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Declining Predation during Development: a Feedback Process

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Empirical evidence suggests that poorer countries have larger amounts of predation. We formulate a neoclassical growth model in which agents devote time to either produce or predate. When the elasticity of substitution between labour and capital is lower than one, the labour share rises with capital, reducing the incentive to predate and increasing the incentive to produce throughout the transition. Consequently, a feedback process between capital accumulation and predation arises, which amplifies income differences generated by differences in productivity. This paper helps to explain why differences between countries have remained stable and the key role that institutions play in development.

INTRODUCTION

Empirical literature documents the failure of many low-income countries to achieve a successful development process (see Quah 1996, 1997; Parente and Prescott 1993). Much effort in current macroeconomic research has been devoted to explain this fact. In this respect, new features such as the nature and composition of economic activities have been explored. It is well known that in economies, resources are devoted to both productive activities (production of goods and services) and unproductive activities. Unproductive activities share the common feature of being profitable but wasteful: they use resources to generate income but not goods (for example, property crime, fraud, begging, corruption, lobbying, rent-seeking, etc.). We will call all these unproductive activities predation from now on. To be more precise, we define predation as any activity in which an agent, acting as a predator, uses factors to capture the production generated from others, the prey.

The empirical evidence suggests that the size of the unproductive sector is larger in low-income countries. Measuring the size of the predation is not a trivial task. Since there is no clear measure of many unproductive activities, the most plausible empirical strategy to obtain a measure of the predation sector is to consider criminal predation as a proxy for it. Obviously, this measure does not include many predatory activities, but it is the only one that is available for many countries. For example, the share of the criminal predatory sector in GDP is 20.7% for Latin America, while it is 6.89% for the USA.[1] Another example in the literature is Bourguignon (1999), who finds that the share of property crime in GDP is 0.5% for the USA, while it is 1.5% for Latin America. More recently, calculations from Soares and Naritomi (2010) show that regions with higher GDP per capita, such as North America and western Europe, also display lower burglary and theft rates. Another clear example of predation is corruption. Since corruption is identified as the abuse of public office for private gain, a broad range of actions such as bribery and embezzlement are pure acts of predation. In this respect, Treisman (2000), Paldam (2001, 2002), Brunetti and Weder (2003) and Rehman and Naveed (2007), among others, evidence that corruption is higher in less developed and developing countries. Furthermore, countries in which corruption is high also display high levels of other forms of predation. An example is the use of pump-and-dump schemes to manipulate stock prices and generate artificial rents (see Khwaja and Mian 2004). Morck *et al.* (2000) find that more corrupt countries display more price manipulation. Other forms of predation are not necessarily illegal. In fact, Murphy *et al.* (1991) use the proportion of students concentrating on law as a proxy for the size of the predatory sector, and they find that predation constitutes an important obstacle for development.

Many recent empirical studies have documented an empirical fact that is crucial for our theory: the elasticity of substitution between labour and capital is less than 1. Using an extensive panel of manufacturing and non-manufacturing firms, Chirinko *et al.* (2004) estimate an elasticity of substitution less than 0.5. Choi and Ríos-Rull (2009) investigate whether the dynamics of labour share are better explained by non-competitive factor prices or by a non-unit elasticity of substitution, and find the latter to be more important. This finding is obtained through a stochastic dynamic general equilibrium model where the value of the elasticity of substitution is assumed to be 0.75 and the path of the price markup is calibrated accordingly. In a recent contribution, León-Ledesma *et al.* (2010) provide a new approach to estimate technological parameters, and they find empirical support that is consistent with the hypothesis of the elasticity of substitution being less than 1.[2]

This paper presents a mechanism that connects the two empirical facts mentioned above: the greater predation in developing countries and the elasticity of substitution being less than 1. When the elasticity of substitution between labour and capital is less than 1, countries with low per capita income display a lower labour share, which implies that agents have little incentive to devote time to production, devoting a relatively large fraction of their time to predation. The existence of predation reduces payments to factors devoted to production even further. This generates a feedback process in which predation reduces the incentive to devote time to production, thus generating even more predation.

The paper presents a neoclassical growth model in which workers devote time to production and to predation. A key assumption in the model is that the elasticity of substitution between labour and capital is lower than 1. This property of the production function implies that the labour share increases throughout the transition to the steady state when the initial per capita capital is lower than the steady state level.[3] Since a lower labour share results in fewer incentives to devote time to production and more incentives for predation, agents therefore devote more time to predation when per capita income is low, and consequently predation declines during the transition to the steady state when the initial per capita capital is lower than the steady state level. Thus the paper shows the existence of a feedback mechanism: predation discourages capital accumulation, and capital accumulation discourages predation.

This feedback mechanism implies that differences in institutions are not a unique explanation for differences in levels of predation among countries; the factor accumulation process also plays an important role in accounting for differences in predation. This new approach contrasts with the standard literature, which traditionally has presented differences in institutions as the sole explanation, and considers that institutions may affect factor accumulation but not the other way around. In this respect, recent empirical studies—such as Glaeser *et al.* (2004) and Djankov *et al.* (2003)—support our hypothesis that predation is affected by not only institutions but also factor accumulation.

The mechanism described above also contributes to a better understanding of why differences in per capita income among countries have remained stable. Conventional wisdom says that differences in total factor productivity (TFP) are one of the main sources of differences in per capita income.[4] This paper proposes a mechanism that amplifies differences in TFP and per capita income generated by technological differences across countries. This mechanism involves the reallocation of resources from predation to productive activities and the incentives to engage in these activities. In this sense, the mechanism is in line with the empirical research that emphasizes the differences in 'social infrastructure', using the terminology of Hall and Jones (1999), to understand differences in TFP across countries, instead of the more conventional view, which considers these differences as mere technological ones. The mechanism would be as follows: when productivity rises, there is a positive direct effect on production and an indirect effect due to the accumulation of capital (the rise in productivity increases the return on savings and therefore the incentives to accumulate more capital). Together with these standard mechanisms, in the current model there is another additional mechanism that amplifies the effect of productivity on per capita income. This new mechanism related to predation, and the assumption that elasticity of substitution is smaller than 1, works as follows: an improvement in productivity fosters the capital accumulation; then labour share increases with the per capita capital (due to the assumption that the elasticity of substitution is lower than 1), reducing the incentive to predate and increasing the portion of labour devoted to production. This increase in the amount of labour devoted to production has three positive effects on the per capita income:

- There is a direct effect on per capita production.
- There is an indirect effect due to the accumulation of capital: when labour rises, it increases the marginal productivity of capital and the incentive to accumulate more capital.
- The reduction in the portion of labour devoted to predation implies that the share of the marginal product of capital that goes to savers goes up, raising the return on savings and promoting the accumulation of capital.

Along the same lines as the literature that emphasizes the role of differences in institutions to explain differences in per capita income,[5] we study the effect of an improvement in the quality of the institutions to deter predation. This institutional change is interpreted as a decrease in the productivity of the predation technology, which reduces the incentives to predation and so increases the portion of labour devoted to production. This increase in labour devoted to production not only has a direct positive effect on production but also encourages the accumulation of capital due to two mechanisms:

- it increases the marginal product of capital and so the return on savings;
- it reduces the portion of payments to capital that goes to predation, increasing the return on savings.

Furthermore, when the capital–labour ratio rises, the labour share in the production sector increases (due to the assumption of an elasticity of substitution lower than 1), and this reinforces the reallocation of labour from predation to production.

We extend the model to analyse the implications of two important issues: the existence of poverty traps and the role of human capital. The first extension is about poverty traps. In contrast with other papers in the literature, multiple equilibria do not arise in our model. However, it is possible to generate poverty traps by introducing a fixed cost in the predation technology of our model. We analysed such an extension and found that when institutional quality is not good enough, multiple steady states arise. More precisely, there are three steady states, and two of them are characterized by low per capita income and the existence of predation. These low-income steady states would be the poverty traps, in which predation discourages capital accumulation and reduces labour share. As a consequence, the amount of time devoted to production decreases, while it encourages predation. The third steady state is characterized by high per capita income and the non-existence of predation. Thus institutional quality is crucial in order to determine the existence of poverty traps. The second extension incorporates skilled and unskilled labour in the model. Some empirical evidence seems to support the hypothesis that the income share of raw labour decreases with economic growth while the income share of human capital increases with economic growth (see Krueger 1999; Sturgill 2012). Given that individuals determine how to allocate their time among different activities, the consideration of these facts might affects the dynamics of predation. We show that these observations are not incompatible with our hypothesis that predation declines along the development process. To be more precise, we show that an increase in the income share of skilled labour, a reduction in the income share of unskilled labour and a reduction in predation are perfectly possible in our model, as long as the drop in the income share of raw labour is smaller than the decrease of the portion of unskilled workers on the labour force.

There is a large body of literature devoted to the allocation of labour and talent among productive and unproductive activities (see, for example, Murphy *et al*. 1991, 1993; Acemoglu 1995; Acemoglu and Verdier 1998; Schrag and Scotchmer 1993; Grossman and Kim 1996, 2002; Zuleta 2004; Andonova and Zuleta 2009; Chassang and Padró-i-Miquel 2010). Moreover, there exists a considerable number of papers that analyse the relationship between social conflict and development. In this respect, Chassang and Padró-i-Miquel (2009) study the opportunity cost for predation in a repeated game. Tornell and Lane (1999) show that under weak institutions, the interaction between powerful groups may cause redistributive distortionary fiscal policies consisting in draining resources from an efficient sector to an inefficient one. The papers most related to ours are the ones that establish a connection between predation and the factorial distribution of income. Using a static general equilibrium setting, Dal Bó and Dal Bó (2011) show that if predation is labour-intensive relative to the whole economy, then favourable shocks in the labour-intensive productive sector reduce predation. The link between labour share and predation has been analysed already in previous contributions by Zuleta (2004) and Andonova and Zuleta (2009). However, labour share in these papers is constant, and consequently there is no feedback process between capital accumulation and predation, since capital accumulation in these models would not affect predation.

The relationship between labour share and development plays an important role in the feedback mechanism described above. This relationship has been recently revised by many empirical studies. While national accounts' statistics typically reveal that labour share is smaller in low-income countries, Gollin (2002) points out that these national account labour shares are underestimated, since self-employed incomes are computed as capital income. Moreover, he observes that this problem is particularly severe for developing countries, where the portion of self-employed in the labour force is quite high. Gollin proposes a set of adjustments to conventional calculations that consist of including some part of self-employment income in labour share. Gollin's preferred adjustment is based on the assumption that the labour income of self-employed is equal to the average wage of employees. However, the literature on self-employment in developing countries shows that, typically, self-employed workers in developing countries are poor, with low levels of education and with most of them working in the informal sector in small-scale businesses, which require low skills (Banerjee and Duflo 2007; Mel *et al*. 2008; Temkin 2009; Narita 2011). Thus the adjustment proposed by Gollin has an upward bias for developing countries since the shadow wage of the self-employed is below that of the employees' wage (as Maarek (2010) pointed out and the above empirical literature confirms). In addition, since most self-employed people in developing countries are engaged in the informal economy, it is likely that part of their production is not accounted for in the GDP (the denominator of the labour share). In spite of this upward bias in the labour share of developing countries, it still remains lower than in developed countries after the adjustment proposed by Gollin. As Jones (2003) puts it: 'in some ways this is a question of the glass half-full versus half-empty. While the shares move closer together when one makes Gollin's correction, they are still substantially different.' Specifically, the average labour share of developing countries reported by Gollin is 0.584, while the average in developed countries is 0.687.[6] Gollin's analysis is a big step forward from the methodological point of view, but it suffers the limitation of the small dataset in which developing countries are underrepresented. In this respect, Harrison (2005)—using a similar methodology but with a much larger dataset with respect to both the number of countries and number of years—confirms that there are significant differences in labour share between developing and developed countries, with developing countries displaying lower shares. Another approach is to use industrial data. This approach has the advantage that the weight of self-employment in the sample is negligible or insignificant. Studies that use industrial data ratify that there is a clear and positive relationship between labour share and development indicators, such as per capita income (Ortega and Rodriguez 2006) or capital accumulation (Decreuse and Maarek 2009; Maarek 2010). Therefore all three empirical methodologies—conventional national account calculation, adjusted national account calculation to incorporate the self-employed, and industrial data—confirm that developing countries exhibit lower labour shares than developed ones.

This paper is organized as follows. Section I develops a model of two sectors: production and predation. Section II derives the agents' decisions, and Section III defines the equilibrium. Section IV explains how labour share and predation evolve with per capita capital. Section V presents the dynamic behaviour of the economy. Section VI analyses the role of the predation explaining the per capita GDP differences due to a shift in productivity. Section VII studies the effect of change in the quality of the institutions that reduces the efficiency of the predation technology. Section VIII discusses two possible extensions: one that generates poverty traps, and another that allows us to discuss the role of human capital in predation. Section IX concludes, and an Appendix presents the proofs and technical details.

1. The Model

Time is continuous with an infinite horizon. The economy is populated with many identical dynasties of homogeneous agents. There is a single good in the economy, which can be used for consumption and investment in physical capital:

$$Y(t) = C(t) + \dot{K}(t) + \delta K(t),$$

where $Y(t)$ denotes aggregate production, $C(t)$ denotes aggregate consumption, $K(t)$ denotes the aggregate capital, and $\delta \in (0,1)$ denotes the depreciation rate. $\dot{K}(t) + \delta K(t)$ is the gross investment.

Technology

The production technology of this good is given by the production function

$$Y(t) = F(K(t), L(t)),$$

where K denotes physical capital and L denotes labour. The production function $F : \mathbb{R}^2_+ \to \mathbb{R}_+$ is assumed to be continuous, increasing (in both arguments) and strictly quasi-concave, and presents constant return on scale. Furthermore, it is twice-continuously differentiable and strictly increasing in $\mathbb{R}^2_{++}$, and zero input implies no output, $F(0, K) = F(K, 0) = F(0, 0) = 0$. Also, Inada conditions are satisfied: $\lim_{\kappa\to 0} F'_K(\kappa,1) = +\infty$ and $\lim_{\kappa\to +\infty} F'_K(\kappa,1) = 0$ where $\kappa \equiv K/L$. Finally, the production function $F(.)$ is assumed to exhibit an elasticity of substitution between its inputs of less than 1: for all $\kappa \in \mathbb{R}_{++}$,

$$\begin{aligned}\sigma^f(\kappa) &\equiv \frac{\partial \ln(\kappa)}{\partial \ln(MRTS_{L,K}(\kappa,1))} \\ &= \left(\frac{\partial MRTS_{L,K}(\kappa,1)}{\partial \kappa}\frac{\kappa}{MRTS_{L,K}(\kappa,1)}\right)^{-1} \\ &< 1,\end{aligned}$$

where $MRTS_{L,K}(\kappa,1)$ is the marginal rate of technical substitution between labour and capital, and $\sigma^f(\kappa)$ is the elasticity of substitution between labour and capital (of the production function), which depends on the capital–labour ratio $\kappa \equiv K/L$. The assumption that the elasticity of substitution is lower than 1 implies that the labour share increases with the capital–labour ratio. This property will play a key role in our results.

Preferences

The preferences of a dynasty are given by a time-separable utility function

$$\int_0^\infty u(c(t))e^{-\rho t}\, dt,$$

where $c(t)$ denotes the per capita consumption of dynasty in period t, and $\rho > 0$ is the discount rate of the utility function. We assume that $u(\cdot)$ is continuous, strictly increasing, strictly concave and differentiable of second order in $\mathbb{R}_{++}$, and we assume that $\lim_{c\to 0} u'(c) = +\infty$. Agents do not differentiate between the consumption of different members of the dynasty; they only care about their aggregate consumption.

The predation technology

Each period, agents are endowed with 1 unit of time that can be devoted to undertake two types of economic activities: to produce goods l and to undertake predation l_p, that is,

$$1 = l(t) + l_p(t).$$

With regard to predation activities, we understand all the activities that imply use of resources to obtain incomes without generating production. We include property crimes, fraud, corruption, lobbying, etc. Agents' income that is obtained through predation is denoted by $\widetilde{y}(t)g(l_p)$, where $\widetilde{y}(t)$ is the per capita production and $g : \mathbb{R}_+ \to [0, 1]$ is the fraction of per capita gross production that each agent obtains when devoting time to predation, which depends positively on the amount of time devoted to such activity, l_p.[7] We assume that the function $g(\cdot)$ is strictly increasing, strictly concave, continuous and differentiable of second order, and $g(0) = 0$, $g(1) < 1$ and $g'(0) \geq 1$.

II. Agents' Decisions

Households

The household's maximization problem is as follows:

$$\max_{\{c(t),l(t),l_p(t),b(t)\}_{t=0}^{\infty}} \int_0^{\infty} u(c(t))\, \mathrm{e}^{-\rho t}\, \mathrm{d}t \tag{1}$$

$$\text{s.t. } \dot{b}(t) = \underbrace{w(t)l(t) + r(t)b(t) - g(\widetilde{l}_p(t))y(t)}_{\text{net income from the production sector}} + \underbrace{g(l_p(t))\widetilde{y}(t)}_{\text{income from predation}} - c(t),$$
$$l(t) + l_p(t) = 1,$$
$$y(t) = w(t)l(t) + (\delta + r(t))b(t),$$

where $b(t)$ denotes the assets of the household, $w(t)$ is the wage per unit of labour, $r(t)$ the *net* return on assets, and $y(t)$ is the household's gross income. Since $r(t)$ is the net return on assets, $\delta + r(t)$ is the gross interest rate, which is the one that appears in the definition of gross income. A tilde (i.e. $\widetilde{\ }$) over a variable means that this variable is a per capita variable of the economy and therefore the household cannot decide on it. Thus $\widetilde{l}_p$ denotes per capita labour devoted to predation, and $\widetilde{y}$ denotes per capita gross income. Income from the production sector is equal to labour income from the production sector $w(t)l(t)$ plus financial income $r(t)b(t)$ minus the amount of this income that is predated by other agents in the economy $g(\widetilde{l}_p(t))y(t)$. The other source of income comes from the predation sector and is equal to $g(l_p(t))\widetilde{y}(t)$. The increase of the household's assets $\dot{b}(t)$ is equal to its savings, which are equal to its income (that from production plus that from predation) minus consumption $c(t)$.

The first-order conditions for the interior solution imply

$$w(t)\left[1 - g(\widetilde{l}_p(t))\right] = g'_{l_p}(l_p(t))\widetilde{y}(t), \tag{2}$$

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\sigma^u(c(t))}\left[(r(t) + \delta)\left(1 - g(\widetilde{l}_p(t))\right) - \delta - \rho\right], \tag{3}$$

where $\sigma^u(c(t)) = -u''(c)c/u'(c)$ is the elasticity of the marginal utility. The first of the above conditions (equation (2)) specifies that the net wage in the production sector after predation should be equal to the marginal payment of predation activities. That is, the time devoted to each activity should have the same marginal payment. Equation (3) is the typical Euler equation. The speed at which consumption grows depends positively on return on savings, $(r(t) + \delta)(1 - g(\widetilde{l}_p(t))) - \delta$, and negatively on the patient rate of the household, ρ. Finally, the more concave the utility function (the higher $\sigma^u(c(t))$), the smoother the consumption path.

The following transversality condition should be also satisfied:

$$\lim_{t\to+\infty} u'(c(t))\ \mathrm{e}^{-\rho t} b(t) = 0.$$

Firms

Firms maximize profits as

$$\max_{k, l^d} F(k, l^d) - wl^d - (\delta + r)k, \tag{4}$$

where k denotes the per capita capital.

The first-order conditions for the above problem are

$$F'_k(k, l^d) = f'(\kappa) = (\delta + r),$$
$$F'_L(k, l^d) = f(\kappa) - f'(\kappa)\kappa = w,$$

where $\kappa = k/l^d$. These conditions are well known and say that firms hire a factor until reaching the point at which the marginal productivity of the factor is equal to its price.

III. Equilibrium Definition

The equilibrium definition is standard: equilibrium occurs when agents maximize their objective functions and markets clear. Since all households are alike, we may define equilibrium in per capita terms.

Definition 1. An equilibrium is an allocation

$$\left\{c(t), l(t), l_p(t), b(t), l^d(t), k(t), \widetilde{l}_p(t), \widetilde{y}(t)\right\}_{t=0}^{\infty}$$

and a vector of prices

$$\{w(t), r(t)\}_{t=0}^{\infty}$$

such that we have the following.

- Households maximize their utility, that is, $\{c(t), l(t), l_p(t), b(t)\}_{t=0}^{\infty}$ is the solution of the household's maximization problem (1).
- Firms maximize profits, that is, for all t, $l^d(t)$, $k(t)$ is the solution of the optimization problem of firms (4).
- Capital market clears: for all t, $k(t) = b(t)$.
- Labour market clears: for all t, $l^d(t) = l(t)$.

- Since households are identical, per capita variables coincide with household variables: for all t, $\widetilde{l}_p(t) = l_p(t)$ and $\widetilde{y}(t) = w(t)l(t) + (\delta + r(t))b(t)$.

Definition 2. Steady-state equilibrium is an equilibrium in which both allocation and prices always remain constant over time.

IV. Predation and Per Capita Capital

Labour share and capital–labour ratio

Let us denote $f(\kappa) = F(\kappa,1)$ as the production per efficient unit of labour, which depends on the capital–labour ratio $\kappa \equiv K/L$ and the capital share $\alpha(\kappa) \equiv f'(\kappa)\kappa/f(\kappa)$. Remember that it was assumed that the elasticity of substitution between labour and capital is less than 1:

$$\begin{aligned}\sigma^f(\kappa) &= \left(\frac{\partial MRTS_{L,K}(\kappa,1)}{\partial \kappa}\frac{\kappa}{MRTS_{L,K}(\kappa,1)}\right)^{-1}\\ &= \left(\frac{\partial((f(\kappa)-f'(\kappa)\kappa)/f'(\kappa))}{\partial\kappa}\frac{\kappa}{(f(\kappa)-f'(\kappa)\kappa)/f'(\kappa)}\right)^{-1}\\ &= \frac{1-\alpha(\kappa)}{-f''(\kappa)\kappa/f'(\kappa)}\\ &< 1.\end{aligned} \tag{5}$$

It is easy to prove that assuming that elasticity of substitution between labour and capital is lower than 1 implies that the labour share increases with capital–labour ratio:

$$\begin{aligned}\frac{\partial(1-\alpha(\kappa))}{\partial\kappa} &= \frac{\partial((f(\kappa)-f'(\kappa)\kappa)/f(\kappa))}{\partial\kappa}\\ &= \frac{-f''(\kappa)\kappa}{f(\kappa)} - \frac{(f(\kappa)-f'(\kappa)\kappa)f'(\kappa)}{(f(\kappa))^2}\\ &= \frac{f'(\kappa)}{f(\kappa)}(1-\alpha(\kappa))\left(\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)}\right)\\ &> 0.\end{aligned} \tag{6}$$

Labour devoted to predation and labour share

Using equation (2) and the fact that all households are identical ($\widetilde{l}_p = l_p$), it follows that

$$\phi(l_p) = \frac{g'(l_p)(1-l_p)}{1-g(l_p)} = 1-\alpha, \tag{7}$$

where $\phi : [0,1] \rightarrow \mathbb{R}_+$ is defined as

$$\phi(x) = \frac{g'(x)(1-x)}{1-g(x)}.$$

Lemma 1. There is a unique $l_p^{\min} \in [0, 1)$ such that $\phi(l_p) > 1$ when $l_p < l_p^{\min}$, $\phi(l_p^{\min}) = 1$ and $\phi(\cdot)$ is strictly decreasing in $[l_p^{\min}, 1]$. Furthermore, $\phi(1) = 0$.

This lemma establishes that $\phi(l_p)$ is larger than 1 when l_p is smaller than $l_p^{\min}$. Since the labour share is always smaller than 1, Lemma 1, together with the equilibrium condition (7), implies that l_p is always strictly larger than $l_p^{\min}$ at the equilibrium, as displayed in Figure 1(a). It is also shown in Figure 1(a) that when l_p is larger than $l_p^{\min}$, the function $\phi(l_p)$ is strictly decreasing, being zero when l_p is 1. This property, together with the equilibrium condition (7), implies that the labour share determines the portion of labour devoted to predation l_p, which is always in the interval $(l_p^{\min}, 1)$.

It follows from Lemma 1, equation (7) and the Implicit Function Theorem that l_p is a decreasing function of labour share:

$$\frac{\partial l_p}{\partial(1-\alpha)} = \frac{1}{\phi'(l_p)} < 0.$$

Obviously, the amount of labour devoted to production is an increasing function of labour share:

$$\frac{\partial l}{\partial(1-\alpha)} = -\frac{\partial l_p}{\partial(1-\alpha)} > 0.$$

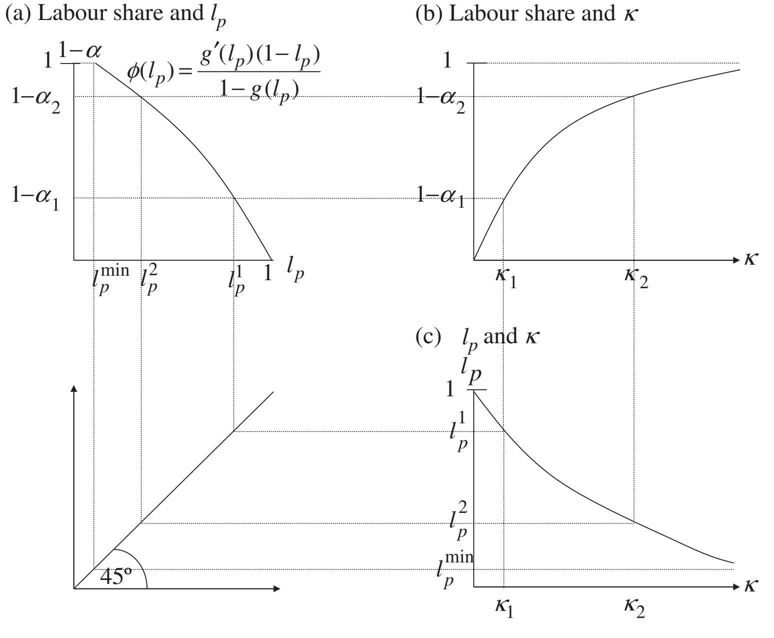

FIGURE 1. Labour devoted to predation and capital–labour ratio.

We may summarize this result in the following corollary.

Corollary 1. The portion of labour devoted to predation l_p is a strictly decreasing function of the labour share, being $l_p = 1$ when $1 - \alpha = 0$ and $l_p = l_p^{\min} < 1$ when $1 - \alpha = 1$.

This corollary states that when the labour share increases, the amount of labour devoted to predation increases as well. From equation (2), we observe that the marginal payment of predation depends on the time devoted to it and per capita income, while the marginal payment in the production sector depends on the time devoted to it, per capita income and labour share. Thus if the labour share goes up, then the payment to productive labour goes up while the payment of predation remains unchanged. This means that the increase in the labour share raises the relative payment of productive labour with respect to predation, encouraging productive activities and discouraging predation.

Labour devoted to predation and capital–labour ratio

Since the amount of labour devoted to predation decreases with labour share, and labour share increases with the capital–labour ratio, we conclude that the amount of labour devoted to predation decreases with the capital–labour ratio.

Proposition 1. The portion of labour devoted to predation at equilibrium l_p is a strictly decreasing function of the capital–labour ratio in production. The portion of labour devoted to production at equilibrium l is a strictly increasing function of the capital–labour ratio in production. At equilibrium, $l_p \in (l_p^{\min}, 1)$ and $l \in (0, l^{\max})$, where $l^{\max} \equiv 1 - l_p^{\min} \in (0, 1)$.

Figure 1(b) shows that when the capital–labour ratio rises in the production sector (from κ_1 to κ_2), due to the elasticity of substitution being lower than 1, the labour share rises as well (from $1 - \alpha_1$ to $1 - \alpha_2$). This reduces the household's incentive to devote time to predation, as Figure 1(a) shows (reallocating the labour devoted to predation from l_p^1 to l_p^2). Figure 1(c) shows that the rise of the capital–labour ratio in the production sector (from κ_1 to κ_2) generates a drop in the labour devoted to predation (passing from l_p^1 to l_p^2).

From now on we will call $l_p(\kappa)$ the function that relates the amount of labour devoted to predation in equilibrium with the capital–labour ratio in the production sector, and $l(\kappa)$ the function that relates the amount of labour devoted to production in equilibrium with the capital–labour ratio in the production sector.

V. Dynamic Behaviour

Dynamic system

It follows from the equilibrium definition that the dynamic behaviour of capital is given by the equation

$$\dot{k}(t) = F(k(t), l(\kappa(t))) - c(t) - \delta k(t).$$

This equation yields the following accumulation equation of the capital–labour ratio in the production sector:

$$\begin{aligned}\dot{\kappa}(t) &= \frac{\dot{k}(t)}{l(t)} - \kappa(t)\frac{\dot{l}(t)}{l(t)} \\ &= f(\kappa(t)) - \frac{c(t)}{l(\kappa(t))} - \delta\kappa(t) - \frac{l'(\kappa(t))\kappa(t)}{l(\kappa(t))}\dot{\kappa}(t) \\ &= \frac{f(\kappa(t)) - (c(t)/l(\kappa(t))) - \delta\kappa(t)}{1 + (l'(\kappa(t))\kappa(t)/l(\kappa(t)))}.\end{aligned}$$

It follows from the Euler equation (3) that

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\sigma^u(c(t))}\left[f'(\kappa(t))(1 - g(l_p(\kappa(t)))) - \delta - \rho\right].$$

Thus the dynamic behaviour of the economy may be characterized by the following dynamic system:

$$\dot{\kappa}(t) = \frac{f(\kappa(t)) - (c(t)/l(\kappa(t))) - \delta\kappa(t)}{1 + \kappa(t)(l'(\kappa(t))/l(\kappa(t)))}, \tag{8}$$

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\sigma^u(c(t))}\left[f'(\kappa(t))(1 - g(l_p(\kappa(t)))) - \delta - \rho\right], \tag{9}$$

$$\lim_{t\to+\infty} u'(c(t))\mathrm{e}^{-\rho t}\kappa(t)l(\kappa(t)) = 0. \tag{10}$$

It follows from (9) that in order to analyse the dynamic behaviour of the economy, it is important to understand the way in which the return on savings evolves with the capital–labour ratio. The following proposition establishes that the return on savings is a decreasing function of the capital–labour ratio in production, as happens in the neoclassical model.

Proposition 2. The net return on savings (after predation), $f'(\kappa(t))(1 - g(l_p(\kappa(t)))) - \delta$, is a decreasing function of κ, and

$$\begin{aligned}\lim_{\kappa\to 0} f'(\kappa(t))(1 - g(l_p(\kappa(t)))) - \delta &= +\infty, \\ \lim_{\kappa\to+\infty} f'(\kappa(t))(1 - g(l_p(\kappa(t)))) - \delta &= -\delta.\end{aligned}$$

Note that when the capital–labour ratio in the production sector rises, the marginal rate of the capital $f'(\kappa)$ goes down but the portion of income that goes to factors after predation $(1 - g(l_p(\kappa(t))))$ goes up. Thus there are two opposite mechanisms determining the evolution of the return on savings. However, Proposition 2 establishes that the return on savings always decreases with the capital–labour ratio in spite of the increasing portion of income that goes to factors after predation.[8]

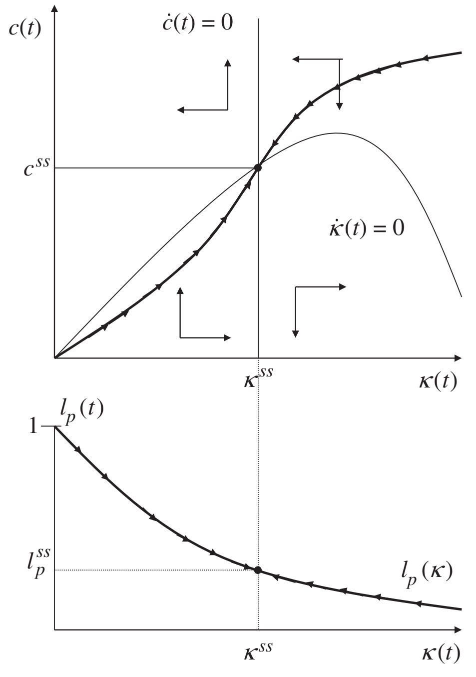

FIGURE 2. Dynamic behaviour.

Corollary 2. There is a unique steady state with positive amount of capital.

The phase diagram in Figure 2 shows that the dynamic behaviour of the economy is characterized by the typical saddle point dynamic: there is a unique path that converges to the steady state. This means that given the initial level of per capita capital,[9] there is a unique equilibrium path, which converges to the steady state. When the initial amount of per capita capital is lower than the steady-state level, the capital–labour ratio, the consumption and the portion of labour devoted to production grow along the equilibrium path, converging to their steady-state levels, while the labour devoted to predation goes down. When the amount of per capita capital is larger than the steady-state level, the opposite happens.

The mechanism that generates this structural change is the increase of the labour share along the transition when the initial level of per capita capital is below the steady-state level. When the elasticity of substitution between labour and capital is smaller than 1, the growth of per capita capital generates an increase of the labour share, raising the payment of productive labour with respect to predation and thus encouraging productive activities and discouraging predation.

VI. PREDATION AS AN AMPLIFICATION MECHANISM OF DIFFERENCES IN PRODUCTIVITY

Many authors have emphasized the key role of differences in productivity to understand differences in per capita income across countries (see Easterly and Levine 2001; Hall and Jones 1999; Parente and Prescott 2000). In this section, we will modify the model to introduce differences in productivity across countries. More precisely, we will consider that production depends on a parameter A, which is an index of total factor productivity:

$$Y(t) = AF(K(t), L(t)),$$

where $F(K, L)$ satisfies all the assumptions presented in Section I. Note that this modification of the model does not affect the relationship between the capital–labour ratio in production and labour share. Thus it does not affect the relationship between capital–labour ratio in production and labour devoted to predation. Therefore the dynamic system that describes the behaviour of the economy (see equations (8)–(10)) is as follows:

$$(11) \qquad \dot{\kappa}(t) = \frac{Af(\kappa(t)) - (c(t)/l(\kappa(t))) - \delta\kappa(t)}{1 + \kappa(t)(l'(\kappa(t))/l(\kappa(t)))},$$

$$(12) \qquad \frac{\dot{c}(t)}{c(t)} = \frac{1}{\sigma^u(c(t))}\left[Af'(\kappa(t))(1 - g(l_p(\kappa(t)))) - \delta - \rho\right],$$

$$(13) \qquad \lim_{t\to+\infty} u'(c(t))\ \mathrm{e}^{-\rho t}\kappa(t)l(\kappa(t)) = 0.$$

The effect of an increase in the total factor productivity index A is displayed in Figure 3. Such as increase makes the locus $\dot{\kappa}(t) = 0$ go up and the locus $\dot{c}(t) = 0$ move to the right. Thus the capital–labour ratio and the amount of labour devoted to production at the steady state go up. This involves an increase in per capita income $y^{ss} = Af(\kappa^{ss})l(\kappa^{ss})$ at the steady state. The fact that there is predation in the model and the labour devoted to predation falls with the capital–labour ratio amplifies the effect of the rise in productivity on per capita income at the steady state due to three mechanisms.

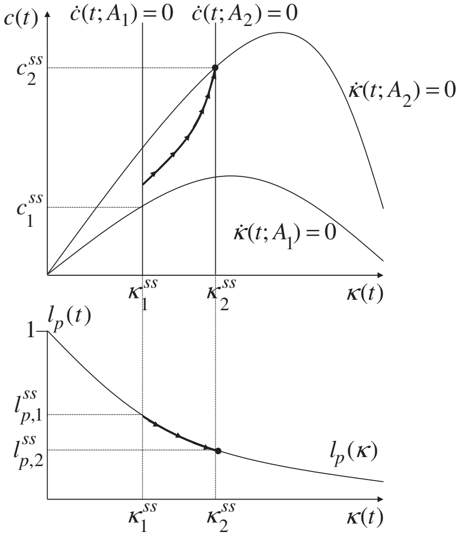

FIGURE 3. Effect of and increase in productivity.

M1 *Fall of predation and rise in the return on savings*. The rise in productivity A increases the return on savings and so the incentive to accumulate capital (see Euler equation (12)). When capital grows, labour devoted to predation falls, reducing the portion of income that goes to predation $g(l_p(\kappa(t)))$. This increases the return on savings, producing an amplification effect on the increase of capital originated by the rise in productivity. Consequently, the amplification effect on the per capita capital produces an amplification effect on the per capita income.

M2 *Increase of both productive labour and marginal productivity of capital*. The return on savings increases due to the fall in the part of income that goes to predation, but an additional amplification effect also exists: when capital increases, owing to the rise in productivity, the portion of labour devoted to production increases, and this implies an increase in the marginal return on capital and also in the return on savings, amplifying furthermore the effect of productivity on the per capita capital accumulation. This additional amplification effect on the per capita capital generates an added amplification effect on the per capita income.

M3 *Increase of productive labour and the direct effect on production*. The amplification effect on the per capita income is not only due to the amplification effect on the per capita capital. There is an additional direct effect on the per capita income due to the increase in the amount of labour devoted to production.

Figure 4 shows the tree mechanism described above. We have considered an increase in the total factor productivity from A_1 to A_2, as $A_2 > A_1$. Figure 4(a) displays the steady-state condition that specifies that the net return on savings, $Af'(\kappa)(1 - g(l_p(\kappa))) - \delta$, must be equal to the utility discount rate ρ. Three curves break down the effect of the increase in the total factor productivity on the net return on savings:

- the thin curve represents the return on savings before the technological change, $A_1 f'(\kappa)(1 - g(l_p(\kappa))) - \delta$;
- the dashed curve represents the return on savings after the technological change, keeping the amount of labour devoted to predation constant at its initial steady-state level, $A_2 f'(\kappa)(1 - g(l_p(\kappa_1^{ss}))) - \delta$;
- the thick curve represents the return on savings after the technological change, taking into account the reduction of labour devoted to predation that occurs when the capital–labour ratio goes up, $A_2 f'(\kappa)(1 - g(l_p(\kappa))) - \delta$.

Thus the horizontal difference between the curve that depicts the return on savings before the technological change (thin) and the curve that depicts the return on savings after keeping predation labour constant (dashed) when the return on savings is equal to the discount rate of the utility, is the standard effect (denoted as SE on the graph), and represents the increase of the capital–labour ratio due to the rise in productivity without taking account of the amplification effect due to the fall in predation—that is, the increase in the capital–labour ratio that would occur if the amount of labour devoted to predation remained constant. The horizontal difference between the curve that depicts the return on savings after the technological change keeping the labour devoted to predation constant (dashed) and the curve that depicts the net return on savings after taking into account the fall in predation labour (thick), when the return on savings is equal to the discount rate of the utility, represents the amplification effect due to mechanism M1 explained above (denoted as M1 in the graph), and represents the increase in the capital–labour ratio due to the fall in the portion of the marginal product

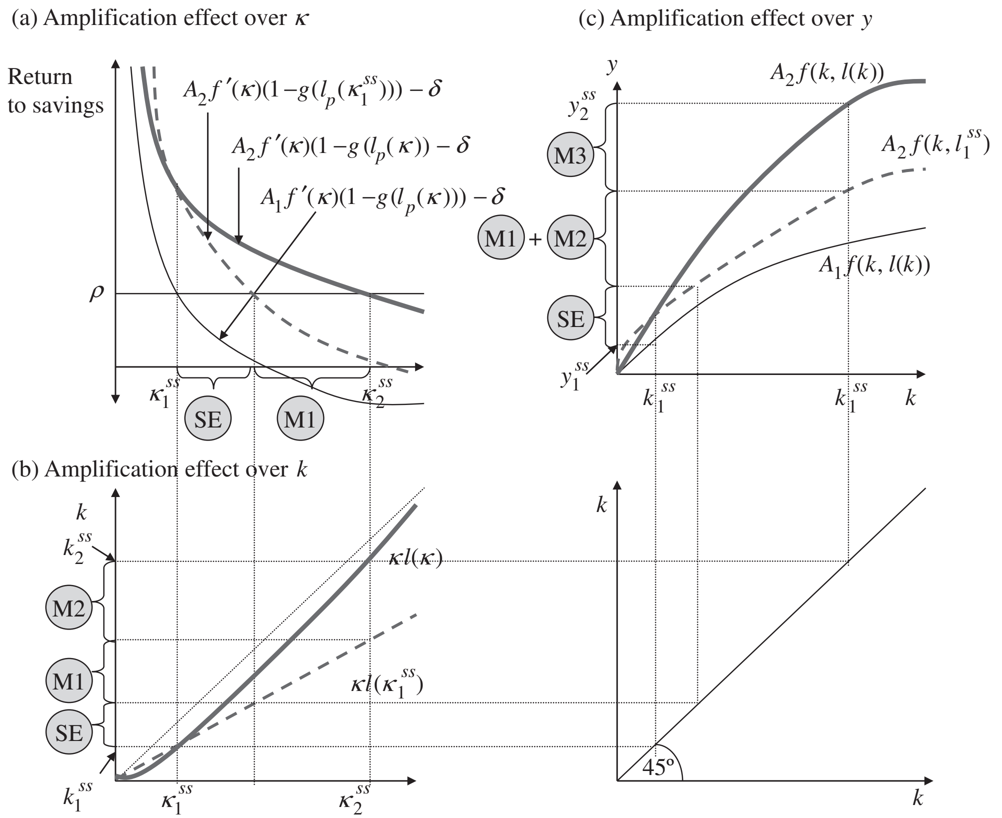

FIGURE 4. Amplification effect of and increase in productivity.

of capital that goes to predators and the rise in the portion that goes to savers, which increases the return on savings and fosters the capital accumulation.

Figure 4(b) displays the relationship between per capita capital and the capital–labour ratio:

$$\kappa = \frac{k}{l(\kappa)} \Leftrightarrow k = \kappa l(\kappa).$$

Two curves show the effect of the decrease of the amount of labour devoted to predation on the relationship between per capita capital and the capital–labour ratio:

- the dashed curve relates the capital–labour ratio to the per capita capital, keeping the amount of labour constant at its initial steady-state level, $k = \kappa l(\kappa_1^{ss})$;
- the thick curve relates the capital–labour ratio to the per capita capital, taking into account the fact that the portion of time devoted to productive activities increases with the capital–labour ratio.

The vertical distance between the two curves, denoted as SE, represents the consequence of translating the standard effect on capital–labour ratio (described in Figure 4(a)) into the per capita capital (that is, without considering the reallocation of labour from predation to production sector). The vertical distance denoted as M1 represents the effect of translating the mechanism M1 on the capital–labour ratio (described in Figure 4(a)) into the per capita capital (that is, without considering the reallocation of labour from predation to production sector). The effect of the increase in productive labour on per capita capital is denoted as M2, and corresponds to the mechanism M2 described above: the increase in productive labour increases the marginal product of capital and the return on savings, fostering capital accumulation.

Finally, Figure 4(c) displays the relationship between per capita capital and per capita production. Three production functions show the effect of the increase in the total factor productivity on the relationship between per capital capital and per capita income:

- the thin curve displays the relationship between per capita capital and per capita income before the technological change, $A_1 f(k,l(k))$;
- the dashed curve displays the relationship between per capita capital and per capita income after the technological change, keeping the amount of per capita labour constant at its initial steady state level, $A_2 f(k, l_1^{ss})$;
- the thick curve displays the relationship between per capita capital and per capita income after the technological change, taking into account the increase in per capita labour due to the increase in per capita capital, $A_2 f(k,l(k))$.

The vertical distance SE in the graph represents the consequence of translating the standard effect on per capita capital (described in Figure 4(b)) into the per capita income (that is, keeping the amount of productive labour constant). The vertical distance M1 + M2 represents the effect of translating amplification mechanisms M1 and M2 into the per capita capital (described in Figure 4(b)) to the per capita income. This represents the amplification mechanisms that the reduction of predation implies on per capita capital and its subsequent effect on per capita income. Finally, the vertical distance M3 represents the direct effect of the increase in the productive labour on per capita income, described above as mechanism M3.

Summarizing, Figure 4 displays four mechanisms that make per capita income rise with technological advancement:

- the standard effect SE, which does not consider either the reduction of predation or the increase in productive labour that occurs when the labour share increases;
- the amplification mechanism M1, which takes into account the effect of the reduction in predation on the return on savings and its consequent increase in the capital accumulation;
- the amplification mechanism M2, which takes into account the effect of the increase in productive labour on the marginal return of capital and therefore on the return on savings and in the capital accumulation;
- the amplification mechanism M3, which considers the direct effect of the increase in productive labour on production.

It is shown in the fourth subsection of the Appendix that the effect of the increase in the productivity on per capita income may be split in two parts: the standard effect and the amplification effect due to predation (due to the three mechanisms described above), that is,

$$\frac{\partial y^{ss}}{\partial A}\frac{A}{y^{ss}} = \underbrace{1 + \frac{\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}{1-\alpha(\kappa^{ss})}}_{\text{standard effect}} + \underbrace{\frac{\alpha(\kappa^{ss})(1-\sigma^f(\kappa^{ss}))}{1-\alpha(\kappa^{ss})}\left[\frac{1+\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}{-\frac{g''(l_p(\kappa^{ss}))l(\kappa^{ss})}{g'(l_p(\kappa^{ss}))}+\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}\right]}_{\text{amplification effect due to predation}}$$

$$> 0.$$

Note that the amplification effect occurs only when the elasticity of substitution is lower than 1. This assumption plays a key role in the amplification effect, since the increase in capital raises the labour share and the incentives to devote more labour to production only when the elasticity of substitution is lower than 1.

VII. Institutional Quality

Many authors have shown the empirical relevance of differences in institutions to explain differences in per capita income (see Acemoglu *et al.* (2005) for a complete survey). In this section, we capture this empirical fact by modifying the production function of the predation sector that is now going to depend negatively on an index of institutional quality denoted by $\Gamma \in \mathbb{R}_+$. Thus an increase in the index of this sector discourages the use of labour in that sector and encourages the use of labour in production. To be more precise, we assume that the amount of per capita gross income that each agent obtains when devoting time to predation is a function $g : \mathbb{R}_+^2 \to [0,1]$ that is continuous and differentiable of second order, strictly increasing and strictly concave in its first argument, that is, $g'_{l_p}(l_p, \Gamma) > 0$, $g''_{l_p^2}(l_p, \Gamma) < 0$, $g(0, \Gamma) = 0$, $g(1, \Gamma) < 1$ and $g'_{l_p}(0, \Gamma) \geq 1$. Furthermore, we assume that for all $l_p > 0$, $g'_\Gamma(l_p, \Gamma) < 0$ and $g''_{l_p,\Gamma}(l_p, \Gamma) < 0$. These last two assumptions mean that institutional quality reduces the reward of predation and its marginal payment. Thus these assumptions imply that an improvement in the institutional quality discourages predation and fosters the allocation of labour to the production sector.

Proposition 3. The portion of labour devoted to predation at equilibrium l_p is a strictly decreasing function of the index of institutional quality Γ.

An increase in the index of institutional quality reduces the productivity of the predation technology and therefore the incentive to devote time to such activity.

The dynamic behaviour of the economy may be characterized by the following dynamic system (see dynamic system (8)–(10)):

$$\dot{\kappa}(t) = \frac{f(\kappa(t))(1 - g(l_p(\kappa(t), \Gamma), \Gamma)) - (c(t)/l(\kappa(t), \Gamma)) - \delta\kappa(t)}{1 + \kappa(t)(l'(\kappa(t), \Gamma)/l(\kappa(t), \Gamma))},$$

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\sigma^u(c(t))}\left[f'(\kappa(t))(1 - g(l_p(\kappa(t), \Gamma), \Gamma)) - \delta - \rho\right],$$

$$\lim_{t \to +\infty} u'(c(t))\, \mathrm{e}^{-\rho t}\kappa(t) l(\kappa(t), \Gamma) = 0.$$

Figure 5 shows the effect of an increase in the index of institutional quality Γ. Such an increase makes the locus $\dot{\kappa}(t) = 0$ go up and the locus $\dot{c}(t) = 0$ move right. Thus the capital–labour ratio and the amount of labour devoted to production go up at the steady state. Furthermore, the amount of labour devoted to predation relative to the capital–labour ratio goes down. Thus an improvement in institutions reduces incentives to predation, and increases the portion of labour devoted to production and the portion of marginal productivity of capital that goes to savers, thus fostering capital accumulation.

The effect of the increase in Γ on per capita income is as follows (see the sixth subsection of the Appendix):

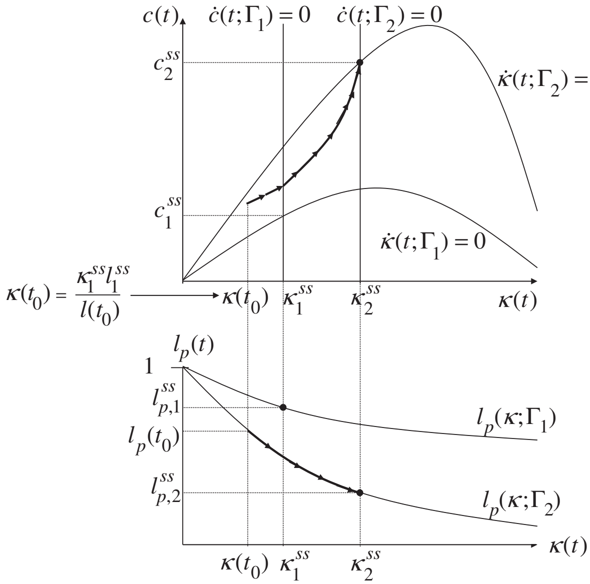

FIGURE 5. Effect of an improvement in institutions.

(14)
$$\begin{aligned}\frac{\partial y^{ss}}{\partial\Gamma}\frac{\Gamma}{y^{ss}} &= \alpha(\kappa^{ss})\frac{\sigma^f(\kappa^{ss})\left[-\varepsilon_\Gamma^{1-g}(\kappa^{ss},\Gamma)+(1-\alpha(\kappa^{ss}))\varepsilon_\Gamma^l(\kappa^{ss},\Gamma)\right]}{1-\alpha(\kappa^{ss})}+\varepsilon_\Gamma^l(\kappa^{ss},\Gamma)\\ &\quad+\left[1-\sigma^f(\kappa^{ss})\right]\frac{\sigma^f(\kappa^{ss})\left[-\varepsilon_\Gamma^{1-g}(\kappa^{ss},\Gamma)+(1-\alpha(\kappa^{ss}))\varepsilon_\Gamma^l(\kappa^{ss},\Gamma)\right]\alpha(\kappa^{ss})}{(1-\alpha(\kappa^{ss}))\sigma^f(\kappa^{ss})}\\ &\quad\times\left[\frac{\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}{-\frac{g''(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa^{ss},\Gamma)}{g'(l_p(\kappa^{ss},\Gamma),\Gamma)}+\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}\right.\\ &\quad\times\left(\frac{1}{-\frac{g''(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa^{ss},\Gamma)}{g'(l_p(\kappa^{ss},\Gamma),\Gamma)}+\alpha(\kappa^{ss})}\right)\\ &\quad\times\left.\left(1+\frac{\alpha(\kappa^{ss})\left[1-\sigma^f(\kappa^{ss})\right]}{-\frac{g''(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa^{ss},\Gamma)}{g'(l_p(\kappa^{ss},\Gamma),\Gamma)}+\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}\right)\right]\\ &> 0,\end{aligned}$$

where

$$\varepsilon_\Gamma^{1-g}(\kappa,\Gamma)=-\frac{g'_\Gamma(l_p(\kappa,\Gamma),\Gamma)\Gamma}{1-g(l_p(\kappa,\Gamma),\Gamma)}>0$$

is the elasticity of the fraction of income that goes to production factors with respect to Γ, and

$$\varepsilon_\Gamma^l(\kappa,\Gamma)=\frac{\partial l(\kappa,\Gamma)}{\partial\Gamma}\frac{\Gamma}{l(\kappa,\Gamma)}$$

is the elasticity of labour with respect to Γ. Note that the last term summed in equation (14) has a factor $(1-\sigma^f(\kappa^{ss}))$. Thus this term represents an amplification effect of the improvement in Γ on per capita income due to the fact that the increase of the capital–labour ratio reduces the incentives to predation due to the increase in the labour share, which occurs when the elasticity of substitution is lower than 1.

Common wisdom has presented differences in institutions as the unique explanation for differences in levels of predation among countries. This view suggests that institutions may affect factor accumulation but not the other way around. However, this paper shows that the relationship is rather more complicated, since factor accumulation also affects predation and this implies a feedback relationship between factor accumulation and predation that is not mediated by institutions. In this respect, new empirical evidence seems to be consistent with this result. Glaeser *et al.* (2004) find strong evidence to support the idea that human capital rather than institutions has a causal effect on economic growth. They show that much evidence points to the primacy of human capital for both growth and democratization. They do not argue that 'institutions do not matter'; rather, they suggest that conceptual revisions should be made in the theoretical analysis. This consideration is also consistent with the contribution of Djankov *et al.* (2003), who argue that institutional implications are not fixed. But institutional outcomes get better as the society grows richer, since institutional opportunities improve. Thus the first-order effect on economic performance comes from human and social capital, which shape both institutional and productive capacities of a society.

VIII. Extensions and Topics for Future Research

Poverty traps

We have proved that in this model there are neither static multiple equilibria (see Lemma 1) nor multiple steady states (see Corollary 2). These results contrast with those of Andonova and Zuleta (2009), who find multiple equilibria regarding the predation decision. This is because the predation technology that we consider is strictly concave, while Andonova and Zuleta (2009) assume the existence of a fixed cost in the predation sector. In this subsection we show that poverty traps arise in the model when a fixed cost in the predation technology is incorporated in the model. More precisely, we assume that the income that each agent obtains when devoting time to predation is equal to $g(l_p-\Gamma)\widetilde{y}$, where the function $g(\cdot)$ satisfies the same assumptions as in the main model (Section I) and $\Gamma\in(0,1)$. Notice that income from predation is a decreasing function of Γ. Thus the parameter Γ may be interpreted as an index of institutional quality as in Section VII. As another modification of the model that we adopt in order to simplify the analysis, we assume that $\lim_{\kappa\to 0}\alpha(\kappa)=0$ and $\lim_{x\to 0}g'(x)=+\infty$.

The internal solution of household's problem satisfies the following necessary conditions:

$$w[1-g(\widetilde{l}_p-\Gamma)]=g'(l_p-\Gamma)\widetilde{y}, \tag{15}$$

$$wl_p[1-g(\widetilde{l}_p-\Gamma)]\le g(l_p-\Gamma)\widetilde{y}. \tag{16}$$

The first of these conditions is equivalent to equation (2): the marginal income of the last unit of labour devoted to production $w[1-g(\widetilde{l}_p-\Gamma)]$ should be equal to the marginal income of the last unit of labour devoted to predation $g'_{l_p}(l_p - \Gamma)\tilde{y}$. The second necessary condition (equation (16)) means that the income that comes from predation, $g(l_p - \Gamma)\tilde{y}$, should always be larger than the income that would be obtained when the labour devoted to predation is used in the production sector, $wl_p[1 - g(\tilde{l}_p - \Gamma)]$. Given the existence of a fixed cost,[10] this second necessary condition implies that predation is worthwhile only if the gain obtained from the time devoted to it is large enough; if not, it is better to devote all the time to production. This means that when the labour share is large enough, predation is not worthwhile due to the existence of the fixed cost. However, if the labour share is small, predation is still lucrative. The following lemma states that there is a threshold labour share, denoted by $\lambda(\Gamma)$, such that when labour share is equal to such a threshold, households earn the same amount of income by devoting some part of their time to predation as using it in production; that is, agents are indifferent between devoting their time to predation or to work in the productive sector.

Lemma 2. There exists $\overline{\Gamma} \in (0,1)$ such that if $\Gamma \geq \overline{\Gamma}$, then $l_p = 0$. Furthermore, there is a decreasing continuous function $\lambda : (0, \overline{\Gamma}] \to (0,1]$ with $\lambda(\overline{\Gamma}) = 0$ such that:

- if $(1 - \alpha) > \lambda(\Gamma)$, then $l_p = 0$;
- if $(1 - \alpha) = \lambda(\Gamma)$, then agents are indifferent between devoting time to predation or not;
- if $(1 - \alpha) < \lambda(\Gamma)$, then $l_p > 0$.

When $(1 - \alpha) < \lambda(\Gamma)$, l_p is a decreasing function of the labour share.

This lemma shows that if the labour share is larger than a certain threshold level $\lambda(\Gamma)$, then there is no predation. This threshold is a decreasing function of the institutional quality Γ. Thus if the institutional quality is large enough (larger than $\overline{\Gamma}$), then there is no predation at all.

Corollary 3. If $(1 - \alpha) = \lambda(\Gamma)$, then there are multiple equilibria.

When the labour share is equal to the threshold $\lambda(\Gamma)$, households are indifferent between devoting a certain part of their time to predation, $l_p(\lambda(\Gamma), \Gamma)$, or using all their time to work in the productive sector, $l_p = 0$. Thus the amount of time devoted to predation is undetermined. Since there are many households, which may take different decisions, the per capita amount of time devoted to predation belongs to the interval $[0, l_p(\lambda(\Gamma), \Gamma)]$. A different equilibrium corresponds to each of these values. This is the reason why multiple equilibria arise.

Proposition 4. There exist Γ_1, Γ_2, where $\Gamma_1 < \Gamma_2$, such that:

- if $\Gamma < \Gamma_1$, then there is a unique steady state with predation;
- if $\Gamma \in (\Gamma_1, \Gamma_2)$, then there are three steady states, two with predation and another without it;
- if $\Gamma > \Gamma_2$, then there is a unique steady state without predation.

Thus when we introduce a fixed cost in the predation technology, poverty traps may arise. Furthermore, institutional quality is crucial for the existence of poverty traps.

Although we have not analysed the importance of differences in TFP to determine the existence of poverty traps, surely it is another factor that may determine whether or not poverty traps exist. Thus designing mechanisms to improve institutions and breaking the poverty traps are key issues in development economics. In this sense, there are at least two ways to deal with these problems:

- reducing the incentive to predate by applying policies that affect directly to predation (for example, improving the protection and enforcement of property rights, improving the legal system, etc.);
- increasing the incentive to work in the productive sector by raising the reward for this activity.

In this sense, redistributive policies or incentive mechanisms such as the one presented by Andonova and Zuleta (2009) may go in the right direction.

The role of human capital

Some studies claim that the income share of raw labour decreases with economic growth but the income share of human capital grows with economic growth (see Krueger 1999; Sturgill 2012). This consideration about the income distribution between skilled and unskilled workers may alter the incentives for predation and the relationship between economic growth and predation. In this subsection, we study the dynamics of predation in a context where the income share of raw labour decreases along the development process, while the income share of human capital increases.

We now consider that there is an additional factor in the economy: the skilled labour. We assume that the portion μ of agents have one unit of skilled labour, and the portion $(1-\mu)$ of agents have one unit of unskilled labour. Each household is composed of a large number of agents who care only about the per capita consumption of the household. All the households are alike: they have the same per capita amount of assets and the same per capita amount of skilled and unskilled workers. We call $Z(H, L)$ the amount of efficiency units of labour in the economy, which depends on the amount of skilled and unskilled labour used in production, denoted by H and L, respectively. The function $Z:\mathbb{R}^2_+ \to \mathbb{R}_+$ is assumed to be continuous, increasing (in both arguments), strictly quasi-concave and homogeneous of degree one (it presents constant return on scale). Furthermore, it is twice-continuously differentiable and strictly increasing in $\mathbb{R}^2_{++}$. The production of the unique good of the economy is given by the production function $F(K,Z)$, which satisfies all the same assumptions as in the main model.

The skilled workers do not have any particular advantage in predation; they are perfectly substituted by unskilled workers. Thus the portion of the income that is obtained through predation by an household is equal to $g(\mu h_p + (1-\mu)l_p)$, where $h_p \in [0,1]$ is the fraction of time of the skilled workers devoted to predation, and $g(\cdot)$ has the same properties as in the main model.

The representative household's maximization problem is as follows:

$$\max_{\{c(t),l(t),l_p(t),h(t),h_p(t),b(t)\}_{t=0}^{\infty}} \int_0^{\infty} u(c(t))\, \mathrm{e}^{-\rho t}\, \mathrm{d}t$$

$$\text{s.t. } \dot{b}(t) = \mu w_h(t)h(t) + (1-\mu)w(t)l(t) + r(t)b(t) - g(\mu\widetilde{h}_p(t) + (1-\mu)\widetilde{l}_p(t))y(t) + g(\mu h_p(t) + (1-\mu)l_p(t))\widetilde{y}(t) - c(t),$$
$$l(t) + l_p(t) = 1,$$
$$h(t) + h_p(t) = 1,$$
$$y(t) = \mu w_h(t)h(t) + (1-\mu)w(t)l(t) + (\delta + r(t))b(t),$$

where $h(t)$ is the amount of time that skilled workers devote to work in the productive sector.

The first-order conditions of skilled workers are

$$(17) \qquad w_h(t)\left[1 - g(\mu\widetilde{h}_p(t) + (1-\mu)\widetilde{l}_p(t))\right] \geq g'(\mu h_p(t) + (1-\mu)l_p(t))\widetilde{y}(t),$$

$$(18) \qquad w(t)\left[1 - g(\mu\widetilde{h}_p(t) + (1-\mu)\widetilde{l}_p(t))\right] \geq g'(\mu h_p(t) + (1-\mu)l_p(t))\widetilde{y}(t),$$

$$(19) \qquad \frac{\dot{c}(t)}{c(t)} = \frac{1}{\sigma^u(c(t))}\left[(r(t)+\delta)\left[1 - g(\mu\widetilde{h}_p(t) + (1-\mu)\widetilde{l}_p(t))\right] - \delta - \rho\right].$$

It follows from equations (17) and (18) that if the skill premium is positive ($w_h(t) > w(t)$), then skilled workers do not devote time to predation. The economic reason is very clear: skilled workers have a higher opportunity cost for predation than unskilled workers, since the wage of skilled workers is higher. Since skilled and unskilled labour are perfect substitutes in the predation technology, skilled labour is devoted entirely to production, which is the sector in which there is comparative advantage.

Using equation (18), the fact that all households are identical ($\widetilde{l}_p = l_p$) and considering that skilled labour is not devoted to predation ($h_p = 0$), it follows that

$$(20) \qquad \phi((1-\mu)l_p) = \lambda(\kappa,\eta)\left(\frac{(1-\mu)l(t)}{\mu + (1-\mu)l(t)}\right)^{-1} = \lambda(\kappa,\eta)(1+\eta),$$

where $\eta = H/L$ denotes the ratio of skilled to unskilled labour at the production sector, and $\lambda(\kappa, \eta) \equiv w(1-\mu)l/y$ denotes the income share of unskilled workers at the production sector. Equation (20) implies that the total amount of unskilled labour devoted to predation depends not only on the share of unskilled labour but also on the portion of unskilled labour in the workforce of the productive sector,

$$\eta = \frac{(1-\mu)l(t)}{\mu + (1-\mu)l(t)}.$$

This implies that the income share of unskilled labour may decrease with the ratio η of skilled to unskilled workers in the productive sector, but if the drop in the income share of raw labour is smaller than the decrease of the portion of unskilled workers as a portion of the labour force, then the time devoted to predation may decline as well. The labour share may be decomposed as

$$(21) \qquad \lambda(\kappa,\eta) = (1-\alpha(\kappa))(1-\beta(\eta)),$$

where $\alpha(\kappa)$ is the capital share, and $\beta(\eta)$ is the proportion of the skilled labour share over the total labour share:

$$\alpha(\kappa) = \frac{f'(\kappa)\kappa}{f(\kappa)},\ \beta(\eta) = \frac{z'(\eta)\eta}{z(\eta)},\ z(\eta) = Z(\eta, 1).$$

Thus, taking equations (20) and (21) together, we reach the conclusion that the net effect of an increase in the ratio η of skilled to unskilled labour on predation will depend on the evolution of the function $(1 - \beta(\eta))(1 + \eta)$:

$$\phi((1-\mu)l_p) = (1 - \alpha(\kappa))(1 - \beta(\eta))(1 + \eta).$$

Proposition 5. There exist $\underline{\mu}$ and $\bar{\mu}$ that satisfy $1 > \bar{\mu} > \underline{\mu} \geq 0$ such that if $\mu \in (\underline{\mu}, \bar{\mu})$ then, at the steady state, the skilled premium is positive ($w_h(t) > w(t)$) and the amount of time devoted to predation, $(1 - \mu)l_p$, at the steady state is a decreasing function of the portion of skilled workers over population, μ.

Here $\bar{\mu}$ denotes the threshold level that makes the skill premium zero. If the portion of skilled labour over population, μ, is above the threshold level $\bar{\mu}$, then the skill premium becomes negative ($w_h(t) < w(t)$) due to the excessive abundance of skilled workers. Also, $\underline{\mu}$ is the threshold level that makes the function $(1 - \beta(\eta))(1 + \eta)$ increasing when $\mu > \underline{\mu}$. If $\mu \in (\underline{\mu}, \bar{\mu})$, then an increase in the portion of skilled workers, μ, increases $(1 - \beta(\eta))(1 + \eta)$, discourages predation and fosters capital accumulation, which increases the labour share, reducing further the incentive to predate.

It is important to notice that the key feature for our result is that the labour income share of unskilled workers, $(1 - \beta(\eta))$, divided by the portion of skilled worker over the labour force of productive sector, $(1/(1 + \eta))$, increases with η. Thus an increase in the ratio of skilled to unskilled labour in the productive sector, η, may produce a decrease in predation if the drop in the income share of the raw labour is smaller than the decrease of the proportion of unskilled labour over the labour force in the productive sector. That is, our results hold even if the share of unskilled workers $\lambda(\kappa, \eta) = (1 - \alpha(\kappa))(1 - \beta(\eta))$ is decreasing in the ratio of skilled to unskilled labour, η, as long as the function $(1 - \beta(\eta))(1 + \eta)$ is increasing.

As an example, suppose that the amount of efficiency units of labour is obtained from a CES production function

$$Z(H, L) = \left[\theta H^{\frac{\sigma-1}{\sigma}} + (1-\theta)L^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}},$$

where the elasticity of substitution satisfies $\sigma > 1$. In this case, the proportion of the unskilled labour share over total labour share

$$\frac{1-\theta}{(1-\theta) + \theta\eta^{\frac{\sigma-1}{\sigma}}}$$

is a decreasing function of η. However, the function

$$(1 - \beta(\eta))(1 + \eta) = \frac{(1-\theta)(1+\eta)}{1 - \theta + \theta\eta^{\frac{\sigma-1}{\sigma}}}$$

is increasing for values of η that are not too small. In this case, an increase in the portion of skilled workers over active population, μ, reduces the amount of time devoted to predation at the steady state, in spite of the fact that the income share of unskilled labour may be reduced due to the increase in the skilled to unskilled labour ratio, η.

Thus the results of our model are not incompatible with an environment in which the income share of raw labour decreases along development and the income share of human capital grows along development. Obviously, the introduction of human capital into the model would require a deeper analysis. To study the role of human capital in predation would not be a mere extension. Because of the technical difficulty and the great relevance of the issue, the consideration of human capital would justify a different paper devoted entirely to analysing this subject.

IX. Conclusion

This paper has presented a neoclassical growth model with predation in which the elasticity of substitution between labour and capital is lower than 1. This property of the production function implies that labour share rises during the transition when the initial per capita capital is lower than the steady-state level. This increase in the labour share implies a reduction in incentives to predation and a reallocation of labour from predation to production during the transition. Thus, this paper analyses not only how predation affects capital accumulation, but also how capital accumulation affects predation and the resulting feedback process.

We also analyse the amplification effect that predation may have on differences in productivity across countries. Even though many authors have pointed out differences in productivity as the main source of differences in per capita income, these differences in productivity are not empirically high enough to generate the differences that are observed in per capita income across countries. This paper proposes a mechanism that amplifies the differences in per capita income generated by differences in productivity. When productivity rises, there is a direct effect on production and an indirect effect due to the accumulation of capital: the rise in productivity increases the return on savings and thus the incentives to accumulate more capital. In our model, together with these standard mechanisms, other mechanisms appear that amplify the effect of productivity on per capita income, related to predation and the assumption that the elasticity of substitution is less than 1. When productivity rises, the per capita capital rises, and this, due to the previous assumption on elasticity, implies that the labour share increases, reducing the incentive for predation and increasing the portion of labour devoted to production. This increment in the amount of labour devoted to production has three effects:

- there is a direct effect on per capita production;
- there is an indirect effect due to the accumulation of capital—when labour rises, it increases the marginal productivity of capital and the incentive to accumulate more capital;
- the reduction in the portion of labour devoted to predation implies that the share of the marginal product of capital that goes to savers increases, thus raising the return on savings and promoting the accumulation of capital.

We analysed the effect of an institutional change that reduces the productivity of the predation technology. Such a change discourages predation by increasing the portion of labour devoted to production. This increase in the labour devoted to production not only has a direct effect on production, but also encourages the accumulation of capital due to two mechanisms:

- it increases the marginal product of capital and therefore the return on savings;
- it reduces the portion of the payments to capital that goes to predation, also increasing the return on savings.

Furthermore, when the capital–labour ratio rises, the labour share in the production sector increases, assuming an elasticity of substitution lower than 1, and this promotes the reallocation of labour from predation to production even more. Finally, we have extended the model to incorporate in the analysis the existence of poverty traps and to analyse the role of human capital.

The approach followed by this paper has interesting implications for empirical analysis. The literature on institutions and development has usually presented differences in institutions as the exclusive explanation for differences in levels of predation between countries, ignoring the possible effect that factor accumulation may have on predation. However, this paper shows that the relationship is rather more complicated, since factor accumulation also affects predation, and this implies a feedback effect between factor accumulation and predation that is not mediated by institutions. Recent empirical evidence supports this hypothesis.

This paper opens new avenues for further research. The framework of this paper can be extended to explore questions such as the relationship between inequality and predation or the possible external effects that predation may generate. Other related factors, such as social conflict and the formation of institutions, can be analysed in this dynamic setting of capital accumulation. The role of human capital in predation also calls for a deeper analysis.

APPENDIX

Proof of Lemma 1

It was assumed that $g(1) < 1$, which implies

$$\phi(1) = \frac{g'(1)(1-1)}{1-g(1)} = 0. \quad \text{(A1)}$$

By assumption, $g'(0) \geq 1$ and $g(0) = 0$, which imply

$$\phi(0) = \frac{g'(0)(1-0)}{1-g(0)} = g'(0) \geq 1. \quad \text{(A2)}$$

Note that if $l_p < 1$ and $\phi(l_p) \leq 1$, then

$$\begin{aligned} \phi'(l_p) &= \frac{g''(l_p)(1-l_p) - g'(l_p) + \phi(l_p)g'(l_p)}{1-g(l_p)} \\ &\leq \frac{g''(l_p)(1-l_p) - g'(l_p) + g'(l_p)}{1-g(l_p)} \\ &= \frac{g''(l_p)(1-l_p)}{1-g(l_p)} \\ &< 0. \end{aligned} \quad \text{(A3)}$$

It follows from equations (A1) and (A2), and the fact that $\phi(l_p)$ is continuous and strictly decreasing when $\phi(l_p) \le 1$ (see equation (A3)), that there is a unique $l_p^{\min} \in [0, 1)$ such that $\phi(l_p^{\min}) = 1$, being $l_p^{\min} = 0$ when $g'(0) = 1$. Furthermore, it follows from equation (A1) and the definition of $l_p^{\min}$ that $\phi(l_p) > 1$ when $l_p < l_p^{\min}$. Finally, it follows from equation (A3) and the definition of $l_p^{\min}$ that $\phi(l_p^{\min})$ is strictly decreasing when $l_p \in [l_p^{\min}, 1]$.

Proof of Proposition 1

We have

$$\text{(A4)} \qquad \frac{\partial l_p}{\partial \kappa} = \frac{\partial l_p}{\partial(1-\alpha)} \frac{\partial(1-\alpha)}{\partial \kappa} = \frac{1}{\phi'(l_p)} \frac{f'(\kappa)}{f(\kappa)} (1-\alpha(\kappa)) \left[\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)} \right] < 0.$$

Proof of Proposition 2

Writing

$$D = \frac{\partial(f'(\kappa)[1-g(l_p(\kappa))] - \delta)}{\partial \kappa}$$

$$D = f'(\kappa)[1-g(l_p(\kappa))] \left[\frac{f''(\kappa)}{f'(\kappa)} - \frac{g'(l_p(\kappa))}{1-g(l_p(\kappa))} l_p'(\kappa) \right].$$

Substituting equations (7) and (A4) then gives

$$D = f'(\kappa)[1-g(l_p(\kappa))] \left[\frac{f''(\kappa)}{f'(\kappa)} - \frac{\phi(l_p(\kappa))}{1-l_p(\kappa)} \frac{1}{\phi'(l_p(\kappa))} \frac{f'(\kappa)}{f(\kappa)} (1-\alpha(\kappa)) \left(\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)} \right) \right],$$

and substituting equation (5) gives

$$\begin{aligned} D &= f'(\kappa)[1-g(l_p(\kappa))] \left[-\frac{1-\alpha(\kappa)}{\sigma^f(\kappa)\kappa} - \frac{\phi(l_p(\kappa))}{1-l_p(\kappa)} \frac{1}{\phi'(l_p(\kappa))} \frac{f'(\kappa)}{f(\kappa)} (1-\alpha(\kappa)) \left(\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)} \right) \right] \\ &= \frac{f'(\kappa)[1-g(l_p(\kappa))](1-\alpha(\kappa))}{\sigma^f(\kappa)\kappa} \left[-1 - \frac{\phi(l_p(\kappa))}{1-l_p(\kappa)} \frac{1}{\phi'(l_p(\kappa))} \frac{f'(\kappa)\kappa}{f(\kappa)} (1-\sigma^f(\kappa)) \right], \end{aligned}$$

thus

$$\text{(A5)} \qquad D = \frac{f'(\kappa)[1-g(l_p(\kappa))](1-\alpha(\kappa))}{\sigma^f(\kappa)\kappa} \left[-1 - \frac{\phi(l_p(\kappa))}{1-l_p(\kappa)} \frac{1}{\phi'(l_p(\kappa))} \alpha(\kappa)(1-\sigma^f(\kappa)) \right].$$

Note that

$$\text{(A6)}\qquad \begin{aligned}\frac{\phi(l_p)}{1-l_p}\frac{1}{\phi'(l_p)} &= \frac{g'(l_p)}{1-g(l_p)}\left(\frac{g'(l_p)(1-l_p)}{1-g(l_p)}\left[\frac{g''(l_p)}{g'(l_p)}-\frac{1}{1-l_p}+\frac{g'(l_p)}{1-g(l_p)}\right]\right)^{-1}\\ &= \left(\left[\frac{g''(l_p)(1-l_p)}{g'(l_p)}-1+\phi(l_p)\right]\right)^{-1}.\end{aligned}$$

Substituting this in equation (A5) yields

$$\begin{aligned}&\frac{\partial(f'(\kappa)[1-g(l_p(\kappa))]-\delta-\rho)}{\partial\kappa}\\ &=\frac{f'(\kappa)[1-g(l_p(\kappa))](1-\alpha(\kappa))}{\sigma^f(\kappa)\kappa}\left[-1-\frac{\alpha(\kappa)(1-\sigma^f(\kappa))}{\frac{g''(l_p(\kappa))(1-l_p(\kappa))}{g'(l_p(\kappa))}-1+\phi(l_p(\kappa))}\right]\\ &=\frac{f'(\kappa)[1-g(l_p(\kappa))](1-\alpha(\kappa))}{\sigma^f(\kappa)\kappa}\left[-1+\frac{\alpha(\kappa)(1-\sigma^f(\kappa))}{-\frac{g''(l_p(\kappa))(1-l_p(\kappa))}{g'(l_p(\kappa))}+\alpha(\kappa)}\right]\\ &=\frac{f'(\kappa)[1-g(l_p(\kappa))](1-\alpha(\kappa))}{\sigma^f(\kappa)\kappa}\left[\frac{\frac{g''(l_p(\kappa))(1-l_p(\kappa))}{g'(l_p(\kappa))}-\alpha(\kappa)\sigma^f(\kappa)}{-\frac{g''(l_p(\kappa))(1-l_p(\kappa))}{g'(l_p(\kappa))}+\alpha(\kappa)}\right]\\ &<0,\end{aligned}$$

where in the third equality we use the equilibrium condition (7), and in the last inequality we use the assumption that states that $g(.)$ is strictly concave, so

$$-\frac{g''(l_p(\kappa))(1-l_p(\kappa))}{g'(l_p(\kappa))}>0.$$

Relationship between per capita income and productivity

Standard case: When $l(\kappa^{ss}) = 1$ (the standard case), the effect of an increase in A over the steady-state capital may be obtained by using the Implicit Function Theorem over the Euler equation at the steady state:

$$\begin{aligned}&f'(\kappa^{ss})-\frac{\delta+\rho}{A}=0,\\ &\frac{\partial\kappa^{ss}}{\partial A}\frac{A}{\kappa^{ss}}=\frac{\sigma^f(\kappa)}{1-\alpha(\kappa)},\end{aligned}$$

where we used equation (5). The effect of a change in productivity over the per capita income at the steady state $y^{ss} = Af(\kappa^{ss})$ is

$$\frac{\partial y^{ss}}{\partial A}\frac{A}{y^{ss}}=1+\left[\frac{f'(\kappa^{ss})\kappa^{ss}}{f(\kappa^{ss})}\right]\frac{\partial\kappa^{ss}}{\partial A}\frac{A}{\kappa^{ss}}=1+\frac{\alpha(\kappa)\sigma^f(\kappa)}{1-\alpha(\kappa)}.$$

Predation: At the steady state, the following condition should be satisfied:

$$f'(\kappa^{ss})[1-g(l_p(\kappa^{ss}))]-\frac{\delta+\rho}{A}=0.$$

Using the Implicit Function Theorem gives

$$\begin{aligned}\frac{\partial\kappa^{ss}}{\partial A}\frac{A}{\kappa^{ss}}&=\left[\frac{1-\alpha(\kappa^{ss})}{\sigma^f(\kappa^{ss})}-\frac{g'(l_p(\kappa^{ss})l(\kappa^{ss})}{1-g(l_p(\kappa^{ss}))}\frac{\alpha(\kappa^{ss})}{-\frac{g''(l_p(\kappa^{ss}))l(\kappa^{ss})}{g'(l_p(\kappa^{ss}))}+\alpha(\kappa^{ss})}\frac{1-\sigma^f(\kappa^{ss})}{\sigma^f(\kappa^{ss})}\right]^{-1}\\&=\frac{\sigma^f(\kappa^{ss})}{1-\alpha(\kappa^{ss})}\left[1-\frac{\alpha(\kappa^{ss})}{-\frac{g''(l_p(\kappa^{ss}))l(\kappa^{ss})}{g'(l_p(\kappa^{ss}))}+\alpha(\kappa^{ss})}[1-\sigma^f(\kappa^{ss})]\right]^{-1}\\&=\frac{\sigma^f(\kappa^{ss})}{1-\alpha(\kappa^{ss})}\left[1+\frac{\alpha(\kappa^{ss})[1-\sigma^f(\kappa^{ss})]}{-\frac{g''(l_p(\kappa^{ss}))l(\kappa^{ss})}{g'(l_p(\kappa^{ss}))}+\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}\right]\\&>0,\end{aligned}$$

where we use equations (5), (7), (A4) and (A6) in the first equality. It follows from equation (A4), the definition of $\phi(.)$ and equation (A6) that

$$\begin{aligned}&\frac{\partial l}{\partial\kappa}\frac{\kappa}{l}=-\frac{\partial l_p}{\partial\kappa}\frac{\kappa}{l}\\&=\frac{l(\kappa)}{\frac{g'(l_p(\kappa))(1-l_p(\kappa))}{1-g(l_p(\kappa))}\frac{1}{1-l_p(\kappa)}\left[-\frac{g''(l_p(\kappa))(1-l_p(\kappa))}{g'(l_p(\kappa))}+1-\phi(l_p)\right]}\frac{f'(\kappa)\kappa}{f(\kappa)}(1-\alpha(\kappa))\left[\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)}\right]\\&=\frac{\alpha(\kappa)}{-\frac{g''(l_p(\kappa))l(\kappa)}{g'(l_p(\kappa))}+\alpha(\kappa)}\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)}\\&>0,\end{aligned}$$

where in the last equality we used equation (7), the definition of $\alpha(\kappa)$ and the equation $l+l_p=1$.

We now analyse the effect of change in productivity over the per capita income $y^{ss}=Af(\kappa^{ss})l(\kappa^{ss})$:

$$\begin{aligned}\frac{\partial y^{ss}}{\partial A}\frac{A}{y^{ss}}&=1+\left[\frac{f'(\kappa^{ss})\kappa^{ss}}{f(\kappa^{ss})}+\frac{l'(\kappa^{ss})\kappa^{ss}}{l(\kappa^{ss})}\right]\frac{\partial\kappa^{ss}}{\partial A}\frac{A}{\kappa^{ss}}\\&=1+\alpha(\kappa^{ss})\frac{\sigma^f(\kappa^{ss})}{1-\alpha(\kappa^{ss})}\left[\frac{1+\frac{1}{-\frac{g''(l_p(\kappa^{ss}))l(\kappa^{ss})}{g'(l_p(\kappa^{ss}))}+\alpha(\kappa^{ss})}\left[\frac{1-\sigma^f(\kappa^{ss})}{\sigma^f(\kappa^{ss})}\right]}{1-\frac{\alpha(\kappa^{ss})(1-\sigma^f(\kappa^{ss}))}{-\frac{g''(l_p(\kappa^{ss}))l(\kappa^{ss})}{g'(l_p(\kappa^{ss}))}+\alpha(\kappa^{ss})}}\right]\\&=1+\frac{\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}{1-\alpha(\kappa^{ss})}+\frac{\alpha(\kappa^{ss})(1-\sigma^f(\kappa^{ss}))}{1-\alpha(\kappa^{ss})}\left[\frac{1+\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}{-\frac{g''(l_p(\kappa^{ss}))l(\kappa^{ss})}{g'(l_p(\kappa^{ss}))}+\alpha(\kappa^{ss})\sigma^f(\kappa^{ss})}\right]\\&>0.\end{aligned}$$

Proof of Proposition 3

Using equation (7) gives

$$\text{(A7)} \qquad \phi(l_p, \Gamma) = \frac{g'_{l_p}(l_p, \Gamma)(1 - l_p)}{1 - g(l_p, \Gamma)} = 1 - \alpha,$$

$$\text{(A8)} \qquad \phi'_{\Gamma}(l_p, \Gamma) = \phi(l_p, \Gamma)\left[\frac{g''_{l_p,\Gamma}(l_p, \Gamma)}{g'_{l_p}(l_p, \Gamma)} + \frac{g'_{\Gamma}(l_p, \Gamma)}{1 - g(l_p, \Gamma)}\right] < 0.$$

Using the Implicit Function Theorem and equation (A8) gives

$$\frac{\partial l_p}{\partial \Gamma} = -\frac{\phi'_{\Gamma}(l_p, \Gamma)}{\phi'_{l^p}(l_p, \Gamma)} < 0,$$

since $\phi'_{l^p}(l_p, \Gamma) < 0$ by Lemma 1.

Effect of Γ *on per capita income*

At the steady state, the following condition should be satisfied:

$$f'(\kappa^{ss})[1 - g(l_p(\kappa^{ss}, \Gamma), \Gamma)] - \delta - \rho = 0.$$

Using the Implicit Function Theorem gives

$$\begin{aligned}
\frac{\partial \kappa^{ss}}{\partial \Gamma}\frac{\Gamma}{\kappa^{ss}} &= \frac{-\frac{g'_{\Gamma}(l_p(\kappa^{ss},\Gamma),\Gamma)\Gamma}{1-g(l_p(\kappa^{ss},\Gamma),\Gamma)} - \frac{g'_{l_p}(l_p(\kappa^{ss},\Gamma),\Gamma)}{1-g(l_p(\kappa^{ss},\Gamma),\Gamma)}\frac{\partial l_p(\kappa^{ss},\Gamma)}{\partial \Gamma}\Gamma}{\frac{f''(\kappa^{ss})\kappa^{ss}}{f'(\kappa^{ss})} - \frac{g'_{l_p}(l_p(\kappa^{ss},\Gamma),\Gamma)}{1-g(l_p(\kappa^{ss},\Gamma),\Gamma)}\frac{1}{\phi'(l_p)}\frac{f'(\kappa)\kappa^{ss}}{f(\kappa)}(1 - \alpha(\kappa))\left[\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)}\right]} \\
&= \frac{-\frac{g'_{\Gamma}(l_p(\kappa^{ss},\Gamma),\Gamma)\Gamma}{1-g(l_p(\kappa^{ss},\Gamma),\Gamma)} + \frac{g'_{l_p}(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa^{ss},\Gamma)}{1-g(l_p(\kappa^{ss},\Gamma),\Gamma)}\frac{\partial l(\kappa^{ss},\Gamma)}{\partial \Gamma}\frac{\Gamma}{l(\kappa^{ss},\Gamma)}}{\frac{1-\alpha(\kappa)}{\sigma^f(\kappa)} - \frac{g'_{l_p}(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa)}{1-g(l_p(\kappa^{ss},\Gamma),\Gamma)}\frac{\alpha(\kappa)}{-\frac{g''(l_p(\kappa))l(\kappa)}{g'(l_p(\kappa))}+\alpha(\kappa)}\left[\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)}\right]} \\
&= \frac{\sigma^f(\kappa)}{1 - \alpha(\kappa)}\left[\varepsilon_{\Gamma}^{1-g}(\kappa^{ss}, \Gamma) + (1 - \alpha(\kappa))\varepsilon_{\Gamma}^{l}(\kappa^{ss}, \Gamma)\right]\left[1 - \frac{\alpha(\kappa)(1 - \sigma^f(\kappa))}{-\frac{g''(l_p(\kappa))l(\kappa)}{g'(l_p(\kappa))} + \alpha(\kappa)}\right]^{-1} \\
&= \frac{\sigma^f(\kappa)}{1 - \alpha(\kappa)}\left[\varepsilon_{\Gamma}^{1-g}(\kappa^{ss}, \Gamma) + (1 - \alpha(\kappa))\varepsilon_{\Gamma}^{l}(\kappa^{ss}, \Gamma)\right]\left[1 + \frac{\alpha(\kappa)(1 - \sigma^f(\kappa))}{-\frac{g''(l_p(\kappa))l(\kappa)}{g'(l_p(\kappa))} + \alpha(\kappa)\sigma^f(\kappa)}\right] \\
&> 0,
\end{aligned}$$

where

$$\varepsilon_{\Gamma}^{1-g}(\kappa, \Gamma) = -\frac{g'_{\Gamma}(l_p(\kappa, \Gamma), \Gamma)\Gamma}{1 - g(l_p(\kappa, \Gamma), \Gamma)} > 0$$

is the elasticity of the fraction of income that goes to production factors with respect to Γ, and

$$\varepsilon_{\Gamma}^{l}(\kappa,\Gamma)=\frac{\partial l(\kappa,\Gamma)}{\partial\Gamma}\frac{\Gamma}{l(\kappa,\Gamma)}>0$$

is the elasticity of labour with respect to Γ, which is positive since

$$\frac{\partial l(\kappa,\Gamma)}{\partial\Gamma}=-\frac{\partial l_p(\kappa,\Gamma)}{\partial\Gamma}>0$$

(see Proposition 3). Note that in the first equality we use equations (7) and (A4), and the equation $l+l_p=1$; in the second equality we use equations (7) and (A6); and in the third equality we use equation (7).

We now analyse the effect of the change in the institutional quality over the per capita income $y^{ss}=f(\kappa^{ss})l(\kappa^{ss},\Gamma)$:

$$\begin{aligned}
\frac{\partial y^{ss}}{\partial\Gamma}\frac{\Gamma}{y^{ss}}&=\left[\frac{f'(\kappa^{ss})\kappa^{ss}}{f(\kappa^{ss})}+\frac{\partial l(\kappa^{ss},\Gamma)}{\partial\kappa}\frac{\kappa^{ss}}{l(\kappa^{ss},\Gamma)}\right]\frac{\partial\kappa^{ss}}{\partial\Gamma}\frac{\Gamma}{\kappa^{ss}}+\frac{\partial l(\kappa^{ss},\Gamma)}{\partial\Gamma}\frac{\Gamma}{l(\kappa^{ss},\Gamma)}\\
&=\left[\alpha(\kappa^{ss})+\frac{\alpha(\kappa^{ss})}{-\frac{g''(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa^{ss},\Gamma)}{g'(l_p(\kappa^{ss},\Gamma),\Gamma)}+\alpha(\kappa^{ss})}\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)}\right]\\
&\quad\times\frac{\sigma^f(\kappa)\left[-\varepsilon_{\Gamma}^{1-g}(\kappa^{ss},\Gamma)+(1-\alpha(\kappa^{ss}))\varepsilon_{\Gamma}^{l}(\kappa^{ss},\Gamma)\right]}{1-\alpha(\kappa^{ss})}\\
&\quad\times\left[1+\frac{\alpha(\kappa^{ss})(1-\sigma^f(\kappa))}{-\frac{g''(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa^{ss},\Gamma)}{g'(l_p(\kappa^{ss},\Gamma),\Gamma)}+\alpha(\kappa^{ss})\sigma^f(\kappa)}\right]+\varepsilon_{\Gamma}^{l}(\kappa^{ss},\Gamma)\\
&=\alpha(\kappa^{ss})\frac{\sigma^f(\kappa)\left[-\varepsilon_{\Gamma}^{1-g}(\kappa^{ss},\Gamma)+(1-\alpha(\kappa^{ss}))\varepsilon_{\Gamma}^{l}(\kappa^{ss},\Gamma)\right]}{1-\alpha(\kappa^{ss})}+\varepsilon_{\Gamma}^{l}(\kappa^{ss},\Gamma)\\
&\quad+\frac{\sigma^f(\kappa)\left[-\varepsilon_{\Gamma}^{1-g}(\kappa^{ss},\Gamma)+(1-\alpha(\kappa^{ss}))\varepsilon_{\Gamma}^{l}(\kappa^{ss},\Gamma)\right]\alpha(\kappa^{ss})[1-\sigma^f(\kappa)]}{(1-\alpha(\kappa^{ss}))\sigma^f(\kappa)}\\
&\quad\times\left[\frac{\alpha(\kappa^{ss})\sigma^f(\kappa)}{-\frac{g''(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa^{ss},\Gamma)}{g'(l_p(\kappa^{ss},\Gamma),\Gamma)}+\alpha(\kappa^{ss})\sigma^f(\kappa)}\right.\\
&\quad\quad+\left(\frac{1}{-\frac{g''(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa^{ss},\Gamma)}{g'(l_p(\kappa^{ss},\Gamma),\Gamma)}+\alpha(\kappa^{ss})}\right)\\
&\quad\quad\left.\times\left(1+\frac{\alpha(\kappa^{ss})[1-\sigma^f(\kappa)]}{-\frac{g''(l_p(\kappa^{ss},\Gamma),\Gamma)l(\kappa^{ss},\Gamma)}{g'(l_p(\kappa^{ss},\Gamma),\Gamma)}+\alpha(\kappa^{ss})\sigma^f(\kappa)}\right)\right]\\
&>0.
\end{aligned}$$

Proof of Lemma 2

We decompose Lemma 2 into two lemmas.

Lemma 3. There exists $\overline{\Gamma}$ such that if $\Gamma \geq \overline{\Gamma}$, then $l_p = 0$.

Proof. Given that at equilibrium $l_p = l\sim_p$ Equations (15) and (16) may be rewritten as

$$\text{(A9)} \qquad \phi(l_p, \Gamma) = \frac{g'(l_p - \Gamma)(1 - l_p)}{1 - g(l_p - \Gamma)} = 1 - \alpha,$$

$$\text{(A10)} \qquad \theta(l_p, \Gamma) = \frac{(g(l_p - \Gamma)/l_p)(1 - l_p)}{1 - g(l_p - \Gamma)} \geq 1 - \alpha.$$

Equations (A9) and (A10) imply the following necessary condition for an internal solution of the household optimization problem:

$$\text{(A11)} \qquad \frac{g(l_p - \Gamma)}{l_p} - g'(l_p - \Gamma) \geq 0.$$

Let us define

$$\text{(A12)} \qquad \chi(l_p, \Gamma) = \frac{g(l_p - \Gamma)}{l_p} - g'(l_p - \Gamma),$$

$$\text{(A13)} \qquad \chi^{\max}(\Gamma) = \max_{l_p \in [\Gamma, 1]} \frac{g(l_p - \Gamma)}{l_p} - g'(l_p - \Gamma).$$

It follows from equation (A11) that

$$\text{(A14)} \qquad \text{if } l_p > 0, \text{ then } \chi(l_p, \Gamma) \geq 0.$$

The necessary condition for an internal solution of problem (A13) is

$$\text{(A15)} \qquad \frac{g'(l_p - \Gamma)}{l_p} - \frac{g(l_p - \Gamma)}{l_p^2} - g''(l_p - \Gamma) = 0.$$

Notice that

$$\text{(A16)} \qquad \chi^{\max}(1) = \frac{g(1-1)}{1} - g'(1-1) = -g'(0) < 0,$$

$$\text{(A17)} \qquad \lim_{\Gamma \to 0} \chi^{\max}(\Gamma) \geq \lim_{\Gamma \to 0} \left[\frac{g(1-\Gamma)}{1} - g'(1-\Gamma)\right] = \frac{g(1)}{1} - g'(1) > 0,$$

(A18) $$\frac{\partial \chi^{\max}(\Gamma)}{\partial \Gamma} = -\frac{g'(l_p-\Gamma)}{l_p} + g''(l_p-\Gamma) = -\frac{g(l_p-\Gamma)}{l_p^2} < 0,$$

where equation (A17) comes from strict concavity and the assumption that $g(0) = 0$,[11] and we used the Envelope Theorem and necessary condition (A15) in equation (A18).

Equations (A16), (A17) and (A18) imply that it is possible to define $\overline{\Gamma} \in (0,1)$ as

(A19) $$\overline{\Gamma} \overset{\text{def}}{\Leftrightarrow} \chi^{\max}(\overline{\Gamma}) = 0.$$

It follows from the definition of $\overline{\Gamma}$ and equation (A18) that if $\Gamma > \bar{\Gamma}$, then the necessary condition (A14) is not satisfied, and consequently $l_p = 0$.

We now study the case in which $\Gamma \leq \overline{\Gamma}$. Notice that if $\Gamma \leq \overline{\Gamma}$, then

$$\lim_{l_p \to \Gamma} \chi(l_p, \Gamma) = \frac{g(0)}{\Gamma} - \lim_{l_p \to \Gamma} g'(0) = -\infty,$$

$$\max_{l_p \in [\Gamma,1]} \chi(l_p, \Gamma) = \chi^{\max}(\Gamma) \geq 0,$$

$$\text{if } \chi(l_p,\Gamma) \leq 0, \text{ then } \frac{\partial \chi(l_p,\Gamma)}{\partial l_p} = -\left[\underbrace{\frac{(g(l_p-\Gamma)/l_p) - g'(l_p-\Gamma)}{l_p}}_{\chi(l_p,\Gamma)\leq 0} + g''(l_p-\Gamma) \right] > 0.$$

Thus there is a unique $\underline{l}_p$ such that the function $\chi(l_p, \Gamma)$ is equal to zero:

(A20) $$\text{for all } \Gamma \in (0, \overline{\Gamma}],\ \underline{l}_p(\Gamma) \overset{\text{def}}{\Leftrightarrow} \chi(\underline{l}_p(\Gamma), \Gamma) = 0,$$

(A21) $$\text{if } l_p \in (\Gamma, \underline{l}_p(\Gamma)), \quad \text{then } \chi(l_p(\Gamma), \Gamma) < 0,$$

(A22) $$\text{if } l_p \in (\underline{l}_p(\Gamma), 1], \quad \text{then } \chi(l_p(\Gamma), \Gamma) > 0.$$

Equations (A20) – (A22) imply that

$$l_p \in \{0\} \cup [\underline{l}_p(\Gamma), 1],$$

and also imply that $\underline{l}_p(\overline{\Gamma}) = 1$ (see the definition of $\overline{\Gamma}$, equation (A19)). Thus if $\Gamma = \overline{\Gamma}$, then $l_p \in \{0\} \cup \{1\}$. However, when $l_p = 1$, equation (A9) does not hold ($\phi(1, \bar{\Gamma}) = 0 < 1 - \alpha$), consequently when $\Gamma = \overline{\Gamma}$, we have $l_p = 0$. □

Lemma 4. There is a decreasing continuous function $\lambda : (0, \overline{\Gamma}] \to (0, 1]$ with $\lambda(\overline{\Gamma}) = 0$ such that:

- if $(1 - \alpha) > \lambda(\Gamma)$, then $l_p = 0$;
- if $(1 - \alpha) = \lambda(\Gamma)$, then agents are indifferent between devoting time to predation or not;
- if $(1 - \alpha) < \lambda(\Gamma)$, then $l_p > 0$.

When $(1 - \alpha) < \lambda(\Gamma)$, l_p is a decreasing function of the labour share.

Proof. Following the same steps as in the proof of Lemma 1, it follows that $\phi(l_p, \Gamma)$ is strictly decreasing in l_p when $\phi(l_p, \Gamma) \leq 1$. Furthermore, $\phi(1, \Gamma) = 0$ and

$$\lim_{l_p \to \Gamma} \phi(l_p, \Gamma) = \lim_{l_p \to \Gamma} \frac{g'(l_p - \Gamma)(1 - l_p)}{1 - g(l_p - \Gamma)} = (1 - \Gamma) \lim_{x \to 0} g'(x) = \infty.$$

Let us define the function $\lambda : (0, \overline{\Gamma}] \to (0, 1]$ and the function $l_p^* : [0, \overline{\Gamma}] \times (0, 1) \to (0, 1]$ as follows:

$$\lambda(\Gamma) = \max_{l_p \in [\underline{l}_p(\Gamma), 1]} \phi(l_p(\Gamma), \Gamma) = \phi(\underline{l}_p(\Gamma), \Gamma),$$

$$l_p^*(\Gamma, 1 - \alpha) \overset{\text{def}}{\Leftrightarrow} \phi(l_p^*(\Gamma, 1 - \alpha), \Gamma) = 1 - \alpha,$$

where the last equality of the first of the above equations follows from the fact that $\phi(l_p, \Gamma)$ is strictly decreasing in l_p. Obviously, if

$$(1 - \alpha) > \lambda(\Gamma) = \max_{l_p \in [\underline{l}_p(\Gamma), 1]} \phi(l_p(\Gamma), \Gamma),$$

then the necessary condition (A9) cannot hold, thus there is no predation.

On the other hand, when $(1 - \alpha) < \lambda(\Gamma)$, then

$$\phi(l_p^*(\Gamma, 1 - \alpha), \Gamma) = 1 - \alpha < \lambda(\Gamma) = \phi(\underline{l}_p(\Gamma), \Gamma),$$

which implies

$$l_p^*(\Gamma, 1 - \alpha) > \underline{l}_p(\Gamma)$$

and hence

$$\chi(l_p^*(\Gamma, 1 - \alpha), \Gamma) > 0,$$

where in the last inequality we used equation (A22). Thus $l_p^*(\Gamma, 1 - \alpha)$ satisfies simultaneously the necessary condition (A9) and the condition (A11) with strict inequality. These two conditions imply that equation (A10) is also satisfied with strict inequality. This last condition implies that $l_p = l_p^*(\Gamma, 1 - \alpha) > 0$.

Finally, if $(1 - \alpha) = \lambda(\Gamma)$, then $l_p^*(\Gamma, 1 - \alpha)$ satisfies simultaneously necessary conditions (A9) and (A11) with equality. These two conditions imply that equation (A10) is also satisfied with equality. This means that households are indifferent between devoting $l_p^*(\Gamma, 1 - \alpha)$ units of time to predation or not devoting time at all ($l_p = 0$). Finally, note that $\lambda(\Gamma)$ is a decreasing function:

$$\begin{aligned}
\lambda'(\Gamma) &= \frac{\partial \phi(\underline{l}_p(\Gamma), \Gamma)}{\partial l_p} \frac{\partial \underline{l}_p(\Gamma)}{\partial \Gamma} + \frac{\partial \phi(\underline{l}_p(\Gamma), \Gamma)}{\partial \Gamma} \\
&= \frac{g''(\underline{l}_p - \Gamma)(1 - \underline{l}_p)\left[\frac{-g'(\underline{l}_p - \Gamma)/\underline{l}_p}{g''(\underline{l}_p - \Gamma)}\right]}{1 - g(\underline{l}_p - \Gamma)} \\
&\quad - \frac{g'(\underline{l}_p - \Gamma)\left[(1 - \phi(\underline{l}_p, \Gamma))\frac{-(g'(\underline{l}_p - \Gamma)/\underline{l}_p) + g''(\underline{l}_p - \Gamma)}{g''(\underline{l}_p - \Gamma)} + \phi(\underline{l}_p, \Gamma)\right]}{1 - g(\underline{l}_p - \Gamma)} \\
&< 0.
\end{aligned}$$

Moreover, $l_p^*(\Gamma, 1-\alpha)$ decreases with $(1-\alpha)$:

$$\frac{\partial l_p^*(\Gamma, 1-\alpha)}{\partial(1-\alpha)} = \frac{1}{\partial\phi(l_p^*, \Gamma)/\partial l_p} < 0,$$

where we have used the Implicit Function Theorem. □

Proof of Proposition 4

Let us define κ^{ssnp} and α^{ssnp} respectively as the capital labour ratio and the capital share in the steady state without predation:

$$\kappa^{ssnp} \overset{\text{def}}{\Leftrightarrow} f'(\kappa^{ssnp}) - \delta = \rho,$$
$$\alpha^{ssnp} \equiv \alpha(\kappa^{ssnp}).$$

Let us also define Γ_1 as the threshold value of Γ such that when the labour share is the one corresponding to the steady state without predation, households are indifferent between predation or not:

$$\Gamma_1 \overset{\text{def}}{\Leftrightarrow} \lambda(\Gamma_1) = 1 - \alpha^{ssnp}.$$

Given Γ, $\widehat{\kappa}(\Gamma)$ is the capital labour ratio in which households are indifferent between predation or not, and $l_p(\kappa, \Gamma)$ is the time devoted to predation associated to this $\widehat{\kappa}(\Gamma)$:

$$\widehat{\kappa}(\Gamma) \overset{\text{def}}{\Leftrightarrow} \lambda(\Gamma) = 1 - \alpha(\widehat{\kappa}(\Gamma)),$$
$$l_p(\kappa, \Gamma) \overset{\text{def}}{\Leftrightarrow} \phi(l_p(\Gamma), \Gamma) = 1 - \alpha(\widehat{\kappa}(\Gamma)).$$

Finally, Γ_2 is the threshold value of Γ such that the capital labour ratio in which agents are indifferent between doing predation or not, $\widehat{\kappa}(\Gamma)$, coincides with the steady state:

$$\Gamma_2 \overset{\text{def}}{\Leftrightarrow} r(\widehat{\kappa}(\Gamma_2), \Gamma_2) = \rho,$$

where $r(\kappa, \Gamma) = f'(\kappa)(1 - g(l_p(\kappa, \Gamma))) - \delta$ is the net interest rate when all households in the economy devote time to predation.

Note that according to Lemma 2, $\lambda(\Gamma)$ is a strictly decreasing function, therefore Γ_1 is well defined. It follows from the Implicit Function Theorem, Proposition 2, Lemma 2 and equation (6) that

$$\text{(A23)} \qquad \frac{\partial\widehat{\kappa}(\Gamma)}{\partial\Gamma} = -\frac{\lambda'(\Gamma)}{\alpha'(\widehat{\kappa}(\Gamma))} < 0$$

and

$$\begin{aligned}
\frac{\partial r(\widehat{\kappa}(\Gamma), \Gamma)}{\partial\Gamma} &= \frac{\partial r(\widehat{\kappa}(\Gamma), \Gamma)}{\partial\kappa}\frac{\partial\widehat{\kappa}(\Gamma)}{\partial\Gamma} + \frac{\partial r(\widehat{\kappa}(\Gamma), \Gamma)}{\partial\Gamma} \\
&= \frac{\partial r(\widehat{\kappa}(\Gamma), \Gamma)}{\partial\kappa}\frac{\partial\widehat{\kappa}(\Gamma)}{\partial\Gamma} - f'(\kappa)g'(l_p(\widehat{\kappa}(\Gamma), \Gamma))\frac{\partial l_p(\widehat{\kappa}(\Gamma), \Gamma)}{\partial\Gamma} \\
&= \frac{\partial r(\widehat{\kappa}(\Gamma), \Gamma)}{\partial\kappa}\frac{\partial\widehat{\kappa}(\Gamma)}{\partial\Gamma} - f'(\kappa)g'(l_p(\widehat{\kappa}(\Gamma), \Gamma))\left[-\frac{\frac{\partial\phi(l_p(\Gamma),\Gamma)}{\partial\Gamma} + \frac{\partial\alpha(\widehat{\kappa}(\Gamma))}{\partial\widehat{\kappa}}\frac{\partial\widehat{\kappa}(\Gamma)}{\partial\Gamma}}{\frac{\partial\phi(l_p(\Gamma),\Gamma)}{\partial l_p}}\right] \\
&= \frac{\partial r(\widehat{\kappa}(\Gamma), \Gamma)}{\partial\kappa}\frac{\partial\widehat{\kappa}(\Gamma)}{\partial\Gamma} + f'(\kappa)g'(l_p(\widehat{\kappa}(\Gamma), \Gamma))\left[\frac{\frac{\partial\phi(l_p(\Gamma),\Gamma)}{\partial\Gamma} + \lambda'(\Gamma)}{\frac{\partial\phi(l_p(\Gamma),\Gamma)}{\partial l_p}}\right] \\
&> 0.
\end{aligned}$$

Thus Γ_2 is well defined. Furthermore, the fact that $\widehat{\kappa}(\Gamma)$ is a strictly decreasing function implies that

$$f'(\widehat{\kappa}(\Gamma_2)) - \delta > f'(\widehat{\kappa}(\Gamma_2))(1 - g(l_p(\widehat{\kappa}(\Gamma_2)))) - \delta = \rho = f'(\widehat{\kappa}^{ssnp}) - \delta = f'(\widehat{\kappa}(\Gamma_1)) - \delta,$$
$$f'(\widehat{\kappa}(\Gamma_2)) > f'(\widehat{\kappa}(\Gamma_1)) \quad \Rightarrow \quad \widehat{\kappa}(\Gamma_2) < \widehat{\kappa}(\Gamma_1) \quad \Rightarrow \quad \Gamma_2 > \Gamma_1.$$

Thus the definition of Γ_1 and Lemma 2 imply that there is a steady state without predation if and only if $\Gamma \geq \Gamma_1$. It follows from the definition of Γ_2, and equations (6) and (A23), that there is a steady state with predation if and only if $\Gamma \leq \Gamma_2$. Finally, notice that for a given Γ, the interest rate is strictly decreasing with the capital–labour ratio κ in the interval $[0, \widehat{\kappa}(\Gamma))$ (see Proposition 2). It is also strictly decreasing in the interval $(\widehat{\kappa}(\Gamma), +\infty)$, and when $\kappa = \widehat{\kappa}(\Gamma)$ there is a continuum of equilibria in which $l_p \in [0, l_p(\widehat{\kappa}(\Gamma), \Gamma)]$. This implies that when $\Gamma \in (\Gamma_1, \Gamma_2)$, there are three steady states: the one in which κ is in the interval $(0, \widehat{\kappa}(\Gamma))$ (with predation), another with $\kappa = \widehat{\kappa}(\Gamma)$ (with predation as well), and finally one with $\kappa > \widehat{\kappa}(\Gamma)$ (without predation).

Proof of Proposition 5

Note that the marginal rate of technical substitution of unskilled for skilled labour is a increasing function of the ratio of skilled to unskilled labour:

$$MRTS_{L,H}(\eta) = \frac{F'_z(K,Z)Z'_L(H,L)}{F'_z(K,Z)Z'_H(H,L)} = \frac{Z'_L(\eta,1)}{Z'_H(\eta,1)} = \frac{z'(\eta)}{z(\eta) - z'(\eta)\eta},$$

where we have used the assumption that $Z(.)$ is homogeneous of degree one, which implies that the first derivative of such a function is homogeneous of degree zero. It follows from first-order conditions of the maximization problem of the firm that the marginal rate of technical substitution is equal to the relative utilization price (wage) of skilled labour with respect to unskilled labour:

$$MRTS_{L,H}(\bar{\eta}) = \frac{w}{w_h} = \frac{1}{1 + ((w_h - w)/w)},$$

where $(w_h - w)/w$ is the skilled premium. Let us define $\bar{\eta}$ as the ratio of skilled to unskilled labour such that the skilled premium vanishes:

$$\bar{\eta} \overset{\text{def}}{\Leftrightarrow} MRTS_{L,H}(\bar{\eta}) = 1.$$

In this proof we concentrate on the case in which $\eta < \bar{\eta}$, which implies a positive skill premium:

$$\eta \leq \bar{\eta} \quad \Rightarrow \quad \frac{w}{w_h} = MRTS_{L,H}(\bar{\eta}) \leq 1.$$

Before proving Proposition 5, we need to prove two lemmas.

Lemma 5. There exists $\underline{\eta} < \bar{\eta}$ such that if $\eta \in (\underline{\eta}, \bar{\eta})$, then the function $(1 - \beta(\eta))(1 + \eta)$ is increasing in η.

Proof. It follows from the definition of β that

$$(1 - \beta)(1 + \eta) = \frac{w(1 - \mu)l(t)}{w_h\mu + w(1 - \mu)l(t)}(1 + \eta) = \frac{1 + \eta}{1 + (w_h/w)\eta}.$$

Then

$$\frac{\partial[(1-\beta)(1+\eta)]}{\partial\eta}=\frac{[1+(w_h/w)\eta]-(1+\eta)(w_h/w)-(1+\eta)(\partial[(w_h/w)]/\partial\eta)\eta}{[1+(w_h/w)\eta]^2}$$

and

$$\begin{aligned}\frac{\partial(w_h/w)}{\partial\eta}&=\frac{\partial(z'(\eta)/(z(\eta)-z'(\eta)\eta)}{\partial\eta}\\&=\frac{w_h}{w}\left[\frac{z''(\eta)}{z'(\eta)}+\frac{z''(\eta)\eta}{z(\eta)-z'(\eta)\eta}\right]\\&=\frac{(w_h/w)z''(\eta)z(\eta)}{(z(\eta)-z'(\eta)\eta)z'(\eta)}\\&=\frac{w_h}{w}\frac{z''(\eta)\eta/z(\eta)}{(1-\beta)\beta}\\&=-\frac{w_h}{w}\frac{1}{\sigma^z(\eta)}\frac{1}{\beta}\end{aligned}$$

imply that

$$\begin{aligned}\frac{\partial[(1-\beta)(1+\eta)]}{\partial\eta}&=\frac{1-\frac{w_h}{w}+\frac{w_h\eta}{w}\frac{1+\eta}{\sigma^z(\eta)}\frac{1}{\beta}}{\left[1+\frac{w_h}{w}\eta\right]^2}\\&=\frac{1-\frac{\beta}{1-\beta}\frac{1}{\eta}+(1+\eta)\frac{\beta}{1-\beta}\frac{1}{\sigma^z(\eta)}\frac{1}{\beta}}{\left[1+\frac{w_h}{w}\eta\right]^2}\\&=\frac{1-\beta\left[\frac{1+\eta}{\eta}\right]\left[1-\frac{\eta}{\sigma^z(\eta)}\frac{1}{\beta}\right]}{(1-\beta)\left[1+\frac{w_h}{w}\eta\right]^2},\end{aligned}$$

where we have used the definition of elasticity of substitution (see equation (5)). Thus

$$\frac{\partial[(1-\beta)(1+\eta)]}{\partial\eta}\geq 0$$

if and only if the following condition holds:

$$\begin{aligned}1-\beta\left[\frac{1+\eta}{\eta}\right]\left[1-\frac{\eta}{\sigma^z(\eta)}\frac{1}{\beta}\right]\geq 0&\Leftrightarrow\frac{1}{\beta}\frac{\eta}{1+\eta}\geq 1-\frac{\eta}{\sigma^z(\eta)}\frac{1}{\beta}\\&\Leftrightarrow\frac{\eta}{\sigma^z(\eta)}\frac{1}{\beta}\geq 1-\frac{1}{\beta}\frac{\eta}{1+\eta}\\&\Leftrightarrow\frac{\eta}{\sigma^z(\eta)}\geq\beta-\frac{\eta}{1+\eta}\\&\Leftrightarrow\frac{\eta}{\beta-(\eta/(1+\eta))}-\sigma^z(\eta)\geq 0.\end{aligned}$$

Note that by the definition of $\bar{\eta}$,

$$\beta(\bar{\eta})=\frac{\bar{\eta}}{1+(w_h(\bar{\eta})/w(\bar{\eta}))\bar{\eta}}=\frac{\bar{\eta}}{1+MRTS_{L,H}(\bar{\eta})}=\frac{\bar{\eta}}{1+\bar{\eta}}.$$

Thus

$$\lim_{\eta \to \bar{\eta}} \left[\frac{\eta}{\beta(\eta) - (\eta/(1+\eta))} - \sigma^z(\eta) \right] = +\infty - \sigma^z(\bar{\eta}) = +\infty.$$

Let us define

$$\underline{\eta} = \inf \left\{ \eta^* : \forall \eta \in (\eta^*, \bar{\eta}), \frac{\eta}{\beta(\eta) - (\eta/(1+\eta))} - \sigma^z(\eta) \geq 0 \right\}.$$

It follows from the continuity of the function

$$\frac{\eta}{\beta(\eta) - (\eta/(1+\eta))} - \sigma^z(\eta)$$

in the interval $(0, \bar{\eta})$ that $\underline{\eta}$ is well defined and $\underline{\eta} < \bar{\eta}$. □

We denote $x \equiv (1 - \mu) l_p$.

Lemma 6. We have

$$\begin{vmatrix} f''(\kappa^{ss})(1 - g(x^{ss})) & -f'(\kappa^{ss}) g'(x^{ss}) \\ \frac{\partial \lambda}{\partial \kappa}(1+\eta) & -\phi'(x^{ss}) \end{vmatrix} \leq 0$$

Proof. We calculate

$$\begin{aligned}
&\begin{vmatrix} f''(\kappa^{ss})(1 - g(x^{ss})) & -f'(\kappa^{ss}) g'(x^{ss}) \\ \frac{\partial \lambda}{\partial \kappa}(1+\eta) & -\phi'(x^{ss}) \end{vmatrix} \\
&\stackrel{1}{=} \frac{f'(\kappa^{ss})}{\kappa} \begin{vmatrix} \frac{f''(\kappa^{ss})\kappa}{f'(\kappa^{ss})}(1 - g(x^{ss})) & -g'(x^{ss}) \\ \frac{\partial \lambda}{\partial \kappa}(1+\eta)\kappa & -\phi'(x^{ss}) \end{vmatrix} \\
&\stackrel{2}{=} \frac{f'(\kappa^{ss})}{\kappa} \begin{vmatrix} -\frac{1-\alpha(\kappa)}{\sigma^f(\kappa)}(1 - g(x^{ss})) & -g'(x^{ss}) \\ \frac{f'(\kappa)\kappa}{f(\kappa)} \left[\frac{1-\sigma^f(\kappa)}{\sigma^f(\kappa)} \right] (1-\alpha(\kappa))(1-\beta)(1+\eta) & -\phi'(x^{ss}) \end{vmatrix} \\
&\stackrel{3}{=} \frac{f'(\kappa^{ss})}{\sigma^f(\kappa)\kappa} \begin{vmatrix} -(1-\alpha(\kappa))(1 - g(x^{ss})) & -g'(x^{ss}) \\ \alpha(\kappa)(1-\sigma^f(\kappa))\phi(x^{ss}) & -\frac{g''(x^{ss})(1-x^{ss}) - g'(x^{ss})(1-\phi(x^{ss}))}{1-g(x^{ss})} \end{vmatrix} \\
&\stackrel{4}{=} \frac{f'(\kappa^{ss})(1-\alpha(\kappa))}{\sigma^f(\kappa)\kappa} \left[g''(x^{ss})(1-x^{ss}) - g'(x^{ss}) \left[1 - \phi(x^{ss}) \left(1 + \frac{\alpha(\kappa)(1-\sigma^f(\kappa))}{1-\alpha(\kappa)} \right) \right] \right] \\
&\stackrel{5}{=} \frac{f'(\kappa^{ss})(1-\alpha(\kappa))}{\sigma^f(\kappa)\kappa} \left[g''(x^{ss})(1-x^{ss}) - g'(x^{ss}) \left[1 - (1-\beta)(1+\eta)(1-\alpha(\kappa)\sigma^f(\kappa)) \right] \right] \\
&\stackrel{6}{\leq} \frac{f'(\kappa^{ss})(1-\alpha(\kappa))}{\sigma^f(\kappa)\kappa} \left[g''(x^{ss})(1-x^{ss}) - g'(x^{ss})\alpha(\kappa)\sigma^f(\kappa) \right] \\
&< 0,
\end{aligned}$$

where we have used equations (5), (6), (20) and (21) in equality 2, equation (A3) in equality 3, and equations (20) and (21) in equality 5. Finally, in inequality 6, we used the fact that $\eta \leq \bar{\eta}$ implies that $(1-\beta)(1+\eta)$ is smaller than 1:

$$(1-\beta)(1+\eta)=\frac{\frac{w(1-\mu)l(t)}{w_h\mu+w(1-\mu)l(t)}}{1+\eta}=\frac{1+\eta}{1+\frac{w_h}{w}\eta}<\frac{1+\eta}{1+\eta}=1. \square$$

At the steady state, the following system of equations should hold:

$$\begin{aligned}
&(f'(\kappa^{ss})+\delta)(1-g(x^{ss}))=\delta+\rho,\\
&\phi(x^{ss})=(1-\alpha(\kappa^{ss}))(1-\beta(\eta^{ss}))(1+\eta^{ss}),\\
&\eta^{ss}=\frac{\mu}{1-\mu-x^{ss}},
\end{aligned}$$

where $x=(1-\mu)l_p$. Using Cramer's Rule and Lemmas 5 and 6, it follows that when $\eta \in [\underline{\eta},\bar{\eta}]$, we have

$$\begin{aligned}
\frac{\partial x^{ss}}{\partial \mu}&=-\frac{\begin{vmatrix} f''(\kappa^{ss})(1-g(x^{ss})) & 0 & 0\\ \frac{\partial\lambda}{\partial\kappa}(1+\eta) & 0 & (1-\alpha(\kappa))\frac{\partial[(1-\beta(\eta))(1+\eta)]}{\partial\eta}\\ 0 & -\eta^{ss}\left[\frac{1}{\mu}+\frac{1}{(1-\mu-x^{ss})}\right] & -1\end{vmatrix}}{\begin{vmatrix} f''(\kappa^{ss})(1-g(x^{ss})) & -f'(\kappa^{ss})g'(x^{ss}) & 0\\ \frac{\partial\lambda}{\partial\kappa}(1+\eta) & -\phi'(x^{ss}) & (1-\alpha(\kappa))\frac{\partial[(1-\beta(\eta))(1+\eta)]}{\partial\eta}\\ 0 & \frac{\eta^{ss}}{1-\mu-x^{ss}} & -1\end{vmatrix}}\\
&=\left(f''(\kappa^{ss})(1-g(x^{ss}))(1-\alpha(\kappa))\frac{\partial[(1-\beta(\eta))(1+\eta)]}{\partial\eta}\eta^{ss}\left[\frac{1}{\mu}+\frac{1}{(1-\mu-x^{ss})}\right]\right)\\
&\quad\times\left(-\begin{vmatrix} f''(\kappa^{ss})(1-g(x^{ss})) & -f'(\kappa^{ss})g'(x^{ss})\\ \frac{\partial\lambda}{\partial\kappa}(1+\eta) & -\phi'(x^{ss})\end{vmatrix}\right.\\
&\quad\left.-f''(\kappa^{ss})(1-g(x^{ss}))(1-\alpha(\kappa))\frac{\partial[(1-\beta(\eta))(1+\eta)]}{\partial\eta}\frac{\eta^{ss}}{(1-\mu-x^{ss})}\right)^{-1}\\
&<0.
\end{aligned}$$

Thus there is a well-defined decreasing function $x^{ss}(\mu)$ that relates the time devoted to predation x^{ss} to the portion of agents that are skilled at the steady state. Let us define

$$\begin{aligned}
&\bar{\mu}\overset{\text{def}}{\Leftrightarrow}\bar{\eta}=\frac{\bar{\mu}}{1-\bar{\mu}-x^{ss}(\bar{\mu})},\\
&\underline{\mu}\overset{\text{def}}{\Leftrightarrow}\underline{\eta}=\frac{\underline{\mu}}{1-\underline{\mu}-x^{ss}(\underline{\mu})}.
\end{aligned}$$

Note that η is an increasing function of μ:

$$\eta(\mu)=\frac{\mu}{1-\mu-x^{ss}(\mu)}.$$

Thus if $\mu \in [\underline{\mu},\bar{\mu}]$, then $\eta \in [\eta(\underline{\mu}),\eta(\bar{\mu})]=[\underline{\eta},\bar{\eta}]$.

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NOTES

1. These numbers are calculated using the studies of Anderson (1999) and Londoño and Guerrero (1998) for the USA and Latin America, respectively.
2. León-Ledesma *et al.* (2010) also summarize some well-known empirical studies for the USA, and observe limited support for unitary substitution elasticities in general. See Chirinko (2008) and Klump *et al.* (2007) for complete surveys.
3. An alternative mechanism is shown in Bethencourt and Perera-Tallo (2012). This paper presents a model with predation in which there is a reallocation of factors from agriculture (more land-intensive) to manufacturing (more labour-intensive) along the transition. This generates a rise in the labour share and a decline in predation.
4. See Easterly and Levine (2001), Hall and Jones (1999), and Parente and Prescott (2000).
5. See Acemoglu *et al.* (2005) for a complete survey.
6. These averages have been calculated considering developing countries to be those in which the per capita GDP reported by Gollin (2002) was smaller than US\$6000 (with 1985 as basis year), and developed countries as those above this threshold. (GDPs reported by Gollin are mostly from 1992, with 1985 being the basis year.) This classification is the one used by the IMF and the World Bank. (The World Bank uses the terminology low- and middle-income countries for developing countries, and high-income countries for developed ones.)
7. We assume that the predation technology depends only on factor labour, which is the standard assumption in the literature (see, for example, Murphy *et al.* 1991, 1993; Acemoglu 1995; Grossman and Kim 1996, 2002; Chassang and Padró-i-Miquel 2010).
8. If the return on savings were not monotonic, multiple equilibria may arise, as reported in other papers in the literature, such as Acemoglu (1995) and Schrag and Scotchmer (1993).
9. Note that the capital–labour ratio in the production sector is an increasing function of per capita capital and vice versa:

$$\kappa = \frac{k}{l(\kappa)} \Leftrightarrow \kappa l(\kappa) - k = 0 \Rightarrow \frac{\partial \kappa}{\partial k} = \frac{1}{l(\kappa) + \kappa l'(\kappa)} > 0.$$

10. Notice that when Γ=0, condition (15) implies condition (16). Using Taylor's Theorem, for $\varepsilon \in (0,1)$ we have $0 = g(0) = g(l_p) - g'(l_p)l_p + (1/2)g''(\varepsilon l_p)(l_p)^2 < g(l_p) - g'(l_p)l_p$. Thus $g(l_p)/l_p > g'(l_p)$, which implies $w[1 - g(\tilde{l}_p)] = g'_{l_p}(l_p)\tilde{y} < (g(l_p)/l_p)\tilde{y}$, hence $wl_p[1 - g(\tilde{l}_p)] < g(l_p)\tilde{y}$.
11. Using Taylor's Theorem, $g(0) = g(x) - g'(x)x + g''(\xi x)x^2$, where $\xi \in (0,1)$. Thus $g(x) - g'(x)x = g(0) - g''(\xi x)x^2 = 0 - g''(\xi x)x^2 > 0$, which implies $g(x) - g'(x)x > 0$, and hence $g(x)/x > g'(x)$.

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