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Public Policy and Industrial Transformation in the Process of Development

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Abstract

This paper studies the role of public policy in promoting industrial transformation from an imitationbased, low-skill economy to an innovation-based, high-skill economy, where technological progress now occurs through the domestic invention of ideas. Industrial transformation is measured by changes in an index of industrial structure, defined as the ratio of the variety of imitation- to innovation-based intermediate goods. A key mechanism through which productivity increases initially in both the imitation and innovation sectors is through a knowledge externality associated with learning by doing in the imitation sector. The process of industrialization increases the demand for high-skill labor, inducing individuals to invest in education. The model also emphasizes the distinction between basic or core infrastructure, which promotes imitation, and advanced infrastructure, which promotes innovation. A calibrated version for a low-income country is used to perform several policy experiments, including an increase in investment in infrastructure, a reduction in the cost of training, and improved enforcement of property rights.

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Contents

1 Introduction

During the past decades manufacturing exports have led the economic transformation of many of today's most successful countries, particularly in East Asia. During a first phase, many of these countries initially competed in international markets by producing labor-intensive, low-cost light manufacturing goods, using technologies imported from abroad. They achieved large productivity gains initially through a reallocation of labor from low-productivity agriculture to high-productivity manufacturing, and from a *learning-by-doing effect* associated with the use of imported technologies. In many cases, this learning effect helped to boost human capital from initially low levels, setting up the stage later on for a switch to skill-intensive, innovation-based activities, which eventually led to a diversification of manufacturing production and exports.

A key aspect of the ongoing debate about economic growth in Sub-Saharan Africa is the extent to which the region can follow a similar path, and capitalize on the factors and advantages that have generated an initial phase of rapid, manufacturing-based development elsewhere—low-cost labor and imitation of foreign technology. So far, however, there has been no large-scale adoption of this strategy in the region. While China's emergence in the global manufacturing market since the early 1980s has resulted in a broad decline in the market share of all regions, the decline in Sub-Saharan Africa's share has been longer and deeper than most. Indeed, Sub-Saharan Africa's share of global light manufacturing has continually declined to less than 1 percent today, and preferential access to U.S. and European Union (EU) markets has made little difference. Manufacturing accounts for only about 9 percent of GDP for Sub-Saharan Africa as a whole, a smaller share than in any region in the world (Dinh et al. (2012*a*, p. 32)). As a result, many workers have remained trapped in low-productivity jobs in the informal economy. Without a significant transformation of its industrial structure, Sub-Saharan Africa is unlikely to catch up with more prosperous countries like China and Vietnam—which in many regards were not very different from Sub-Saharan Africa when their own transformation process was initiated.

This paper contributes to this ongoing debate by studying the role and sequencing of public policy in promoting industrial transformation and economic development. The process that it highlights involves, in a first stage, mostly imitation of foreign technology, using unskilled labor. In that context, technological progress occurs essentially by copying foreign ideas. The second stage, which requires wages to be high enough to induce individuals to invest in skills, involves the gradual development of a home-grown innovation sector. Technological progress now occurs mostly by inventing new ideas. The model can replicate a key empirical regularity (see for instance Vandenbussche et al. (2006)): imitation is the main source of productivity growth at early stages of development, whereas innovation can become the main engine of growth as the economy approaches the technology frontier. We measure industrial transformation by changes in an index of industrial structure, defined as the ratio of the variety of imitation-based intermediate goods to innovation-based intermediate goods. The key mechanism through which productivity increases initially in both the imitation and innovation sectors is through a *knowledge externality* associated with learning by doing in the imitation sector. This tends to raise wages and productivity not only in that sector, but also in the innovation sector, because imitation activities contribute to the stock of knowledge available to all workers. Thus, imitation can serve as a "stepping stone" for innovation, as for instance in Glass (2010). At the same time, however, this positive externality is not only weaker for skilled workers but it is also subject to diminishing returns. Therefore, the marginal benefit of present imitation effort weakens over time.

Equally important to our analysis is the fact that the process of industrialization increases the demand for high-skill labor (in both final production and innovation activities), inducing individuals to invest in education. In turn, education stimulates further productivity and technological advancement in the innovation sector. Investment in human capital is therefore *not* a prerequisite for promoting growth and development in its initial stages.[1] Once the process of imitation takes off, it contributes to the accumulation of knowledge available to all in the economy, thereby promoting investment in education and an increase in the quality of the labor force. Beyond some point, however, these benefits tend to fade, and it becomes crucial to find new ways to increase productivity in the innovation sector. Otherwise, a country may become caught in a so-called "middle-income growth trap," with a substantial drop in productivity and slow growth (see Agénor and Canuto (2012)).

To conduct our analysis we consider an endogenous growth model, dwelling on Romer (1990), in which designs are produced in two sectors: an *imitation* sector (which uses only unskilled labor) and an *innovation* sector (which uses only skilled labor). The production technology in these sectors is crucial to understand the dynamics of development. The acquisition of foreign ideas generates two opposing forces. On the one hand, as a country catches up with the more advanced nations, imitation opportunities gradually decline, thereby reducing growth. On the other, the externality associated with imitation tends to promote innovation activities (as discussed earlier), thereby promoting growth. The strength of this externality determines the speed at which industrial transformation occurs.

Another important feature of the model is the distinction between two types of infrastructure: *basic* infrastructure (which consists of roads, energy, and basic telecommunications) and *advanced* infrastructure, which consists of advanced information and communication technologies (ICTs) in general, and high-speed communication networks in particular. Access to broadband facilitates the buildup of knowledge networks, thereby promoting the dissemination of ideas within and across borders, and fostering innovation (see Romer (2010) and Agénor and Canuto (2012))). Basic infrastructure helps to promote productivity in the imitation sector, whereas advanced infrastructure benefits mainly the innovation sector. A low level of productivity in the imitation sector, to begin with, may therefore be due to the lack of access to infrastructure.

[1] This is consistent for instance with Iacopetta (2010), where unlike Funke and Strulik (2000) the sequencing between human capital formation and innovation is reversed.

From that perspective, to promote imitation activities, which eventually leads to a more diversified production structure, access to high levels of human capital is neither necessary nor sufficient.[2]

The remainder of the paper is organized as follows. Section 2 presents the model. Its condensed dynamic form is derived in Section 3. Section 4 calibrates the model, assuming an initial situation where the proportion of the labor force consisting of skilled workers is small, the innovation sector is embryonic (so that most the skilled workers, which are in low numbers to begin with, are engaged in the production of final goods), access to basic infrastructure is limited, access to advanced infrastructure is almost inexistent, the cost of acquiring skills is high, and the enforcement of property rights is weak. Section 5 presents a variety of policy experiments, involving an increase in investment in basic infrastructure, a reduction in the cost of training, and improved enforcement of property rights. An illustrative composite reform program, involving a sequential combination of some of these policies, together with investment in advanced infrastructure, is also analyzed. Section 6 draws together the policy implications of the analysis. The final section offers some concluding remarks.

2 The Model

The economy that we consider is populated by individuals (grouped into families) with different innate abilities, firms, and a government. There are five production sectors: one producing a homogeneous final good, two producing intermediate goods (*core* and *enhanced* inputs from now on), and two creating designs, or blueprints used for the production of each of the two categories of intermediate inputs.[3] The design sectors are "imitation" and "innovation" sectors, and their relative importance—a measure of industrial diversification, as discussed later—varies in the course of development. The final good is produced by combining both private and public inputs, and is used for consumption, private and public investment, and the production of intermediate goods. Public inputs—basic public infrastructure, which consists of roads, electricity, water and sanitation, and basic telecommunications; and advanced infrastructure, which consists essentially of high-speed telecommunications—are provided free of charge but are subject to congestion.[4] Production in the design sectors combines public and private (labor) inputs as well, but in different ways.

Firms in the final good and design sectors are perfectly competitive whereas those in the intermediate good sectors are monopolistically competitive, each producing (as

[2] Contributions focusing on the transition between development regimes and related to our analysis include van Elkan (1996), Walz (1996), Funke and Strulik (2000), Garcia-Castrillo and Sanso (2002), Iacopetta (2010), Gómez (2012), and Chen and Funke (2012). However, none of them addresses the issues of skill distribution and composition of public capital, as we do here.

[3] As discussed later, skills are acquired through formal education or training, but we do not explicitly introduce a Lucas-type human capital accumulation sector.

[4] We abstract from any direct utility benefit associated with public capital, as discussed in a number of contributions.

in Romer (1990)) a differentiated variety of good. The total number of blueprints existing at a certain point in time coincides with the number of intermediate input varieties and represents the stock of nonrival knowledge available in the economy. The *composition* of that stock is used later on to measure industrial structure and to study its transformation over time. Knowledge accumulated in the imitation sector creates an externality that promotes productivity in both design sectors, but this benefit is subject to diminishing marginal returns. Finally, labor (both skilled and unskilled) is perfectly mobile between the final good and design sectors.

2.1 Consumption and Labor Supply

There is a continuum of families indexed by ability $a \in (0, 1)$. Ability follows a uniform distribution, with a cumulative distribution function $F(a) = a$ and mean 0.5. All members of a family have the same ability level, equal to a. Each family is modeled as a dynastic household whose size grows over time at an exogenously given rate $n > 0$. Each individual member of a family lives forever. With N_0 denoting the number of members of each family at time $t = 0$, the size of the representative family—and, by extension, population size—at time t is $N_t = N_0 \exp(nt)$. Each family owns a stock of assets, which consists of physical capital and the stock of designs produced in the economy. Income is devoted to the consumption of final goods and the acquisition of new assets.

Each family maximizes utility so as to determine the evolution of consumption expenditure over time. Individual members also decide whether to enter the labor force as unskilled workers or (following a training period) skilled workers. In making these decisions, each family takes wages and the interest rate as given.

Each individual knows his (her) own ability level a, as do all the firms that might potentially hire him (her). To avoid corner solutions, we will assume that individuals with ability $a \in (0, a^L)$ never choose to undergo training, whereas individuals with ability $a \in (a^H, 1)$ always choose to do so.[5] An individual with ability $a \in (a^L, a^H)$ can choose to enter the labor force at t as an unskilled worker and earn from then on the wage w_t^U (which is independent of the worker's ability). Alternatively, he may decide to spend first an exogenously given period of time T in training, incur a cost tc_t during $(t, t+T)$, and enter the labor force at $t+T$ as a skilled worker. From then on a skilled worker with ability a earns a wage $a^\chi w_t^S$, where $\chi > 0$ is a productivity parameter (common to all individuals with the same ability) which measures the efficiency of training.[6] Thus, skilled workers with higher ability levels earn higher wages, although this may occur with diminishing returns to ability ($\chi < 1$). During training time $(t, t+T)$, workers earn no income. Thus, the opportunity cost of becoming skilled

[5] Because both skilled and unskilled labor are essential inputs in the production of the final good, and the production function is Cobb-Douglas, these assumptions serve indeed to eliminate the case of zero output.

[6] As noted earlier, both categories of labor are perfectly mobile between the final good sector and the design sectors. This implies that there is a single, economy-wide wage for each category of labor.

is equal to the discounted value of foregone unskilled wage income. Income is also assumed to be evenly shared within each family (that is, between employed members and trainees) so that, at each point in time, consumption expenditure is the same for each member of a family.

The optimization problem of a family with ability a and size N_0 is

$$\max U_t^a = \int_t^\infty N_0 u_t^a \exp[-(\rho - n)(s-t)]ds, \tag{1}$$

where $\rho > 0$ is the constant subjective discount rate, and u_t^a is the static utility function of each household member, which is defined as

$$u_t^a = \frac{1-(C_t^a)^{1/\sigma}}{1-1/\sigma}, \tag{2}$$

where C_t^a is consumption by each individual member of the family.

With V_t^a denoting the family's stock of assets, its flow budget constraint is

$$\dot{V}_t^a = r_t V_t^a + (1-\tau)Y_t - N_t C_t^a, \tag{3}$$

where r_t is the market interest rate, Y_t the economy's output of final goods, and $\tau \in (0,1)$ the tax rate on income.

The solution to the family's dynamic optimization problem yields the standard intertemporal equation,

$$\frac{\dot{C}_t^a}{C_t^a} = \sigma(r_t - \rho), \tag{4}$$

together with the transversality condition $\lim_{t\to\infty}(C_t^a)^{-\sigma}V_t^a\exp(-\rho t) = 0$. In familiar fashion, equation (4) states that per capita consumption expenditure grows over time if and only if the market interest rate exceeds the subjective discount rate.[7]

Consider now labor supply decisions.[8] As noted earlier, training and employment decisions are made to maximize each family's discounted wage income, which is equivalent to maximizing each member's discounted wage income. There are two types of costs associated with training. The first is time devoted to training, which depends on whether the individual member earns the unskilled wage, w_t^U, or becomes a skilled worker and then earns the wage $a^\chi w_t^S$. The second is the training cost, tc_t.

Thus, it is optimal for an individual with ability $a \in (a^L, a^H)$ to train and become

[7] When the market interest rate is relatively high for instance, family members want to save more now and spend more later, resulting in positive growth in per capita consumption expenditure over time. Note that the left-hand side of (4) does not depend on ability, and thus neither on wages earned in production.

[8] The discussion here dwells in part on Dinopoulos and Segerstrom (1999) and Agénor and Canuto (2012). See also Hori (2011) and Davis (2013).

a skilled worker if and only if[9]

$$\int_{t+T}^{\infty} a^{\chi} w_s^S \exp[-\rho(s-t)]ds - tc_t \geq \int_t^{\infty} w_s^U \exp[-\rho(s-t)]ds. \quad (5)$$

The right-hand side (RHS) of this inequality equals the discounted wage income of an individual from being employed as an unskilled worker and earning the wage w_s^U from time $s = t$ onward. The left-hand side (LHS) is the lifetime income of a skilled worker, who earns zero income during his training period (t, T) and w_s^S from time $s = t + T$ onward, adjusted for the training cost tc_t occurred during $(t, t + T)$.

The training cost per unit time s is assumed to be proportional to the wage that skilled workers make once training is completed and they become employed, so that $\mu a^{\chi} w_s^S$, with $\mu \in (0, 1)$. For simplicity, this cost is taken to incur from that point on until the infinite future. Thus, $tc_t = \int_{t+T}^{\infty} \mu a^{\chi} w_s^S \exp[-\rho(s-t)]ds$.[10]

Condition (5) can be readily used to determine the supply of unskilled labor. Indeed, because the LHS of (5) is increasing in a, whereas the RHS is independent of a, there exists a threshold level of ability denoted by a_t^C such that (5) holds as an equality. All individuals with ability lower than $a_t^C > 0$ (including then with ability lower than a^L) choose to remain unskilled, and all individuals with ability greater than $a_t^C \leq 1$ (including then those with ability greater than a^H) choose to undergo training and then enter the labor force as skilled workers.

Assuming that (5) holds with equality yields

$$\int_{t+T}^{\infty} (a_s^C)^{\chi}(1-\mu) w_s^S \exp[-\rho(s-t)]ds = \int_t^{\infty} w_s^U \exp[-\rho(s-t)]ds,$$

which simplifies to

$$\frac{\exp(-\rho T)(a_t^C)^{\chi}(1-\mu) w_t^S}{\rho} = \frac{w_t^U}{\rho}.$$

Solving this condition for a_t^C yields

$$a_t^C = [\frac{w_t^U}{(1-\mu) w_t^S}]^{1/\chi} [\exp(\rho T)]^{1/\chi}, \quad (6)$$

which is equal to a^H if the expression on the RHS exceeds a^H.

Because $\exp(\rho T) \geq 1$ and $\chi > 0$, the net wage earned by a skilled worker $(1-\mu) w_t^S$ must be higher than the wage of an unskilled worker w_t^U for an individual to *choose*

[9] Because each family's discounted utility is increasing in consumer expenditure and there is no disutility associated with training or working, each family maximizes its discounted utility by maximizing its discounted wage income.

[10] An alternative assumption would be to assume that the cost is incurred *during* the training period $(t, t+T)$ as a fraction of the going skilled wage, so that tc_t is instead equal to $\int_t^{t+T} \mu a^{\chi} w_s^S \exp[-\rho(s-t)]ds$. However, because in the calibration presented later we normalize T to zero, this specification is less tractable.

to become skilled.[11] An increase in the duration of training T, the proportional cost of training μ, or in the relative wage of unskilled labor, raises the fraction of the population that chooses to remain unskilled.

Given (6), the supply of unskilled labor, N_t^U, equals the number of individuals in the population who choose to remain unskilled:

$$N_t^U = a_t^C N_t. \tag{7}$$

To derive the supply of skilled labor, N_t^S, note first that at any time t, $(1 - a_t^C)N_t$ individuals either work as skilled workers or are training to become skilled workers. In this sub-population, those who are actually working as skilled workers are the older individuals, namely, those individuals who were born before $t - T$:

$$\int_{-\infty}^{t-T} n(1 - a_t^C)N_s ds = n(1 - a_t^C) \int_{-\infty}^{t-T} N_0 \exp(ns)ds = (1 - a_t^C) \exp(-nT)N_t.$$

The average skill level of workers with ability $a \in (a_t^C, 1)$ who have finished training equals $(a_t^C + 1)/2$; thus, the supply of skilled labor at time t, measured in efficiency units of human capital, can be defined as

$$N_t^S = \frac{(1 + a_t^C)}{2}(1 - a_t^C) \exp(-nT)N_t,$$

or equivalently

$$N_t^S = \frac{1 - (a_t^C)^2}{2} \exp(-nT)N_t. \tag{8}$$

From equations (6), (7), and (8), it can be seen that a decline in the relative wage of unskilled workers decreases a_t^C and N_t^U and increases N_t^S, resulting in a rise in the relative supply of skilled labor, N_t^S/N_t^U.

2.2 Final Good

Production of the final good, Y_t, requires the use of skilled labor, $N_t^{S,Y}$, unskilled labor, $N_t^{U,Y}$, private capital, K_t^P, basic public infrastructure, K_t^B, and the combination of core intermediate inputs, $x_{s,t}^I$, where $s \in (0, M_t^I)$, and enhanced intermediate inputs, $x_{s,t}^R$, where $s \in (0, M_t^R)$:[12]

$$Y_t = [\frac{K_t^B}{(\bar{K}_t^P)^{\zeta_K} N_t^{\zeta_N}}]^\omega (N_t^{S,Y})^{\beta^S} (N_t^{U,Y})^{\beta^U} X_t^\gamma (K_t^P)^\alpha, \tag{9}$$

[11] Recall that all individuals with ability $a \in (a^H, 1)$ always choose to become skilled.

[12] In the model advanced public capital does not affect production of the final good, only (as discussed later) productivity in the innovation sector. In general, of course, both the innovation and manufacturing sectors could be assumed to benefit from access to that type of infrastructure. For instance, it is well documented that in recent years ICTs have helped to integrate supply chains both within and across borders, thereby boosting efficiency in the production of manufactured goods. For the purpose of our analysis, however, what matters is only that the effect of ICTs is relatively stronger on activity in the innovation sector, compared to the final good sector.

where $\beta^S, \beta^U, \alpha, \gamma \in (0,1)$, $\omega > 0$, $\zeta_K, \zeta_N > 0$, $\alpha = 1 - (\beta^S + \beta^U) - \gamma$, $\bar{K}_t^P$ is the aggregate private capital stock, and X_t is a composite intermediate input defined as

$$X_t = [\int_0^{M_t^I} (x_{s,t}^I)^\eta ds]^{\nu/\eta} \cdot [\int_0^{M_t^R} (x_{s,t}^R)^\eta ds]^{(1-\nu)/\eta}, \tag{10}$$

where $\eta \in (0,1)$ and $1/(1-\eta) > 1$ is (the absolute value of) the price elasticity of demand for each intermediate good, and $\nu \in (0,1)$. Thus, the composite intermediate input exhibits constant returns to scale with respect to core and enhanced inputs.[13] Although coefficient ν itself could be made a function of the composition of intermediate goods (falling over time, as the economy's relative production of enhanced inputs increases), for simplicity it is taken to be constant.

Specification (9) implies that there are constant returns in private inputs, and that basic public capital is partially rival and subject to congestion, measured by the aggregate private capital stock and population size. The strength of congestion effects is measured by the parameters ζ_K and ζ_N.

Profits of the representative firm are given by

$$\Pi_t^Y = Y_t - \int_0^{M_t^I} P_t^{I,s} x_{s,t}^I ds - \int_0^{M_t^R} P_t^{R,s} x_{s,t}^R ds - w_t^S N_t^{S,Y} - w_t^U N_t^{U,Y} - (r_t + \delta_P) K_t^P,$$

where $P_t^{I,s}$ ($P_t^{R,s}$) is the price of core (enhanced) intermediate good s, w_t^S (w_t^U) the skilled (unskilled) wage rate, r_t the (net) rental rate of private capital, and $\delta_P \in (0,1)$ the rate of depreciation of private capital. The final good is used as the numéraire and its price is normalized to unity.

Each producer maximizes profits subject to (9)-(10) with respect to labor, private capital, and quantities of all intermediate goods $x_{s,t}^j$, $\forall s$, taking factor prices and M_t^j as given, $j = I, R$. This yields

$$w_t^S = \beta^S \frac{Y_t}{N_t^{S,Y}}, \quad w_t^U = \beta^U \frac{Y_t}{N_t^{U,Y}}, \tag{11}$$

$$r_t = \alpha \frac{Y_t}{K_t^P} - \delta_P, \tag{12}$$

$$x_{s,t}^j = (\frac{\gamma \nu^j Z_t^j}{P_t^{j,s}})^{1/(1-\eta)}, \quad s = 1, ...M_t^j, \tag{13}$$

$$Z_t^j = Y_t / \int_0^{M_t^j} (x_{s,t}^j)^\eta ds, \tag{14}$$

[13] The Cobb-Douglas form used in (10) is more tractable analytically than an additive form, which would imply that core and enhanced intermediate inputs, as a whole, are perfect substitutes. A more general specification would be to use a CES function with a relatively low—but possibly variable—elasticity of substitution between the two categories of inputs (instead of unity), but this would prevent the derivation of an explicit dynamic form. Alternatively, as in Afonso and Thompson (2011) for instance, intermediate goods could be assumed to be complementary.

where $j = I, R$ and $\nu^I = \nu$, $\nu^R = 1 - \nu$.

The law of motion of private capital is given by

$$\dot{K}_t^P = I_t + (1 - \delta_P)K_t^P, \tag{15}$$

where I_t is private investment.

2.3 Intermediate Goods

There are two sets of intermediate goods (IG) producers: those producing core inputs, based on blueprints produced by the imitation sector, and those producing enhanced inputs, based on designs produced by the innovation sector. Each firm produces one, and only one, horizontally-differentiated intermediate good. In both cases, production of each unit of intermediate good requires one unit of the final good.

Consider first producers of core intermediate goods, $x_t^{I,s}$, $s = 1, ...M_t^I$. Each producer must pay a one-off license fee, Q_t^I, to the firm that produced the relevant design in the imitation sector, before producing its own specialized good. Thus, the license fee represents a fixed entry cost. Once the fee is paid, each producer sets its price to maximize profits, given the perceived demand function for its good (13), which determines marginal revenue. Under a symmetric equilibrium, profits are given by $\Pi_t^I = (P_t^I - 1)x_t^I$ or using (13) and (14), $\Pi_t^I = (P_t^I - 1)[\gamma\nu Y_t/P_t^I M_t^I (x_t^I)^\eta]^{1/(1-\eta)}$. The solution yields the optimal price as

$$P_t^{I,s} = \frac{1}{\eta}, \quad \forall s = 1, ...M_t^I, \tag{16}$$

which indicates, in standard fashion, that firms cannot charge a price higher than marginal cost (the price of a unit of the final good), when intermediate goods are perfect substitutes ($\eta = 1$).

Using (13), the quantity demanded at this price is $x_{s,t}^I = (\gamma\eta\nu Z_t^I)^{1/(1-\eta)}$, $\forall s$, that is, noting that under symmetry $\int_0^{M_t^I} (x_{s,t}^I)^\eta ds = M_t^I (x_t^I)^\eta$,

$$x_t^I = \gamma\eta\nu(\frac{Y_t}{M_t^I}), \tag{17}$$

with maximum profit given by

$$\Pi_t^I = (1 - \eta)\gamma\nu(\frac{Y_t}{M_t^I}). \tag{18}$$

In equilibrium, the license fee must be set equal to current profits:[14]

$$Q_t^I = \Pi_t^I. \tag{19}$$

[14]This assumption that the license fee depends on current profits only rather than the present discounted value of all future profits (as would be the case with a license of infinite duration) allows us to eliminate dynamics in terms of Q_t^I and to focus on price incentives to innovation, as discussed next.

Consider now the production of enhanced intermediate goods. Each firm must purchase an infinitely-lived patented design from the innovation sector. Once the patent is paid, each intermediate good producer sets its sale price to maximize profits, given the perceived demand function for its good (13). Under a symmetric equilibrium, and using (13) and (14), profits are given by $\Pi_t^R = (P_t^R - 1)[\gamma(1-\nu)Y_t/P_t^R M_t^R (x_t^R)^\eta]^{1/(1-\eta)}$. The solution yields again the optimal price as

$$P_t^R = \frac{1}{\eta}, \tag{20}$$

with quantity demanded as, using (13),

$$x_t^R = \gamma\eta(1-\nu)(\frac{Y_t}{M_t^R}), \tag{21}$$

and maximum profit as

$$\Pi_t^R = (1-\eta)\gamma(1-\nu)(\frac{Y_t}{M_t^R}). \tag{22}$$

If the market for new enhanced designs is competitive, standard arbitrage implies that the price of a patent, Q_t^R, must be equal to the present discounted stream of profits that the potential producer could make by producing the intermediate input. Thus,

$$Q_t^R = \int_t^\infty \Pi_s^R \exp(-R_{t,s})ds,$$

where $R_{t,s} = \int_t^s r_v dv$. Differentiating this expression with respect to time yields $\dot{Q}_t^R = -\exp(R_{t,t}) + \dot{R}_{t,t}\int_t^\infty \Pi_s^R \exp(-R_{t,s})ds$, that is, given that $R_{t,t} = r_t$,[15]

$$\dot{Q}_t^R = r_t Q_t^R - \Pi_t^R. \tag{23}$$

2.4 Design Sectors

Designs are produced in two sectors: an imitation sector, which employs only unskilled labor, in quantity $N_t^{U,I}$, and an innovation sector, which employs only skilled labor, in quantity $N_t^{S,R}$. There is no aggregate uncertainty in either sector. In the imitation sector, local firms invest resources in order to absorb and adapt the information needed to replicate new products invented abroad, that is, "reverse engineering." Thus, imitation differs from innovation in that the number of goods that can be copied at any point in time is limited to the rate at which imitable goods are being discovered elsewhere.

[15]Equation (23) can be rewritten in the familiar no-arbitrage form $r_t = \Pi_t^R/P_t^R + \dot{P}_t^R/P_t^R$, which equates the rate of return on private capital to the rate of return on the alternative "asset" (the exclusive right to produce a new design for enhanced intermediate goods), given by the sum of the net revenue (divided by the asset price to give a rate) plus any capital gain associated with a change in that price.

Both imitation and innovation create two kinds of knowledge. First, *private* knowledge, which is acquired (for a price) by intermediate goods firms to produce a new production input. Second, *public* knowledge, which spills over to other firms in the imitation and innovation sectors—in ways specified later—and increases productivity there. In addition, we also assume that there is an externality from imitation for innovation—as agents learn to imitate, they also develop cognitive skills that help them to innovate. This is consistent with the idea, discussed in the introduction, that imitation can be a "stepping stone" for true innovation.[16]

Consider the imitation sector first. The aggregate technology is defined as

$$\dot{M}_t^I = A_t^I(\frac{N_t^{U,I}}{N_t})(1+g^W)^{\kappa^I}, \tag{24}$$

where A_t^I is a productivity factor, $g^W > 0$ is the growth rate of the stock of designs available internationally that can be effectively imitated in the country under consideration, or equivalently the rate at which the imitation technology frontier changes. We assume that the technology parameter $\kappa^I \in (0,1)$ is less than unity, to capture the fact that the growth in imitable goods worldwide entails diminishing marginal benefits for domestic imitation—perhaps because some technical specifications involved in foreign ideas are fairly complex, or that adaptation costs are large, thereby constraining (at the margin) the country's ability to imitate. We also assume, as in Chen and Funke (2012) for instance, that the international knowledge pool available for copying, grows at an exogenous rate.[17] We also assume, to eliminate scale effects, that it is the *ratio* of unskilled workers to total population that affects activity in that sector.[18]

Productivity in imitation activities depends on the economy's stock of imitated designs and access to basic infrastructure:

$$A_t^I = (k_t^B)^{\phi_1^I}(m_t^I)^{\phi_2^I} M_t^I, \tag{25}$$

where $k_t^B = K_t^B/K_t^P$, $m_t^I = M_t^I/K_t^P$, $\phi_1^I > 0$, and $\phi_2^I \geq 0$. Thus, as in Romer (1990), each design creates a positive externality for future imitation activities. In addition, as in Agénor and Canuto (2012), we account for the fact that—at least temporarily—productivity may exhibit increasing marginal returns ($\phi_2^I > 0$) with respect to imitative knowledge, as a result of strong learning-by-doing effects. We also assume that access

[16] As in Perez-Sebastian (2007), we could also assume that the benefit of imitation diminishes as the country gets closer to the world technological frontier for imitated goods. However, doing so directly would add further analytical complications. Instead, we capture this effect indirectly, as discussed later.

[17] The exogeneity of the law of motion of the international pool of ideas implies that we abstract from the fact that domestic innovation (under the relevant regime) might yield new goods that will add up to the international pool of imitable designs. We do so for simplicity. Notice, however, that this effect will be small at low levels of economic development because then the production of innovative designs is low or inexistent.

[18] This specification is consistent with the "dilution effect" discussed by Dinopoulos and Segerstrom (1999). See also Grossmann and Thomas (2007).

to basic public capital is subject to (proportional) congestion, measured by the private capital stock.

Firms in the imitation sector choose labor so as to maximize profits, $\Pi_t^I = Q_t^I \dot{M}_t^I - w_t^U N_t^{U,I}$, subject to (24), and taking the wage rate, the license fee, Q_t^I, and productivity A_t^I, as given. The first-order condition with strictly positive employment ($N_t^{U,I} > 0$) is given by

$$w_t^U = (\frac{Q_t^I A_t^I}{N_t})(1 + g^W)^{\kappa^I}, \tag{26}$$

Consider now the innovation sector. The aggregate technology is defined as

$$\dot{M}_t^R = A_t^R (\frac{N_t^{S,R}}{N_t}), \tag{27}$$

where A_t^R is productivity, which depends on access to advanced infrastructure and *both* stocks of technological knowledge—with innovation creating a stronger spillover effect than imitation::

$$A_t^R = (k_t^A)^{\phi_1^R} (m_t^R)^{\phi_2^R} (M_t^R + \phi_3^R M_t^I), \tag{28}$$

where $k_t^A = K_t^A / K_t^P$, $m_t^R = M_t^R / K_t^P$, $\phi_1^R > 0$, $\phi_2^R \geq 0$ and $0 \leq \phi_3^R < 1$. This specification accounts again for the possibility of increasing marginal returns associated with innovative knowledge ($\phi_2^R > 0$), if only for a temporary period, as in Agénor and Canuto (2012). For tractability, access to advanced infrastructure is again congested by the private capital stock.[19]

We also assume that imitation enhances productivity in the innovation sector. This specification accounts for an efficiency gain associated with imitation—if only during a transitory phase: the more a country engages initially in copying, the more its workers become familiar with existing innovations made abroad, and the easier it is to engage in original innovation. However, we also assume that the knowledge created as a by-product of imitation creates (marginal) efficiency gains that are less significant than those associated with home-grown innovation, so that $\phi_3^R < 1$. Our specification also accounts for the possibility that imitation may not create any spillover at all for innovation ($\phi_3^R = 0$), or that the spillover may weaken over time if the ratio M_t^I / M_t^R itself decreases over time, which may well occur if the development of the innovation sector is sufficiently rapid.

Firms in the innovation sector choose labor so as to maximize profits,

$$\Pi_t^R = (1 - \lambda) Q_t^R \dot{M}_t^R - w_t^S N_t^{S,R},$$

subject to (27), and taking the wage rate, the patent price, Q_t^R, and productivity as given. In this expression, the coefficient $\lambda \in (0, 1)$ measures the deadweight loss associated with a poorly functioning system to enforce property rights (administration

[19]This assumption makes the treatment of congestion in the design sectors symmetric and is convenient analytically. Alternatively, congestion could be measured by the level of activity in the innovation sector, that is, the stock of innovative blueprints.

of patents, etc.). The view is that these inefficiencies translate into a lower ability of firms in the innovation sector to appropriate the rents created by their activity—that is, the profits of the intermediate good firm using their design. Put differently, even though the price of the patent paid by each intermediate good producer is Q_t^R, due to inefficiencies in enforcing property rights the producer receives only a fraction $1-\lambda$ of that price.[20]

The first-order condition is given by

$$w_t^S \geq \frac{(1-\lambda)Q_t^R A_t^R}{N_t}, \tag{29}$$

with equality if $N_t^{S,R} > 0$. Thus, innovation takes place only if skilled wages are not too low. In addition, improved enforcement of property rights translates into higher wages, which tends to draw more labor into the innovation sector and to promote activity there.

2.5 Government

The government levies a tax on final good output at the rate τ, invests a total of G_t^B and G_t^A on basic and advanced infrastructure, and spends G_t^U on other items. Its services are provided free of charge. It cannot issue bonds and must therefore run a balanced budget:

$$G_t = \sum G_t^h = \tau Y_t. \tag{30}$$

Shares of public spending are all assumed to be constant fractions of government revenues:

$$G_t^h = \upsilon_h \tau Y_t, \quad h = A, B, U \tag{31}$$

Combining (30) and (31) therefore yields

$$\sum_h \upsilon_h = 1. \tag{32}$$

Stocks of public capital evolve according to

$$\dot{K}_t^j = \varphi_G G_t^j + (1-\delta_G)K_t^j, \quad j = A, B \tag{33}$$

where $\delta_G \in (0,1)$ is a depreciation rate and $\varphi_G \in (0,1)$ an efficiency parameter, which measures the extent to which investment flows translate into actual accumulation of public capital. As in Agénor (2010, 2012), we interpret this parameter as an indicator of the quality of public sector management. For simplicity, both δ_G and φ_G are assumed to be the same for the two types of public capital.

[20] See Eicher and García-Peñalosa (2008) and Lorenczik and Newiak (2012) for a more formal analysis of property rights in an innovation-based model of economic growth.

2.6 Market-Clearing Conditions

To close the model requires specifying the equilibrium conditions between supply and demand in the goods market, and the labor markets for skilled and unskilled labor.

The equilibrium condition of the final good market is

$$Y_t - \int_0^{M_t^I} x_{s,t}^I ds - \int_0^{M_t^R} x_{s,t}^R ds = N_t C_t^a + I_t + G_t, \tag{34}$$

with the left-hand side representing value added.

Under symmetry, $\int_0^{M_t^j} x_{s,t}^j ds = M_t^j x_t^j$, and as shown earlier, $x_t^j = \gamma\eta\nu^j Y_t / M_t^j$, $j = I, R$. Thus, equation (34) becomes

$$(1 - \gamma\eta)Y_t = N_t C_t^a + I_t + G_t,$$

that is, using (30),

$$(1 - \gamma\eta - \tau)Y_t = N_t C_t^a + I_t. \tag{35}$$

This equation can be solved for private investment, I_t.

Equilibrium of the market for unskilled labor implies that workers are employed either in the production of the final good or in the imitation sector, that is, $N_t^{U,Y} + N_t^{U,I} = N_t^U$, or equivalently, in terms of ratios,

$$\theta_t^{U,Y} + \theta_t^{U,I} = \theta_t^U, \tag{36}$$

where $\theta_t^U = N_t^U / N_t$ is the total supply of unskilled labor in proportion of the total population, which from (7) is equal to a_t^C.

Similarly, equilibrium of the market for skilled labor implies that workers are employed either in the production of the final good or in the innovation sector, that is, $N_t^{S,Y} + N_t^{S,I} = N_t^S$, or equivalently, in relative terms,

$$\theta_t^{S,Y} + \theta_t^{S,R} = \theta_t^S, \tag{37}$$

where $\theta_t^S = N_t^S / N_t$ is the supply of skilled labor, measured in efficiency units, in proportion of the total population, which from (8) is equal to $0.5[1-(a_t^C)^2]\exp(-nT)$.[21]

With the marginal product conditions (11) solved for $\theta_t^{U,Y}$ and $\theta_t^{S,Y}$, (26) and (29), the latter holding with equality, solved for w_t^U and w_t^S, and θ_t^U and θ_t^S determined as indicated earlier from (7) and (8), conditions (36) and (37) can be solved for $\theta_t^{U,I}$ and $\theta_t^{S,R}$ residually.

Figure 1 summarizes the production structure of the model and the distribution of labor across sectors.

[21] Note that, because the supply of skilled labor is measured in efficient units of human capital, the equality $\theta_t^S + \theta_t^U = 1$ does *not* hold. This is because the *number* of skilled workers $(1 - a_t^C)N_t$ is adjusted for average ability, as measured by$(a_t^C + 1)/2$.

3 Dynamics and Steady State

Consider now the dynamics of the economy, under a "mixed" regime where both imitation and innovation activities coexist ($\dot{M}_t^I > 0$ and $\dot{M}_t^R > 0$). In general, there are two margins to consider:

a) the decision to acquire skills for individuals with ability $a \in (a^L, a^H)$, which depends on whether the unskilled wage is lower or higher than the skilled wage, $w_t^U \lesseqgtr w_t^S$;

b) whether employment in the innovation sector is positive, that is, $\theta_t^{S,R} > 0$, which depends on whether (29) holds with equality.

In the mixed regime, where both $\theta_t^S > 0$ (with $a_t^C \leq 1 - a^H$) and $\theta_t^{S,R} > 0$, equations (28) and (29) yield[22]

$$w_t^S = (\frac{Q_t^R}{N_t})(k_t^A)^{\phi_1^R}(m_t^R)^{\phi_2^R}[1 + \phi_3^R(\frac{m_t^I}{m_t^R})]M_t^R. \tag{38}$$

To determine the growth rate, the first step is to derive the restrictions on the congestion parameters in (9). In a symmetric equilibrium,

$$X_t = [(M_t^I)^{1/\eta}x_t^I]^\nu[(M_t^R)^{1/\eta}x_t^R]^{1-\nu}. \tag{39}$$

From (17) and (21), $x_t^j = \gamma\eta\nu^j(Y_t/M_t^j)$, for $j = I, R$. Substituting these results in (39) yields

$$X_t = \gamma\eta\nu^\nu(1-\nu)^{1-\nu}[(M_t^I)^{\nu(1-\eta)/\eta}(M_t^R)^{(1-\nu)(1-\eta)/\eta}]Y_t,$$

or equivalently,[23]

$$X_t = \Lambda_1(m_t^I)^{\nu(1-\eta)/\eta}(m_t^R)^{(1-\nu)(1-\eta)/\eta}(\frac{Y_t}{K_t^P})(K_t^P)^{1/\eta},$$

where $m_t^j = M_t^j/K_t^P$, $j = I, R$ and $\Lambda_1 = \gamma\eta\nu^\nu(1-\nu)^{1-\nu}$. Substituting this expression in (9) yields

$$Y_t = (\theta_t^{S,Y})^{\beta^S}(\theta_t^{U,Y})^{\beta^U}N_t^{\beta^S+\beta^U-\omega\zeta_N} \tag{40}$$
$$\times(k_t^B)^\omega\left\{\Lambda_1(m_t^I)^{\nu(1-\eta)/\eta}(m_t^R)^{(1-\nu)(1-\eta)/\eta}(\frac{Y_t}{K_t^P})\right\}^\gamma(K_t^P)^{\alpha+\gamma/\eta+\omega(1-\zeta_K)},$$

The following restrictions on the congestion parameters ζ_K and ζ_N are imposed:

Assumptions: $\beta^S + \beta^U - \omega\zeta_N = 0$, $\alpha + \gamma/\eta + \omega(1-\zeta_K) = 1$.

[22] Given the assumptions made earlier, even if $w_t^U > w_t^S$, there is always some supply of skilled labor in the economy—those with ability $a \in (a^H, 1)$; that is, $a_t^C = 1 - a^H$. Even so, however, this does not imply that an innovation sector will emerge; in addition, condition (38) must hold. Put differently, having skilled labor in the economy is a *necessary*, but not *sufficient*, condition for innovation activity to take place.

[23] Note that $(K_t^P)^{(1-\eta)/\eta} = (K_t^P)^{\nu(1-\eta)/\eta}(K_t^P)^{(1-\nu)(1-\eta)/\eta} = (K_t^P)^{1/\eta}/K_t^P$.

Thus, the level of output becomes:

$$Y_t = \frac{(k_t^B)^{\omega/(1-\gamma)}\Lambda_2}{[(\theta_t^{S,Y})^{\beta^S}(\theta_t^{U,Y})^{\beta^U}]^{-1/(1-\gamma)}}\left\{(m_t^I)^{\nu(1-\eta)/\eta}(m_t^R)^{(1-\nu)(1-\eta)/\eta}\right\}^{\gamma/(1-\gamma)} K_t^P, \tag{41}$$

where $\Lambda_2 = \Lambda_1^{\gamma/(1-\gamma)}$. Equation (41) is thus linear in the private capital stock.

To simplify notations, suppose for the moment that training occurs instantaneously, so that $T = 0$.[24] Thus, equations (6), (7), and (8) become

$$a_t^C = \begin{cases} \max[a^L, [w_t^U/(1-\mu)w_t^S]^{1/\chi}] & \text{if } w_t^U < (1-\mu)w_t^S \\ 1-a^H & \text{if } w_t^U \geq (1-\mu)w_t^S \end{cases}, \tag{42}$$

$$\theta_t^U = \frac{N_t^U}{N_t} = a_t^C, \qquad \theta_t^S = \frac{N_t^S}{N_t} = \frac{1-(a_t^C)^2}{2}. \tag{43}$$

From the first-order conditions (11), $w_t^U/w_t^S = \beta(N_t^{S,Y}/N_t^{U,Y})$, where $\beta = \beta^U/\beta^S$. This expression is equivalent to $w_t^U/w_t^S = \beta(\theta_t^{S,Y}/\theta_t^{U,Y})$. Thus, the unskilled-skilled wage ratio varies inversely with the relative supplies of skilled and unskilled labor in the final good sector. Using this result, Appendix A shows that the dynamic system that drives the economy when $w_t^U < (1-\mu)w_t^S$ (which we consider to be the "normal" case) consists of six first-order differential equations and five static equations:

$$\frac{\dot{k}_t^j}{k_t^j} = \left\{\upsilon_j\varphi_G\tau(k_t^j)^{-1} - (1-\gamma\eta-\tau)\right\}(\frac{Y_t}{K_t^P}) + z_t^C + \delta_P - \delta_G, \tag{44}$$

$$\frac{\dot{z}_t^C}{z_t^C} = n + [\sigma\alpha - (1-\gamma\eta-\tau)](\frac{Y_t}{K_t^P}) + z_t^C - \sigma(\rho+\delta_P) - (1-\delta_P), \tag{45}$$

$$\frac{\dot{m}_t^R}{m_t^R} = (k_t^A)^{\phi_1^R}(m_t^R)^{\phi_2^R}[1+\phi_3^R(\frac{m_t^I}{m_t^R})](\theta_t^S - \theta_t^{S,Y}) - (1-\gamma\eta-\tau)(\frac{Y_t}{K_t^P}) + z_t^C - (1-\delta_P), \tag{46}$$

$$\frac{\dot{m}_t^I}{m_t^I} = (k_t^B)^{\phi_1^I}(m_t^I)^{\phi_2^I}(1+g^W)^{\kappa^I}(\theta_t^U - \theta_t^{U,Y}) - (1-\gamma\eta-\tau)(\frac{Y_t}{K_t^P}) + z_t^C - (1-\delta_P), \tag{47}$$

$$\dot{Q}_t^R = [\alpha(\frac{Y_t}{K_t^P}) - \delta_P]Q_t^R - (1-\eta)\gamma(1-\nu)(\frac{Y_t}{K_t^P})(m_t^R)^{-1}, \tag{48}$$

$$\frac{Y_t}{K_t^P} = \frac{(k_t^B)^{\omega/(1-\gamma)}\Lambda_2}{[(\theta_t^{S,Y})^{\beta^S}(\theta_t^{U,Y})^{\beta^U}]^{-1/(1-\gamma)}}\left\{(m_t^I)^{\nu(1-\eta)/\eta}(m_t^R)^{(1-\nu)(1-\eta)/\eta}\right\}^{\gamma/(1-\gamma)}, \tag{49}$$

$$\theta_t^{S,Y} = \frac{\beta^S}{1-\lambda}(\frac{Y_t}{K_t^P})\frac{(k_t^A)^{-\phi_1^R}}{Q_t^R(m_t^R)^{(1+\phi_2^R)}}[1+\phi_3^R(\frac{m_t^I}{m_t^R})]^{-1}, \tag{50}$$

[24] Eicher and García-Peñalosa (2001) and Howitt and Mayer-Foulkes (2005) make a similar assumption to facilitate the theoretical analysis of their models. However, given our focus on numerical results, we reintroduce later inertia in the acquisition of skills—albeit in a different way.

$$\theta_t^{U,Y} = \frac{\beta^U}{(1-\eta)\gamma\nu}(k_t^B)^{-\phi_1^I}(m_t^I)^{-\phi_2^I}(1+g^W)^{-\kappa^I}, \tag{51}$$

$$\theta_t^U = \max\left\{a^L, [\frac{\beta}{1-\mu}(\frac{\theta_t^{S,Y}}{\theta_t^{U,Y}})]^{1/\chi}\right\}, \tag{52}$$

$$\theta_t^S = \min\left\{\frac{1-(a^H)^2}{2}, \frac{1-(\theta_t^U)^2}{2}\right\}, \tag{53}$$

for $j = A, B$.

These equations determine the dynamics of the system in terms of k_t^A, k_t^B, z_t^C, m_t^I, m_t^R, and Q_t^R. In the steady state, $\dot{k}_t^A = \dot{k}_t^B = \dot{z}_t^C = \dot{m}_t^I = \dot{m}_t^R = \dot{Q}_t^R = 0$. Variables z_t^C and Q_t^R are jump variables, whereas the others are backward-looking variables. Given the complexity of the model, saddlepath stability (which requires the Jacobian of the system to have two positive eigenvalues) cannot be established analytically; however, given the range of parameter values that we consider later, and the numerical simulations that we perform, the model turns out to be saddlepath stable.

In the steady state, the growth rates of the private and public capital stocks, the growth rate of consumption, the growth rate of imitation- and innovation-based knowledge, are all equal, whereas the license fee and the price of patents are constant. From the static conditions (49)-(53), Y_t/K_t^P, $\theta_t^{S,Y}$, $\theta_t^{U,Y}$, θ_t^U, and θ_t^S are also constant. Thus, the steady-state growth rate of output is the same as the growth rate of the private capital stock. The constancy of θ_t^U and θ_t^S (which is related to the constancy of a_t^C) implies that in the steady state factor supplies grow at the same rate as the population, that is, $\dot{N}_t^S/N_t^S = \dot{N}_t^U/N_t^U = \dot{N}_t/N_t = n$.

The long-run growth rate, $\boldsymbol{\gamma}$, can be written in several equivalent ways. In particular, as shown in Appendix A,

$$\boldsymbol{\gamma} = (\tilde{k}^A)^{\phi_1^R}(\tilde{m}^R)^{\phi_2^R}[1+\phi_3^R(\frac{\tilde{m}^I}{\tilde{m}^R})](\tilde{\theta}^S - \tilde{\theta}^{S,Y}), \tag{54}$$

where $\tilde{\theta}^S \leq 1 - a^L$.

During the transition process, the stock of imitative knowledge increases, which through the learning by doing effect, raises productivity of unskilled labor in the imitation sector—possibly at a very rapid rate initially (see (25)). This helps to increase productivity of *both* types of labor in the production of the final good as well, and therefore wages for both categories of workers. If the skilled wage increases faster than the unskilled wage, the proportion of the labor force willing to invest in the acquisition of skills will also increase (see (8)), which in turn will dampen the rise in wages in the final good sector. At the same time, as the skilled wage given in (38) increases, $\theta_t^{S,R}$ will also increase, thereby promoting activity in the innovation sector. Thus, learning through the imitation sector may indeed help to accelerate the transition toward an innovation-based economy.

The model can also produce alternative development regimes, depending on the wage conditions that determine individual occupational choices and the emergence of an innovation sector. The two main cases that may arise (pure imitation and pure innovation), and the associated dynamic systems, are discussed in Appendix B. In what follows, we maintain our focus on a mixed regime, but one in which the innovation sector is very small (rather than inexistent) to begin with, and calibrate the model to study the transitional dynamics and the long-run effects of policy shocks.

Before we do so it is worth noting that two variables that summarize the different phases of development highlighted above are the effective supply of skilled workers, θ_t^S, and more importantly the relative ratio of the stocks of imitative to total knowledge, $m_t = m_t^I/(m_t^I + m_t^R) = M_t^I/(M_t^I + M_t^R)$.[25] During the transition, θ_t^S is increasing if the relative skilled wage is increasing, whereas m_t tends to fall if the economy is converging toward an innovation-based regime; the "modern" or "innovation-based" economy is achieved when the imitation sector becomes a residual, so that m_t takes a relatively small value.[26] Alternatively, the economy may be "stuck" in an imitation-based regime, in the sense that m_t, although falling, remains positive in the steady state.[27]

Important considerations to assess the behavior of θ_t^S and m_t are the actual length of the transition to a mature economy and the role of public policy in affecting the nature of, and most importantly the *speed* at which, skills are acquired and industrial transformation occurs. We now turn to these issues, using a calibrated version of the model.

4 Calibration

To study the transitional dynamics of the model and the steady-state effects of public policy, we calibrate it as follows. On the *household* side, the annual discount rate is set at 0.04, a fairly conventional choice. The elasticity of intertemporal substitution σ is set at 0.3, in line with the evidence for developing countries reviewed in Agénor and Montiel (2008). The parameter that measures the efficiency of training, χ, is set initially at 0.5 and sensitivity analysis is conducted later. We normalize N_0 to unity (thus, each family starts with one member) and set the growth rate of the population, n, at 2.1 percent. We assume that the cost of acquiring an education is quite high

[25] Note that, because of the assumption that η is the same for both types of intermediate goods, their prices—as can be seen in (16) and (20)—are the same. The index m_t can thus be measured directly in terms of quantities.

[26] A third indicator could be the relative cost of innovation, $x_t = c_t^R/(c_t^I + c_t^R)$, defined as the ratio of the cost of innovation, $c_t^R = w_t^S/A_t^R$, to the cost of imitation, $c_t^I = w_t^U/A_t^I$ (with innovation being more costly if $c_t^R > c_t^I$). Note also that n the present setting, both design sectors grow at the same rate in the steady state, even though (as shown numerically) the relative size of the imitation sector shrinks over time.

[27] The model also has implications for the *nature* of the final good produced in the economy, even though we have considered only one (aggregate) final good. In the early stages of development, where imitation activities predominate, the final good can be viewed essentially as a light manufactured good. As innovation activities develop, it can be viewed as a more advanced manufacturing good, for instance an equipment good. A more advanced treatment would of course consist in modeling the "light" and "heavy" manufacturing sectors separately.

and initially set μ at 0.15 of the skilled wage. We also maintain the normalization of T to zero (which was imposed in the previous section); but to introduce inertia in the transformation of unskilled labor into skilled labor, we impose a partial adjustment on θ_t^U to its equilibrium value as given in (52).[28] By implication, the share of skilled workers in the labor force, θ_t^S, also adjusts gradually. This specification therefore captures indirectly the fact that training is a process that takes time.

In the *final good* sector, the elasticity of production with respect to basic public capital, ω, is set at 0.14, the average value reported by Bom and Ligthart (2011).[29] The elasticity of production with respect to unskilled labor, β^U, is set at 0.2, the elasticity with respect to skilled labor, β^S, at 0.35, and the elasticity of production with respect to private capital, α, at 0.3, a fairly standard choice (see Agénor (2011)). By implication, the elasticity of output with respect to enhanced intermediate goods, γ, is equal to 0.15. This is substantially lower than the value of 0.36 used by Funke and Strulik (2000) and Sequeira (2011) for instance, but it is more appropriate for a low-income country where, to begin with, the share of intermediate goods is relatively small, compared to capital and especially labor. We also assume that the relative share of imitated goods in the composite intermediate good X_t, as measured by ν (which, when multiplied by γ, measures the relative share of that input in final production), is set at 0.9.[30] The depreciation rate for private capital is set at 0.068, which corresponds to the average value estimated by Bu (2006, Table 8) for three African countries (Ghana, Kenya, and Zimbabwe).

In the *intermediate goods* sectors, the parameter η (which determines the price elasticity of the demand for intermediate goods) is set to 0.61, similar to the value set by Chen and Funke (2012, Table 1).[31] This implies an elasticity of substitution of about 2.6, which corresponds also to the value found by Acemoglu and Ventura (2002).

In the *imitation* sector, the growth rate of the international pool of blueprints available for imitation, g_I^W, is set at 0.02, in Chen and Funke (2012, Table 1). The elasticity with respect to the growth rate of imitable goods worldwide, κ^I, is set initially at 0.35, in line again with Chen and Funke (2012, Table 1). The elasticity with respect to basic infrastructure ϕ_1^I is set initially at 0.2, whereas the externality coefficient ϕ_2^I is set at 0.

In the *innovation* sector, parameter ϕ_1^R, which measures the response to advanced infrastructure, is set initially at 0.2. Parameter ϕ_2^R is set initially at 0.0. The parameter

[28] This assumption prevents large, and unrealistic, jumps in the composition of the labor force from contaminating the overall dynamics. Conceptually, given the assumption of infinite-horizon households, a partial adjustment process is also more appealing than fixing T arbitrarily.

[29] Note that other studies, based on simultaneous equation methods, obtain substantially higher values; see Agénor and Neanidis (2010).

[30] In preliminary experiments, an alternative value of $\nu = 0.5$ was also used; the results did not prove very sensitive to this change.

[31] By comparison, Funke and Strulik (2000) use a value of 0.54, whereas Sequeira (2011) uses alternative values of 0.4 and 0.94. The latter value implies a fairly high elasticity of substitution between intermediate goods and captures market conditions that are close to competitive, given that it implies a low price markup.

measuring the externality associated with the stock of imitative knowledge, ϕ_3^R, is set initially equal to a very low value 0.04. The results turn out to be quite sensitive to the magnitude of the learning-by-doing effect of imitative knowledge, and sensitivity analysis is also reported later on. We assume that initially enforcement of property rights is poor and set the parameter λ at 0.8. Thus, the "effective" patent price is only 20 percent of the actual price.

Regarding the *government*, the tax rate on final output, τ, is set equal to 0.151, which corresponds to the average ratio of tax revenues to GDP for low-income countries calculated by Baldacci et al. (2004, p. 530). By definition, because the model does not consider deficit financing, this is also the share of government spending in output. The share of government investment in basic infrastructure, υ_B, is set equal initially to 4.5 percent (or 0.7 percent of GDP), and the share of investment in advanced infrastructure to 0.5 percent. Thus, we consider the case of a country where initially much of public investment in infrastructure—which is low to begin with—is devoted to "core" infrastructure, roads, basic phone lines, and so on. This is a natural assumption for a low-income country. The depreciation rate for public capital, δ_G, is set at 0.03, as in Agénor et al. (2008).[32] To estimate the efficiency parameter of public spending, φ_G, we use the median value estimated by Dabla-Norris et al. (2011) for a sample of 71 developing countries, that is, 0.4.[33] Thus, we assume that initially 60 percent of both types of investment is "wasted", in the sense that it does not transform into public capital. This creates, *prima facie*, a strong case for governance reform.

Parameter values are summarized in Table 1. In the actual solution for the growth rate, a multiplicative constant is introduced in order to yield an initial annual growth rate of final output equal to 2.4 percent per annum, which corresponds to the average growth rate in Sub-Saharan Africa over the period 1990-2010.

We also set initial values for several other variables. The initial proportion of the population that is unskilled, θ^U, is set at 0.95; using formula (43), this gives $\theta^S = 0.049$. The absolute share of the unskilled labor force in final good production, $\theta^{U,Y}$, is set at 0.7, which implies that the share of that type of labor in the imitation sector is 0.25. Similarly, the share of the (effective) skilled labor force in the final good sector, $\theta^{S,Y}$, is set at 0.04, which implies that the share of that type of labor in the innovation sector is 0.009. The core infrastructure-private capital ratio is set initially at $k^B = 0.2$, whereas the advanced infrastructure-private capital ratio is set initially at $k^A = 0.05$. The ratio of imitation-based goods to private capital is set equal to $m^I = 0.4$, whereas the ratio of innovation-based goods to private capital is set equal to $m^R = 0.05$. By implication, our index of industrial structure, $m = m^I/(m^I + m^R)$, is initially equal to 0.89.

In sum, the low-income economy that we calibrate is characterized initially by *a*) a

[32] By way of comparison, Cubas (2011) uses a uniform value of 0.04 in compiling his estimates of public capital stocks across countries.

[33] An alternative approach is to use the governance index defined in Baldacci et al. (2008, Table 1), which once normalized to be between 0 and one, gives a value of 0.5. However, the results are not highly sensitive to that change.

positive but low growth rate in income per capita; *b*) an embryonic innovation sector and a relatively more developed imitation sector; *c*) a high cost of acquiring skills; *d*) a large unskilled labor force, employed in both the imitation sector and final good production (and more so in the latter); *e*) a small fraction of skilled workers in the labor force, employed almost entirely in final good production (in line with the assumption that the innovation sector is negligible in size); *f*) limited availability of basic infrastructure and almost nonexistent advanced infrastructure; and *g*) correspondingly a relatively low share of public investment in basic infrastructure and a much lower one on advanced infrastructure. At the same time, both stocks of public capital are relatively small in proportion to the private capital stock.

Figure 2 shows the evolution of the economy's industrial structure, based on the above initial conditions.[34] The results are displayed for three different values of parameter, ϕ_3^R, which measures the strength of the knowledge externality associated with imitation activities for the innovation sector: the benchmark case with a calibrated value of 0.04, and higher values of 0.2 and 0.5. In the base case, the relative size of the imitation sector increases slightly at first and comes down fairly slowly, dropping to close to zero after about 80 years. During the same time frame, the share of the unskilled labor force, θ^U, falls from 0.95 to 0.63 (with an increase in the proportion of unskilled workers in the final good sector from 0.70 to 0.74), whereas the share of the (effective) skilled labor force, θ^S, grows from 0.049 to 0.31.[35] By contrast, in the other cases, the relative size of the imitation sector falls at a faster pace; in particular, with $\phi_3^R = 0.5$, the index of industrial structure drops to close to zero in about 50 years. Thus, the benchmark case that we consider is still a rather mixed picture. The learning effect associated with imitation activities does have a substantial impact on industrial structure and the economy does become eventually a mature, innovation-based economy. However, left on its own, this process would take decades to occur. The question then is to what extent public policy can help to *accelerate* the transition. As noted earlier, this is the sense in which we define industrial policy.

5 Public Policy

We now consider a variety of public policies aimed at promoting growth and industrial transformation. Specifically, we consider a policy aimed at promoting access to basic infrastructure; a training subsidy aimed at reducing the cost of acquiring skills; and

[34]In all the simulations reported in this paper, we assume that the min and max functions in (52) and (53) do not bind. Because of difficulties with solving numerically the continuous-time version of the model, it is solved as a discrete time approximation using the Extended Path algorithm of Fair and Taylor (1983). The discrete-time approximation is actually more appropriate for implementing the sequential, composite reform program discussed later.

[35]The growth rate of final output converges to the benchmark value of 2.4 percent per annum. Note that the fact that m_t tends to zero does *not* mean that the imitation sector disappears; rather, it implies that it becomes small in relative terms, compared to the size of the innovation sector. In the steady state, both sectors grow at the same rate, as discussed earlier.

a policy aimed at improving enforcement of intellectual property rights. To highlight the role of policy complementarities, we also consider a sequential, composite program which involves combining some of these policies, together with investment in advanced infrastructure.

5.1 Provision of Basic Infrastructure

Consider first a permanent, budget-neutral increase in the share of spending on basic infrastructure, υ_B, from an initial value of 0.045 to 0.085, financed by a cut in unproductive spending, υ_U.[36]

The first impact of this policy is to promote activity in both the final good sector and the imitation sector. Both effects tend to increase the marginal product of unskilled labor and therefore the economy-wide wage for that category of workers. In the initial phase, this tends to reduce incentives for workers to acquire skills, and therefore to reduce the (effective) supply of skilled labor. However, the increase in activity in the imitation sector enlarges the pool of knowledge accessible to all workers and generates two types of externalities: it raises productivity not only in the imitation sector but also in the innovation sector. In turn, this puts upward pressure on skilled wages, which mitigates the initial adverse effect on individual incentives to invest in education. The net effect on economic growth depends on the extent to which these opposite effects on skilled labor supply offset each other or not.

Note also that because public capital in basic infrastructure raises labor productivity in *both* the final good and the imitation sectors, the extent to which the allocation of the unskilled labor force is affected depends on the parameters characterizing the production technology. Under some parameter configurations, it is possible that there may be no change in the sectoral distribution of the unskilled labor force, with the adjustment of the labor market operating essentially through a redistribution of workers across skill categories.

Figure 3 shows the impact of this policy on industrial transformation for three different values of the ϕ_3^R, the parameter that measures the strength of the externality associated with imitation activities for the innovation sector, These values are the same as those used in Figure 2.[37] The results show that, as can be expected, the relative size of the imitation sector increases at first; however, as the spillover effect of imitation-related knowledge for innovation begins to matter, this increase is reversed—the larger the effect of ϕ_3^R, the faster this reversal occurs.

[36] In what follows, when considering shifts in productive spending, we only consider offsetting cuts in unproductive spending. The trade-offs involved otherwise are not well known. Note also that the very assumption that the government can reduce unproductive spending to finance investment implies that there may be far-reaching governance reforms involved.

[37] Note that in Figure 3, as well as in Figures 4 to 6, the index of industrial structure converges back to its baseline value. Recall that in the baseline value the index drops to zero in finite time; what this implies therefore is that the fundamental role of the permanennt policy shocks that we consider is only to speed up the transition to an innovation-based economy.

5.2 Training Subsidy

Consider now a policy aimed at reducing training costs. As discussed earlier, this cost is assumed to be proportional to the skilled wage, at the rate $\mu = 0.15$ initially. We assume that the policy involves a permanent reduction in this rate to 0.05, and is financed through a reallocation among components of unproductive spending. Thus, this policy is also budget neutral.

Naturally enough, the reduction in the training cost induces more workers to invest in education. The increase in skilled labor supply, at first, tends to lower wages in that sector; however, because the increase in skilled employment occurs both in the final good sector and in the innovation sector, promoting activity there, a secondary, indirect effect is also at play: the increase in the variety of innovation-based (or enhanced) intermediate goods helps to promote activity in the final good sector. In addition, because the shift toward innovation raises the productivity of labor in that sector, the initial effect is magnified. At the same time, however, the increase in the supply of skilled labor in the final good sector tends to raise the marginal product of unskilled workers, which tends to raise the unskilled wage—thereby mitigating the initial effect on incentives to acquire skills.

Figure 4 shows the impact of this policy on the country's industrial structure, for two values of the parameter χ, 0.4 (the benchmark case) and a lower value of 0.2, which measures the strength of ability's effect on wages; the smaller χ is, the weaker this effect, which means that individuals with lower abilities would earn less. Even though the quantitative effect of the training subsidy on the industrial structure is relatively small, the net effect of the training subsidy is a higher supply of skilled labor and higher activity in the innovation sector, thereby explaining the initial increase in the relative size of that sector. The smaller the parameter χ is, the stronger these effects are.

5.3 Enforcement of Property Rights

Consider a reform of property rights that is designed to promote innovation activities—such as improved functioning of the bureau of patents, for instance. This is captured by considering a drop in the coefficient λ, from an initial value of 0.8, to first 0.4, and then to 0.0. In the second scenario, therefore, firms in the innovation sector earn the full patent price.

The economic effects of this shock are fairly intuitive. By increasing the ability of firms engaged in innovation to secure the return to their activity, improved protection of property rights tends also to raise labor demand in that sector—and thus wages as well. The increase in skilled wages induces more workers to invest in skills, thereby promoting growth. Thus, the growth effect is unambiguously positive. Figure 5 shows the impact of this policy on industrial structure. It shows that securing property rights may play an important role in accelerating the process of industrial transformation. These reforms have sizable effects not only because they increase the direct return to innovation, but also because they provide greater incentives for workers to acquire skills.

It is worth noting that a key reason why the growth effect of this policy is unambiguous is, of course, the fact that in the model poor enforcement of property rights creates a deadweight loss; no one really benefits from intellectual piracy. However, in a more general setting with multiple final goods, piracy could generate significant benefits for some producers; if so the net effect of improving the protection of property rights on growth could be mitigated—and, in some extreme cases, possibly reversed.

5.4 Sequential, Composite Reform Program

We now consider a sequential program, characterized by the following components: during an initial period of 8 years, the share of spending on basic infrastructure, υ_B, is increased from 0.045 to 0.085; it is then reduced gradually by one percentage point every year, to 0.025 over 6 years, and kept at that level permanently. During an initial period of 7 years, the share of spending on advanced infrastructure, υ_A, is kept at the benchmark level of 0.005; it is then increased to 0.045 for a subsequent period of 7 years, reduced over the following two years by one percentage point each year to 0.025, and kept at that level permanently. There is no training subsidy for the first 4 years, so that μ remains equal to its benchmark value of 0.15; then the subsidy reduces μ to 0.10 for the following 5 years, and to 0.05 permanently thereafter. For the first seven years there are no efforts to improve the enforcement of property rights, so that λ remains at its benchmark value of 0.8; then, through appropriate reforms, λ is reduced to 0.6 over a period of 4 years; 0.3 over another period of 4 years; and finally to 0, permanently from then on. Of course, there is a significant element of arbitrariness in this timing. But what we are trying to capture is a policy focusing first on improving access to basic infrastructure (through a "Big Push" in public investment) and imitation activities; next, an effort to promote human capital accumulation through training subsidies and enforcement of property rights; and, soon after, access to advanced infrastructure, to promote innovation.

Figure 6 shows the impact of this reform program on industrial structure. As the parameter that measures the strength of the externality associated with imitation activities for the innovation sector, ϕ_3^R, increases from its benchmark value of 0.04 to higher values of 0.2 and 0.5, the magnitude of the transitory drop in the index of industrial structure becomes larger. Thus, if indeed external learning effects are associated with imitation, a sequential reform program that is front-loaded on access to basic infrastructure can speed up the transition process to a mature economy. Put differently, in a low-income economy where to begin with unskilled labor is in abundant supply, the imitation sector is relatively small, and the innovation sector embryonic, public investment in basic infrastructure yields higher marginal growth benefits than investment in advanced infrastructure. The key reason is that expansion of activity in that sector would remain constrained by the lack of skilled workers in the labor force. In a second stage, higher investment in advanced infrastructure, if preceded by a policy that induces more individuals to acquire skills, and if accompanied by a policy that helps to promote the enforcement of property rights, would generate higher marginal growth benefits than investment in basic infrastructure. The learning externality associated with imitation activity in a first stage can help magnify the benefits that can be generated in this second stage.

6 Policy Implications

The foregoing discussion has important implications both for growth-promoting policies in today's poor countries in Sub-Saharan Africa and, more generally, for understanding the industrial transformation process whereby countries can move from imitation to innovation.

During the past decade, the region's GDP grew at an average of over 5.2 percent a year between 2001 to 2010, compared with an average of -0.4 percent in the 1990s (see Dinh et al. (2012*b*)).[38] However, to a large extent, this outcome was the result of booming commodity prices, rather than the result of a deep transformation of the industrial structure. Yet, as noted in the introduction, such transformation is essential to generate sustained growth in output and employment—as illustrated by the experience of East Asian countries during the 1960s, and more recently China's during the 1980s. Indeed, these countries followed initially a growth strategy that relied heavily on the development of light manufacturing, taking advantage of relatively cheap labor and their ability to imitate foreign goods. The lesson from East Asia's experience in transiting from low- to middle-income status is clear: a sustainable growth strategy in Sub-Saharan Africa should focus, in a first stage, on increasing the productivity of medium and large formal firms and on alleviating the key constraints that they face, namely, in terms of access to basic infrastructure (most importantly electricity, see Andersen and Dalgaard (2013)). As noted by Dinh et al. (2012*b*), as local producers increase the scale of their operations, improve the quality of their products, and accumulate experience with technology, management, and marketing, they become better positioned to take advantage of emerging export opportunities. As China's competitive edge in the global export market in light manufactures continues to erode—as a result of steeply rising costs of land, regulatory compliance, and especially labor (including both wages and benefits) in the country's coastal export manufacturing centers—the redistribution of cost advantages in labor-intensive manufacturing presents an opportunity for Sub-Saharan Africa to start producing and exporting a wide range of light manufacturing goods.[39]

[38] These numbers may actually underestimate the region's performance in recent years. According to Young (2012), measures of real consumption based on a variety of nonstandard indicators suggest that living standards in Sub-Saharan Africa have grown 3 to 4 four times faster than the rates indicated in conventional data sets.

[39] The possibility for Sub-Saharan Africa to becoming competitive in light manufacturing worldwide may well occur despite the fact that new entrants (Bangladesh, Cambodia, and China's interior provinces) have already begun to line up; see UNIDO (2009) and Chandra et al. (2012).

This strategy is feasible because Sub-Saharan Africa has two major potential advantages that could help promote competitiveness in light manufacturing. The first is a labor cost advantage. The second is an abundance of natural resources that supply raw materials, such as skins for the footwear industry, hard and soft timber for the furniture industry, land for the agribusiness industry, and so on. Even with its relatively low-skill workforce, Sub-Saharan Africa could become competitive in a broad range of light manufacturing sectors. In the apparel sector, for instance, small numbers of managers and technicians can guide hundreds of workers.[40] For the longer term, upgrading to more complex production will undoubtedly require a better-trained workforce than is currently available. But the expansion of light industry need not await higher school enrollment and better-quality schooling. Industrial transformation can begin rapidly by targeting promising sectors with modest skill requirements and then adopting policy measures—such as industry-specific vocational training programs—that may contribute to lowering the cost of acquiring skills and promote learning-by-doing effects.[41] This approach would help to channel scarce resources for infrastructure services to specific locations or industries, thereby mitigating the adverse effect that the lack of access to these services has had on production costs and labor productivity. As documented by Eifert et al. (2008) and Foster and Briceño-Garmendia (2010) for instance, indirect costs related to infrastructure services continue to account for a relatively high share of the costs of firms in poor African countries.[42] If indeed the lack of access to infrastructure is the most significant constraint on the expansion of labor-intensive light manufacturing industries, then it is important for African governments to focus their scarce resources in that area, making sure that economies of scale are properly exploited.[43]

Our model, and the simulation results that it produced, provide much support for this strategy. The key features of our calibration capture fairly well some of the characteristics of a "typical" low-income economy in Sub-Saharan Africa: an embryonic innovation sector and a relatively more developed imitation sector (yet small in terms of the size of the economy); a high cost of acquiring skills, possibly due to a lack of tangible collateral for securing loans to finance human capital accumulation; a small fraction of skilled workers in the labor force, and correspondingly a large unskilled labor force, operating partly in the imitation sector; limited availability of basic infrastructure and almost nonexistent advanced infrastructure. The simulations help to emphasize the fact

[40] As noted by Dinh et al. (2012*a*) for instance, specialists report that inexperienced workers can learn to operate sewing machines in no more than two weeks.

[41] Mathews (2006) for instance discusses the techonological learning gains that occurred in Taiwan, China through its electronics sector.

[42] Although the survey results reported in Dinh and Clarke (2012) suggest that firm managers in the region are most concerned about electricity, other areas of infrastructure may also constrain firm performance in Africa. Eifert et al. (2008) show that, in particular, transportation and communication costs are high in Sub-Saharan Africa.

[43] The successful experience of East Asia with industrial parks is an example in that regard. Instead of waiting to solve the infrastructure problem for the whole country, they focused instead on providing infrastructure for enterprises located inside the parks.

that learning through imitation may enable firms to improve productivity significantly in a first stage, and that this may eventually benefit innovation activity as well. Put differently, imitation contributes to create the knowledge base necessary for fostering innovation; by doing so, it helps to increase labor productivity and to create incentives for workers to invest in higher education.

The experience of East Asian countries in transitioning from middle- to high-income status provides also important lessons for Sub-Saharan Africa. As noted earlier, these countries successfully relied on a growth strategy based on low wages and technology imitation. However, once the pool of underemployed rural workers started to shrink and wages began to rise, competitiveness deteriorated, and the productivity gains associated with sectoral reallocation and technology catch-up began to disappear in many of them. Rising wages made labor-intensive manufacturing exports less competitive on world markets (Chandra and Kolavalli (2006)). At that point, some countries (most importantly Korea) were able to switch from imitation as the main source of productivity growth to broad-based, home-grown innovation.[44] Others, however, were unable to make that switch and ended up as a result in a so-called "middle-income growth trap," with a substantial reduction in growth and total factor productivity. As discussed by Agénor and Canuto (2012, 2013), avoiding this trap requires timely implementation of public policies aimed at improving access to advanced infrastructure, enhancing the protection of property rights, reforming labor markets, and promoting access to finance. These policies have proved central to fostering technological learning, attracting talented individuals into R&D activities, and allowing inventors to finance the development of their ideas. The lesson from that experience for today's poor countries in Sub-Saharan Africa is again very clear: governments in the region should act early—rather than late, when the benefits of cheap labor and the gains from imitating foreign technology are all but exhausted—and decisively to promote innovation and boost productivity.

Our numerical results also support the view that, following a first stage where countries should invest significantly in basic infrastructure, policies aimed at promoting innovation must be put in place without much delay; these include institutional reforms aimed at promoting property rights related to research activities, and the provision of advanced infrastructure, which is essential to encourage the buildup of national and international knowledge networks. This second stage should begin well before the benefits of low wages and imitation of foreign technology yield diminishing returns or are completely exhausted.

7 Concluding Remarks

The purpose of this paper was to study the role of public policy in promoting industrial transformation from an imitation-based, low-skill economy, where technological

[44] Crespi and Zuniga (2012) also provide evidence for six Latin American countries that firms that innovate have higher labor productivity.

progress results mainly from copying and adapting foreign ideas, to an innovation-based, high-skill economy, where technological progress now occurs mostly by inventing new ideas domestically. Using a model of endogenous growth, industrial transformation was measured by changes in an index of industrial structure, defined as the ratio of the variety of imitation- to innovation-based intermediate goods. In the model, a key mechanism through which productivity increases initially in both the imitation and innovation sectors is through a knowledge externality associated with learning by doing in the imitation sector. The process of industrialization was shown to increase the demand for high-skill labor, inducing individuals to invest in education. In turn, education stimulates further productivity and technological advancement in the innovation sector. The model also emphasized the distinction between basic or core infrastructure, which promotes imitation, and advanced infrastructure, which promotes innovation. In this setting, investment in human capital is *not* a prerequisite for promoting growth and development in its initial stages.

The model was calibrated for a "typical" low-income country and used to perform a variety of policy experiments, involving an increase in investment in basic infrastructure, a reduction in the cost of training, and improved enforcement of property rights. An illustrative composite reform program, combining these policies sequentially, together with investment in advanced infrastructure, was also analyzed. The results showed the importance of improved access to basic infrastructure to initiate a growth and development process based on imitation, in a first stage, and higher investment in advanced infrastructure to promote a shift to an innovation-based process, at a later stage. The broader policy implications of the analysis were also discussed. A key point of our analysis (largely corroborated by the evidence) is that the lack of skills is not a binding constraint for launching a two-pronged growth strategy, aimed in a first phase at promoting the development of labor-intensive manufacturing industries and, in a second phase, at promoting skill-intensive domestic innovation. At the same time, our analysis helps to emphasize the importance of access to advanced infrastructure and enforcement of intellectual property rights to achieve that second phase.

An important extension of our framework would be to introduce explicitly financing constraints, both at the level of the production of goods and the production of ideas. The evidence collected in Dinh and Clarke (2012) shows that in Sub-Saharan Africa, while start-up firms can survive and grow without access to bank loans or other support from the formal financial sector, for them to grow bigger they need access to finance. Beck et al. (2005) also found that the growth of small firms is particularly affected by lack of credit. There is also much recent evidence, as discussed in Agénor and Canuto (2013), to document the fact that firms engaged in innovation suffer from a variety of frictions that may limit their ability to resort to external finance. Indeed, although information asymmetries matter for external financing of all types of investments, they are particularly significant in limiting financing of innovation investments due to the complexity and specificity of the innovation process.

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Table 1
Calibrated Parameter Values: Benchmark Case

Parameter	**Value**	**Description**
Households		
ρ	0.04	Annual discount rate
σ	0.3	Elasticity of intertemporal substitution
n	0.021	Growth rate of population
χ	0.5	Productivity parameter (efficiency of training)
μ	0.15	Training cost (in proportion of skilled wage)
Final Goods		
ω	0.14	Elasticity wrt to public-private capital ratio
β^U	0.2	Elasticity with respect to unskilled labor
β^S	0.35	Elasticity with respect to skilled labor
α	0.3	Elasticity with respect to private capital
γ	0.15	Elasticity with respect to composite intermediate input
ν	0.9	Share of core inputs in composite intermediate input
δ_P	0.068	Rate of depreciation, private capital
Intermediate goods		
η	0.61	Substitution parameter, intermediate goods
Imitation sector		
κ^I	0.35	Elasticity wrt distance from technology frontier
ϕ_1^I	0.2	Elasticity wrt basic public infrastructure
ϕ_2^I	0.0	Productivity parameter, stock of imitated goods
g^W	0.02	Growth rate of world stock of imitable goods
Innovation sector		
ϕ_1^R	0.2	Elasticity wrt advanced public infrastructure
ϕ_2^R	0.0	Productivity parameter, stock of innovative goods
ϕ_3^R	0.04	Learning effect, stock of imitated goods
λ	0.8	Proportion of patent price lost due to poor property rights
Government		
τ	0.151	Tax rate on output of final good
υ_A	0.005	Share of spending on advanced infrastructure
υ_B	0.045	Share of spending on basic infrastructure
φ_G	0.4	Efficiency parameter, public investment
δ_G	0.03	Rate of depreciation, public capital

Figure 1
Production Structure and Labor Supply

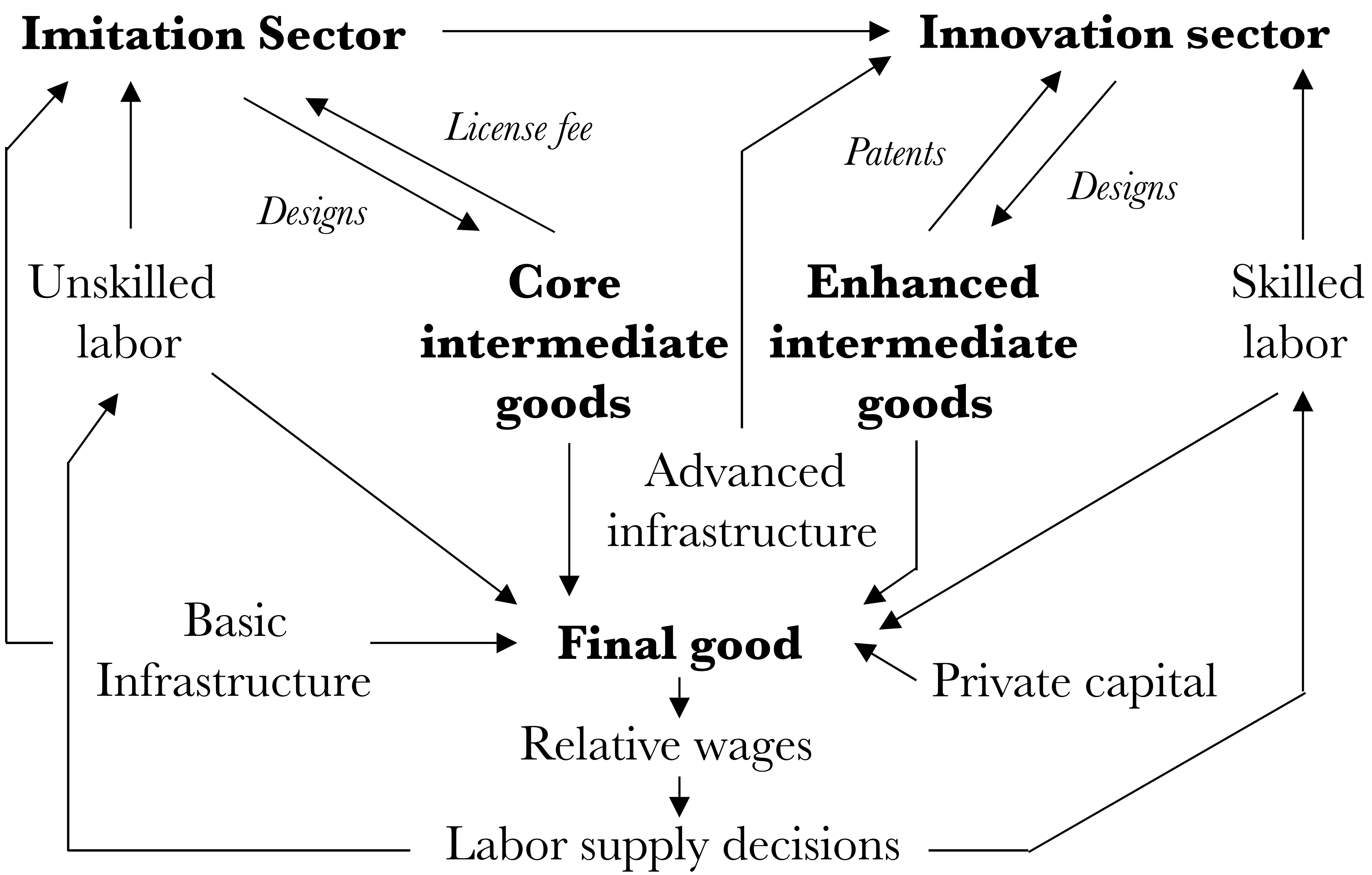

Figure 2
Baseline Scenario: Index of Industrial Structure
for Different Parameter Values

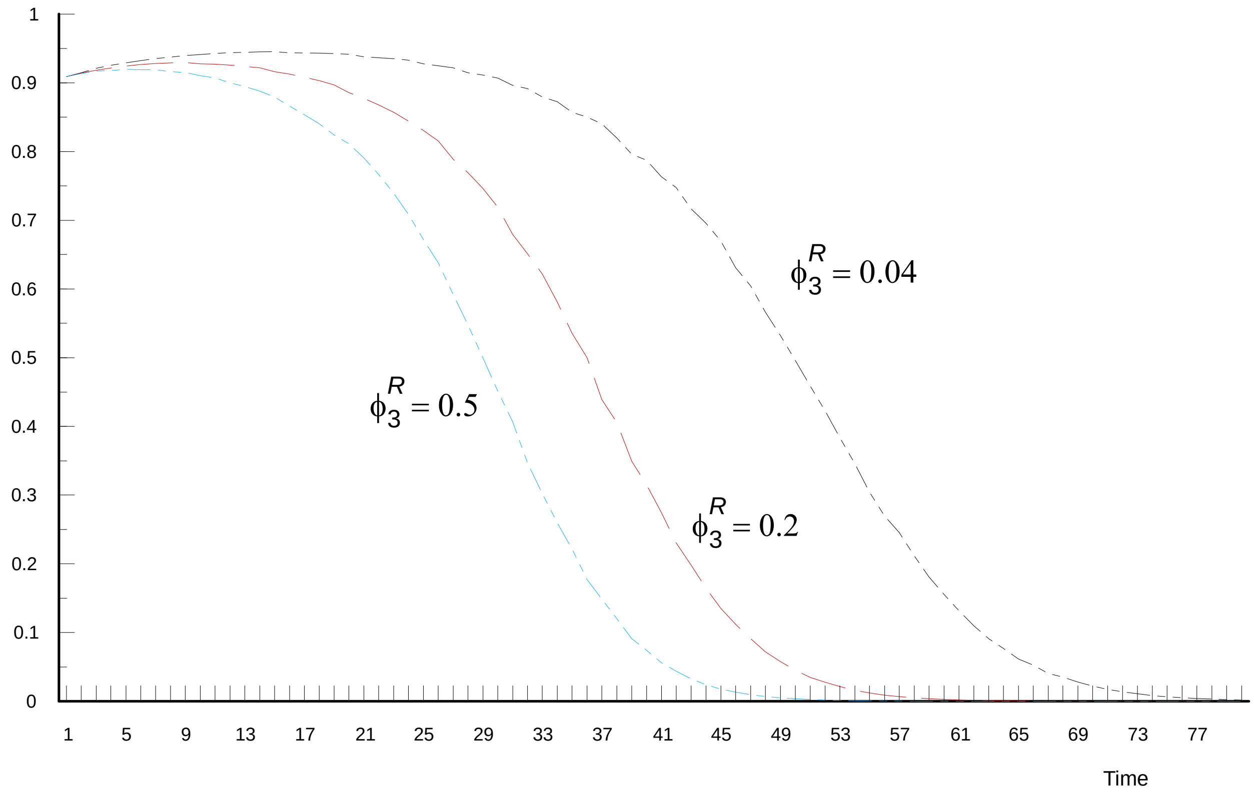

Figure 3
Higher Share of Investment in Basic Infrastructure
(Absolute deviations from baseline)

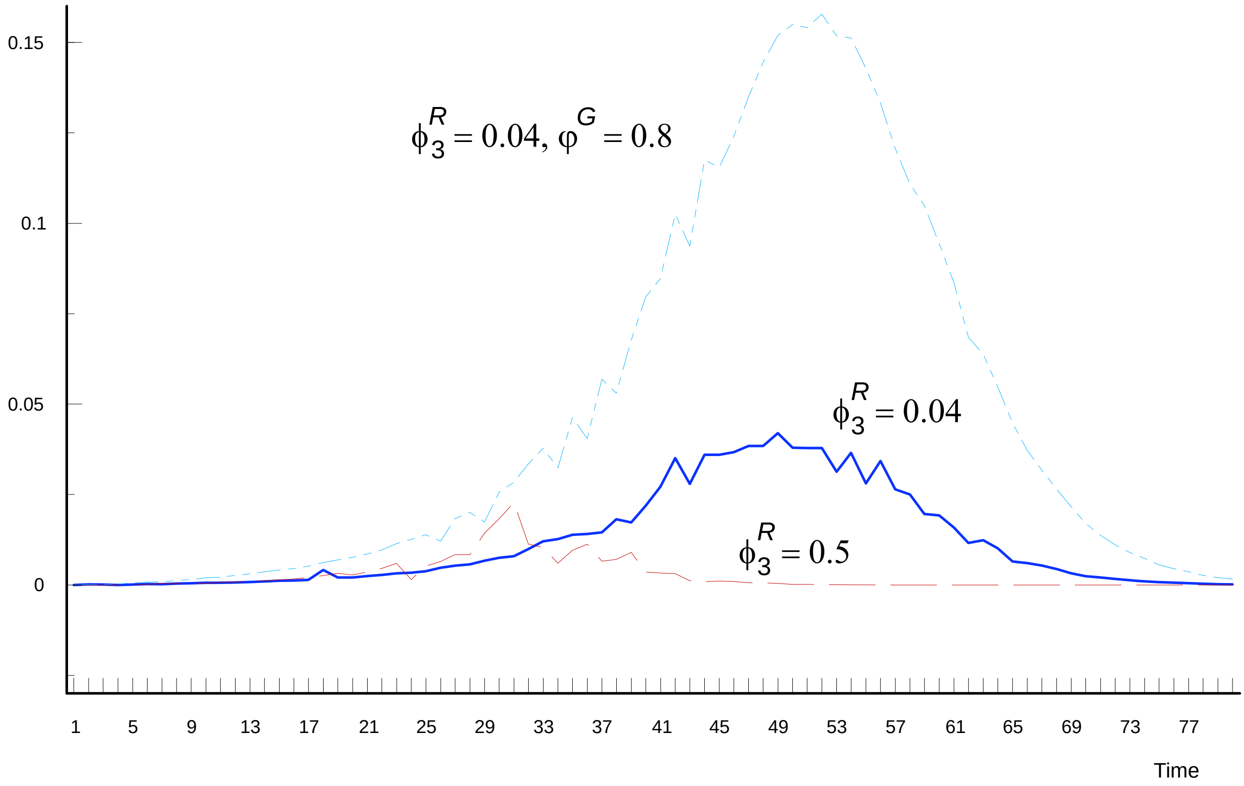

Figure 4
Reduction in the Cost of Acquiring Skills
(Absolute deviations from baseline)

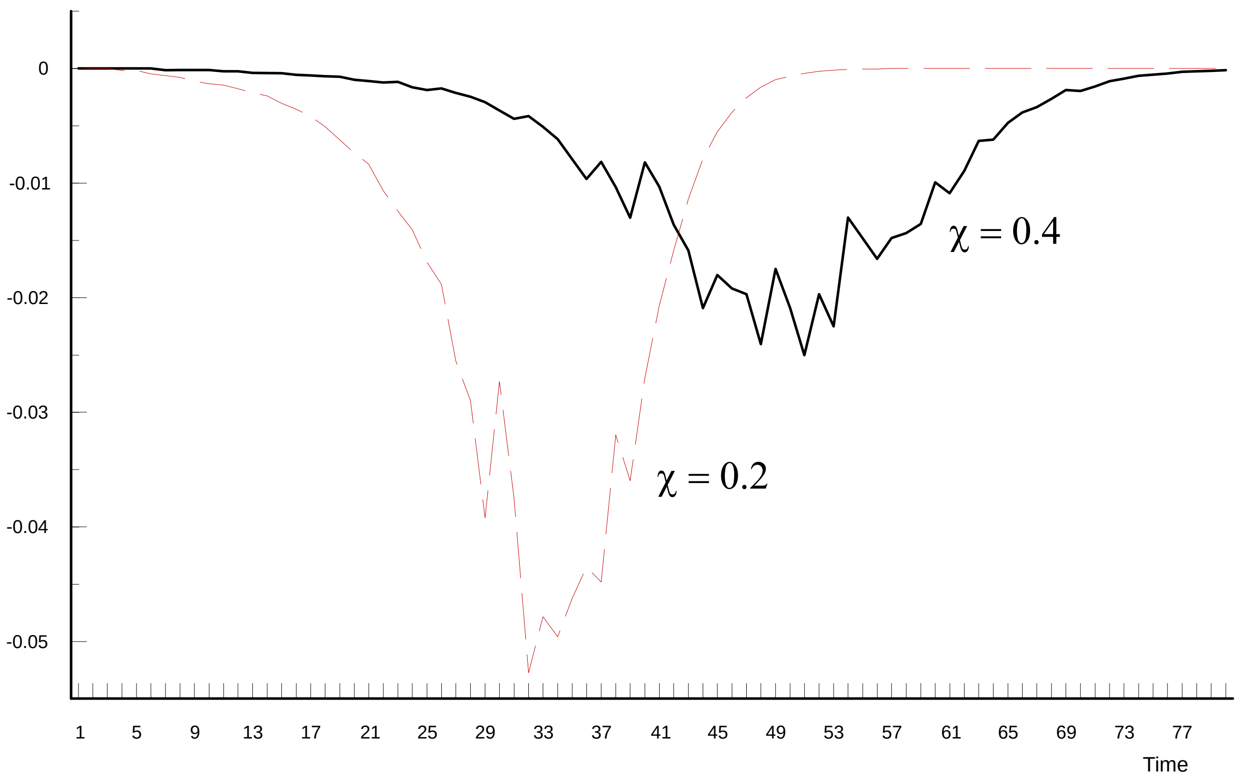

Figure 5
Improved Enforcement of Property Rights
(Absolute deviations from baseline)

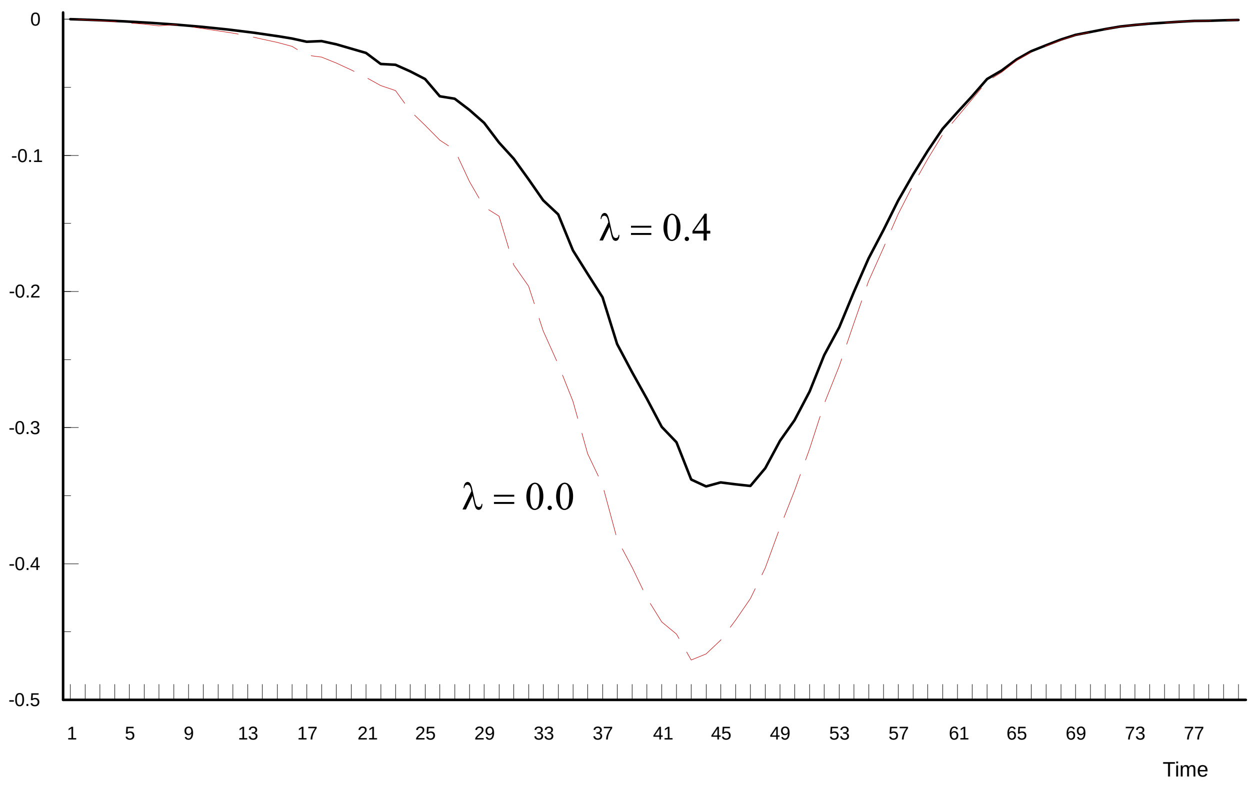

Figure 6
Sequential, Composite Reform Program
(Absolute deviations from baseline)