq}+\frac{Y/K-r}{\rho-(1-\sigma)g}\frac{dg}{dq}+\frac{\sigma\Phi}{\alpha b}\frac{dg}{dq}\right]$$

A.2. Study of the QQ and LL functions

Differentiating the LL schedule, we have

$$\frac{dq}{dL_Y}=-\frac{(1-\beta)b\varphi\left(a\rho+\sigma(1-\beta)L\right)}{\left((1-\beta)b\varphi L_y+\left(1-\varphi^{\alpha}\right)\left(a\rho+\sigma(1-\beta)(L-L_y)\right)\right)^2}<0,$$

implying that it is decreasing. Also

$$sign\left[\frac{d^2q}{dL_Y{}^2}\right]=sign\left[\alpha^{\frac{1}{1-\alpha}}-\sigma\left(b^{\frac{\alpha}{1-\alpha}}-\alpha^{\frac{\alpha}{1-\alpha}}\right)\right].$$

The LL schedule is thus convex for any value of *b* such that $\alpha(1+\alpha/\sigma)^{(1-\alpha)/\alpha}>b$. This condition is certainly satisfied for $b=\alpha$, but may not be satisfied for large values of *b*, in which case the schedule would be concave. The function takes the values $q=1/(1-\varphi^{\alpha})>1$ and $q=a\rho/\left((1-\beta)b\varphi L+a\rho(1-\varphi^{\alpha})\right)>0$ at $L_Y=0$ and $L_Y=L$, respectively.

Differentiating QQ, we find $dq/dL_Y<0, d^2q/dL_Y^2<0$, implying that it is decreasing and concave in L_Y. Given our assumptions on $F[L_B]$, the QQ schedule is less than 1 at $L_Y=0$, and is 0 at $L_Y=L$. The LL schedule is therefore above the QQ schedule at both $L_Y=0$ and $L_Y=L$. Hence, there are either two intersections between LL and QQ or none.

A.3. Dynamic analysis with endogenous institutions

The dynamic analysis is an extension of Arnold (2000), and we refer the interested reader to the original article for extensive discussions of the detailed derivations. To simplify the dynamics, we assume a cost differential of competitive firms of $b=\alpha$, which implies $\varphi=1$ and hence $Y=AL_Y^{1-\alpha}x_m^{\alpha}$ and $K=Ax_m$. We also express the equilibrium in terms of normalized variables, $\chi\equiv C/K, z\equiv Y/K$. Utility maximization implies $\dot{C}/C=(r-\rho)/\sigma$, which together with the capital accumulation constraint (4) yields $\dot{\chi}/\chi=(r-\rho)/\sigma-z+\chi$. Since the marginal product of capital in the final good sector, αz, must be equal to the price of intermediate goods, $p_m=r/\alpha$, the interest rate is given by $r=\alpha^2 z$. We then have

$$\frac{\dot{\chi}}{\chi}=\frac{\alpha^2 z-\rho}{\sigma}-z+\chi. \qquad \text{(A.1)}$$

Wage equalization between the final goods sector and the research sector gives the equilibrium price of blueprints, $P_A=a(1-\alpha)Y/(1-\beta)qAL_Y$, which we can differentiate to find the evolution of the price of technology over time that is compatible with a labor market equilibrium. That is

$$\frac{\dot{P}_A}{P_A}=\frac{\dot{Y}}{Y}-\left(\frac{\dot{A}}{A}+\frac{\dot{L}_Y}{L_Y}\right)-\frac{\dot{q}}{q}. \qquad \text{(A.2)}$$

Differentiating the production function with respect to time, we obtain

$$\frac{\dot{Y}}{Y}-\left(\frac{\dot{A}}{A}+\frac{\dot{L}_Y}{L_Y}\right)=-\frac{\alpha}{1-\alpha}\frac{\dot{z}}{z}, \qquad \text{(A.3)}$$

which allows us to express (A.2) as

$$\frac{\dot{P}_A}{P_A}=-\frac{\alpha}{1-\alpha}\frac{\dot{z}}{z}-\frac{\dot{q}}{q}. \qquad \text{(A.2')}$$

The no-arbitrage condition requires that the value of a patent satisfies $\dot{P}_A+\pi=rP_A$. Recall that profits can be expressed as $\pi=(1-\alpha)p_m x_m=(1-\alpha)Y/A$. The labor market equilibrium condition $(1-\alpha)Y/L_Y=(1-\beta)qAP_m/a$ can be used to substitute for *Y/A* in this expression, so that profits can be written as $\pi=\alpha(1-\beta)qP_A L_Y/a$. Substituting for profits and using the fact that $r=\alpha^2 z$, we can express the no-arbitrage condition as

$$\frac{\dot{P}_A}{P_A}=\alpha^2 z-\frac{\alpha(1-\beta)qL_Y}{a}. \qquad \text{(A.2'')}$$

Equations (A.2') and (A.2'') together give the evolution of the output-capital ratio

$$\frac{\dot{z}}{z}=(1-\alpha)\left((1-\beta)q\frac{L_Y}{a}-\alpha z-\frac{\dot{q}}{\alpha\, q}\right). \qquad \text{(A.4)}$$

To obtain the evolution of L_Y, we express the output-capital ratio as $z = \left(AL_Y / K\right)^{1-\alpha}$. Totally differentiating z and using the production function $Y = (AL_Y)^{1-\alpha} K^{\alpha}$, the goods market clearing condition $\dot{K}/K = z - \chi$, and the expression for the rate of technology growth (5), yields

$$\frac{\dot{L}_Y}{L_Y} = \frac{\dot{z}/z}{1-\alpha} - \frac{(1-\beta)(L-L_Y)}{a} + z - \chi . \qquad \text{(A.5)}$$

Differentiating (26), we obtain the evolution of institutions over time,

$$\frac{\dot{q}}{q} = -\beta \frac{\dot{L}_Y / L_Y}{(L/L_Y - 1)} . \qquad \text{(A.6)}$$

The dynamic evolution of the economy is then characterized by the system formed by (A.1), (A.4), (A.5), and (A.6). The system can be solved for its steady state $\dot{z} = \dot{\chi} = \dot{L}_Y = \dot{q} = 0$, yielding

$$\chi^* = \frac{a\rho - (1-\beta)(L-L_Y)(\alpha^2 - \sigma)}{a\alpha^2} \qquad \text{(A.7)}$$

$$z^* = \frac{a\rho + (1-\beta)(L-L_Y)\sigma}{a\alpha^2} \qquad \text{(A.8)}$$

$$q^* = \frac{a\rho + (1-\beta)(L-L_Y)\sigma}{(1-\beta)L_Y\alpha} . \qquad \text{(A.9)}$$

The steady state equilibrium levels of institutions and manufacturing employment are then given by equation (A.9), which is QQ in the text, together with LL.

Stability analysis

In order to assess the stability in the (q, L_Y) space, we need to sign $\partial\dot{L}_Y / \partial L_Y$. From the implicit function theorem we have

$$\left.\frac{dq}{dL_Y}\right|_{L_Y=0} = -\frac{\partial\dot{L}_Y / \partial L_Y}{\partial\dot{L}_Y / \partial q} .$$

From equation (A.9) we know $dq/dL_Y\big|_{L_Y=0} < 0$, implying that $\partial\dot{L}_Y / \partial L_Y$ has the same sign as $\partial\dot{L}_Y / \partial q$. Substituting for $\dot{z}/z$ into equation (A.5) and using the steady state values z^* and χ^*, we can express $\dot{L}_Y = 0$

$$\frac{(L-L_Y)(a\rho + (1-\beta)(\sigma L - (\sigma + \alpha q)L_Y)}{a((\sigma+\beta)L_Y - \sigma L)} = 0 ,$$

and differentiating we have

$$\frac{\partial\dot{L}_Y}{\partial q} = \frac{\alpha(1-\beta)(L-L_Y)L_Y}{a(\sigma L - (\sigma+\beta)L_Y)} .$$

Hence $\partial \dot{L}_Y / \partial L_Y > 0$ if and only if $\sigma L - (\sigma + \beta) L_Y > 0$. Since all equilibria must satisfy $q^* < 1$, equation (LL) implies that for $\beta \geq \alpha$, the two equilibrium allocations of labor satisfy $L^*_{Y1,2} > \overline{L}_Y$. That is, if institution builders are sufficiently productive, the high-growth equilibrium is stable and the low-growth equilibrium unstable.

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